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# ASSESSING THE STUDENTS' UNDERSTANDING RELATED TO MOLECULAR GEOMETRY USING A TWO-TIER DIAGNOSTIC TEST

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**Abstract.** *In this research, the comprehension levels and misconceptions of university students on the subject of molecular geometry were determined via a two-tier diagnostic test consisting of 25 items developed by researchers. It was applied on 110 university students. The reliability and validity tests and item analyses were conducted in relation to the test, and the difficulty and discrimination indices of the items were detected. The reliability coefficient of the test was found to be 0.856 while the mean difficulty value of the test was 0.487. According to the findings obtained from the second tier of the test containing open end questions, the students had a great deal of wrong information and numerous misconceptions in relation to the molecular geometry. Such statements as "atoms move in the resonance structure" and "bond angles of two molecules having a trigonal pyramidal shape cannot be different" are counted among the most important misconceptions determined in the study.*

**Key words:** *Misconception, molecular geometry, two-tier diagnostic test, university students.*

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## Introduction

Concept teaching is one of the targets expected to be achieved in education. In addition to teaching concepts correctly, determining to what extent these concepts are perceived correctly by the students is another essential part of concept teaching (Karadeniz Bayrak, 2013). Investigating and determining misconceptions considered to pose an obstacle in learning are of paramount importance for effective learning (Azizoğlu, Alkan, & Geban, 2006; Case & Fraser, 1999; Coştu, Ayas, & Ünal, 2007). For the students to perceive the concepts correctly, the instructor explaining the concept in the class needs to configure these concepts in their minds correctly. Therefore, the studies carried out to determine the misconceptions of pre-service teachers are of great importance (Doğan & Demirci, 2011).

### *Two-tier Diagnostic Tests*

Numerous traditional and alternative measurement and assessments such as concept maps, interviews, portfolios, open-ended tests and diagnostic tests are used in determining the comprehension levels of the students in relation to concepts and their misconceptions (Anderson, Fisher, & Norman, 2002; Kabapınar, 2003; Schmidt, 1997; White & Gunstone, 1992).

Diagnostic tests have been one of the most common materials preferred in detecting the concept learning levels and misconceptions in the research conducted so far (Kabapınar, 2003; Karataş, Köse, & Coştu, 2003; Peterson, Treagust, & Garnett, 1986; Treagust, 1988). Although they are similar to multiple choice tests in terms of structure, the reason why this type of test is preferred is that it allows students to explain the reasons of their answers. By investigating these reasons, education researchers and teachers can detect the misconceptions of the students (Anderson, Fisher, & Norman, 2002; Bernhisel, 1999; Chen, Lin, & Lin, 2002; Çakır & Aldemir, 2011; Griffard, 2001;

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Jang, 2003; Karadeniz Bayrak, 2013; Odom & Barrow, 1995; Taber, 1999; Treagust & Haslam, 1986). Since two-tier diagnostic tests provide ease of scoring and application, concept-related structures in the minds of the students can be evaluated in a valid and reliable manner (Kılıç & Sağlam, 2009).

The first two-tier diagnostic tests were developed in 1980s and since then, they have been used commonly by many researchers in the physical science education owing to their features covering the deficiencies of multiple choice tests (Garnett & Treagust, 1992; Haslam & Treagust, 1987; Karataş, Köse, & Coştu, 2003; Mann & Treagust, 1998; Peterson, Treagust, & Garnett, 1989; Tan, Goh, Chia, & Treagust, 2002; Tyson, Treagust, & Bucat, 1999; Odom & Barrow, 1995; Voska & Heikkinen, 2000). Two-tier diagnostic tests are used to determine the levels of students to comprehend the basic concepts in any subject. The comprehension levels of students usually contain misconceptions. Such tests are generally particular to a specific subject in any discipline. They are not prepared to address general subjects or several topics. The structure of these tests resembles to that of multiple choice tests, and thus, they can be applied on a great number of students. However, differently from multiple choice tests, the aim is to reveal the existing misconceptions with these test items. In this case, the student should have considerably clear (clear from misconceptions) information to reach the correct answer. As these tests can be scored easily, they can be used as summative at the end of the process and formative throughout the process. Two-tier diagnostic tests have three types. In the first type, both tiers include multiple choice tests. In the second, the first tier contains true-false questions while the second tier has a multiple choice test. In the last one, the first tier has a multiple choice test while the second tier includes open-ended questions. The second tier of the two-tier diagnostic tests differs from the multiple choice tests. This tier aims at unearthing the misconceptions of the students (Mann & Treagust, 1998; Voska & Heikkinen, 2000). In two-tier diagnostic tests, the students are asked to mark one of the confusing options containing the correct answer in the first tier. In the second tier, they are expected to write down their reasons to mark that option. In this way, the misconceptions of the students in relation to their answers can be determined (Treagust, 1988). Furthermore, such competences of the students as assessment and questioning can be better measured, and whether they have alternative concepts to their previous misconceptions can be determined (Coştu, 2006; Mann & Treagust, 1998; Voska & Heikkinen, 2000). Two-tier diagnostic tests also enable the students and instructors to be much more successful in the process of concept learning (Tsai & Chou 2002).

### *Molecular Geometry*

Molecular geometry is an important subject in comprehending the substance correctly since it has a significant role in the determination of the physical and chemical properties of a molecule (Dale, 2006; Meyer, 2005). While students try to comprehend the substance, they create a macroscopic perception mostly by using their experiences and environments (Levy Nahum, Hofstein, Mamlok-Naaman, & Bar-Dov, 2004). However, for understanding the chemistry concepts explained spatially in the most accurate way, one should internalize the three levels of the substance together, that is to say, macroscopic (physical structure), sub-microscopic (particulate structure) and symbolic (chemical notation and mathematical symbols) structures (Nakhleh, 1992; Raviolo, 2001). In the studies, it was reported that the failure in comprehending these structures together and correctly might be the most important reason of misconceptions (Ayas & Demirbaş, 1997; Nakhleh, 1992; Ünal, Coştu, & Ayas, 2010).

When the studies in the literature are examined, it can be seen that some concepts related to the molecular geometry were studied in the field of chemical bonds, associated with the former. It is determined in numerous studies that students have difficulty in comprehending these subjects (Birk & Kurtz, 1999; Coll & Treagust, 2003; Furió & Calatayud, 1996; Furió, Calatayud, Bárcenas, & Padilla, 2000; Gabel, 1998; Nicoll, 2001; Özmen, 2004; Pabuçcu & Geban, 2006; Taber, 2003; Yılmaz & Özgür, 2012).

The studies where various diagnostic tests are preferred to determine the comprehension levels and misconceptions of the students in the subject of molecular geometry have been encountered in the literature review (Goh & Sai, 1992; Fergus & Hitch, 2014; Furió et al., 2000; Kousathana & Tsaparlis, 2002; Peterson, Treagust, & Garnett, 1989; Wang, 2007). Considering the usability of the diagnostic tests in the subject of molecular geometry as stated in the previous studies, it is thought that the two-tier diagnostic test to be developed in the present study will be useful to determine the difficulties the students have in relation to the concepts of molecular geometry as well as their misconceptions.

*Research Focus*

The aim of this research is to determine the levels of the students studying science at university to comprehend the subject of molecular geometry as well as their misconceptions via a valid and reliable two-tier diagnostic test to be developed. In the research, whether there are any differences in the comprehension levels of the freshmen and sophomores studying chemistry teaching in the subject of molecular geometry according to their levels of learning has also been examined. In this context, the answers are sought for the following questions:

- What are the comprehension levels and misconceptions of the students studying Physics, Chemistry and Biology teaching in the Faculty of Education in relation to the molecular geometry?
- Are there any differences between the comprehension levels of the freshmen and sophomores in the department of Chemistry teaching according to their levels of learning?

**Methodology of Research**

In order to determine students' comprehension levels and misconceptions of the subject of molecular geometry, a study was designed in which participants were asked to answer a series of test items which contained the essential concepts and molecular structures that are relevant to this topic. Having this purpose in mind, a case study design was found to be most appropriate.

*Research Design*

For in-depth analysis of students' comprehension levels regarding molecular geometry topic, case study design was used. A case study is an exploratory type research design which illuminated a given situation, did the assessments and revealed possible relationships among the events (Yin, 2003). Case study aims to understand the case in depth, and in its natural setting, recognizing its complexity and its context (Punch, 2009, p. 119). Case study design provides the researcher to attempt to learn about a little known phenomenon by studying a single case in depth (Johnson & Christensen, 2000). Yin (2003) stated that an exploratory case study is often used to lay the groundwork for subsequent, possibly more quantitative studies by defining questions and hypotheses. The case study has a holistic focus, aiming to understand the wholeness and unity of the case. Thus, the case may be an individual, or a role, or a small group, or a nation or a process. This research was focused on a single case, namely, the exploration of comprehension levels and misconceptions of the students studying science in the Faculty of Education in relation to the molecular geometry. So, in this study, the students' levels of conceptual understanding related to the molecular geometry topic were examined.

*Research Sample*

A total of 110 university students who were freshmen in the departments of Physics, Chemistry and Biology Teaching and sophomores in the department of Chemistry Teaching in a state university in the spring term of the 2012-2013 academic year participated in the research. 41 of the participants were male**,** while 69 of them were female. 82 % of the participants were in the 18-20 age group (N=90)**,** while 18 % of them were in the 20-22 age group (N=20). The students were placed in the undergraduate programs of Physics and Biology Teaching with UPE (MPS-2) [Undergraduate Placement Exam (Mathematics-Physical Sciences-2)] score type and in the undergraduate program of Chemistry Teaching with HEE-2 score type (Higher Education Entrance Exam-2). The freshmen participating in the research were taught the subject of molecular geometry in the unit of "Introduction to Carbon Chemistry" in the last year of the high school education and fall term of the first year of the university education. The reason why these students were included in the research sample was that they had studied the subject both in high school and university, thus they had some prior knowledge on this subject. The sophomores participating in the research study the subject of molecular geometry in the course of Inorganic Chemistry at an advanced level following the first year of the university education. The sophomores were included in the sample so as to be able to examine whether the misconceptions of the students still continued. Table 1 gives the descriptive statistics concerning the department/grade and gender properties of the participants.

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**Table 1. Frequencies of the participants according to department, grade and gender.**

| Department | Chemistry | | Chemistry | | Physics | | Biology | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| Grade | 1 | | 2 | | 1 | | 1 | | | |
| Gender | f | % | f | % | f | % | f | % | f | % |
| Male | 11 | 10.0 | 12 | 10.9 | 11 | 10.0 | 7 | 6.4 | 41 | 37.3 |
| Female | 17 | 15.5 | 15 | 13.6 | 15 | 13.6 | 22 | 20.0 | 69 | 62.7 |
| Total | 28 | 25.5 | 27 | 24.5 | 26 | 23.6 | 29 | 26.4 | 110 | 100.0 |

*Data Collection Tool*

In the research, two-tier diagnostic test was used as a data collection tool. The first tier of the two-tier diagnostic test contains multiple choice questions, while the second tier contains open-ended questions. The students are asked to mark the correct one out of confusing options concerning the question in the first tier, and explain the reasons for choosing this option in the second tier.

*Development Process of the Two-Tier Diagnostic Test*

In this part, the development process of the two-tier diagnostic test, including its validity and reliability was respectively presented.

*Validity of the Two-Tier Diagnostic Test*

The content of the test items was determined via the statement sentences obtained through the review of the literature related to the molecular geometry and the examination of the concept maps prepared by the students participating in the research. The freshmen studying chemistry teaching in the fall term of the 2011-2012 academic year (N=32) were requested to prepare the concept maps. They were made to prepare the concept maps after studying the subject of molecular geometry in the course of General Chemistry. They were primarily provided with information on how to prepare the concept maps. The students were asked to construct concept maps upon the concept of "molecular geometry" by using the strategy of constructing concept maps from scratch. In this manner, it was aimed at revealing the cognitive structures of the students in relation to the subject without any limitations. The concept maps constructed by the students were analyzed descriptively. Categories were set up for the concepts of Resonance, Octet Law, Lewis dot structures, VSEPR theory, Hybrid orbitals (Hybridization), Molecular orbitals, Intermolecular forces of attraction, and the statements associated with each concept were collected under the corresponding category. Categorization was carried out by the researchers two times at intervals for assuring reliability. A 30-item draft question form was prepared by the researchers in line with the data obtained in the previous procedures. After the content of the test was determined, four instructors specialised in chemistry education (two instructors), inorganic chemistry (one instructor) and biochemistry (one instructor) were consulted to assure the scope validity of the question form, which means whether the questions serve the purpose of the measurement and represent what is meant to be measured.

*Pilot study*

Pilot study of the test was carried out with 209 students studying in the Faculty of Education of a state university in the 2011-2012 academic years. 52 of these students (24.9 %) were studying biology teaching, 53 of them (25.4 %) were studying physics teaching and 104 of them (49.8 %) were studying chemistry teaching. A pilot study was conducted after the students learned the subject of molecular geometry in the course of General Chemistry. The aim of the pilot study was to determine the comprehension difficulties of the students in relation to the questions in the test as well as the total time required to answer the whole test. The test on Molecular geometry was revised in the light of the data obtained from the pilot study.

*Reliability of the Two-Tier Diagnostic Test*

Internal consistency reliability method was used in the reliability study of the test prepared. In this method, each item included in the test is analyzed after the assessment tool is applied. After the analysis, Cronbach Alpha coefficient, which indicates to what extent the items are consistent with each other, is calculated (Büyüköztürk, 2007; Çakır & Aldemir, 2011). If this coefficient is higher than 0.70, the test is accepted to be reliable (Büyüköztürk, Çakmak, Akgün, Karadeniz, & Demirel, 2008; Jang, 2003). The results of the item analysis were calculated by using SPSS 15.0 program. In the item analysis, difficulty and discrimination indices of all items were separately calculated in addition to the reliability of the test.

**Table 2. Discrimination and difficulty indexes of two-tier diagnostic test items.**

| Item no | Item discrimination index (r) | Item difficulty index (p) |
|---|---|---|
| I1 | 0.284 | 0.261 |
| I2 | 0.342 | 0.826 |
| I3 | 0.405 | 0.609 |
| I4 | 0.330 | 0.500 |
| I5 | 0.274 | 0.630 |
| I6 | 0.251 | 0.500 |
| I7 | 0.421 | 0.187 |
| I8 | 0.432 | 0.761 |
| I9 | 0.418 | 0.348 |
| I10 | 0.295 | 0.435 |
| I11 | 0.269 | 0.478 |
| I12 | 0.446 | 0.630 |
| I13 | 0.469 | 0.326 |
| I14 | 0.537 | 0.826 |
| I15 | 0.449 | 0.391 |
| I16 | 0.453 | 0.565 |
| I17 | 0.293 | 0.543 |
| I18 | 0.388 | 0.230 |
| I19 | 0.501 | 0.630 |
| I20 | 0.488 | 0.187 |
| I21 | 0.501 | 0.478 |
| I22 | 0.503 | 0.565 |
| I23 | 0.444 | 0.609 |
| I24 | 0.499 | 0.435 |
| I25 | 0.408 | 0.230 |
| **Average value** | **0.404** | **0.487** |

Table 2 gives the findings related to the results of the item analysis of the test developed in the research. According to these results, 5 items with item discrimination indices lower than 0.20 were excluded from the test on the grounds that they were not distinctive and usable enough.

Discrimination indices of the test items in the final form consisting of 25 items ranged between 0.251 and 0.537 while difficulty indices ranged between 0.187 and 0.826. At the end of the item analysis made, Cronbach Alpha coefficient of the 25-item test was found to be 0.856. This value shows that the test is highly reliable (Büyüköztürk et al., 2008; Jang, 2003).

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Table 3 gives the distribution of the items included in the two-tier diagnostic test which consists of 25 items in the final form by the subjects determined.

**Table 3. Subject matters of two-tier diagnostic test items.**

| Subject matter | Items |
|---|---|
| Resonance | 16, 21 |
| Structures violating the Octet Rule | 1, 4 |
| Repulsion of electron pairs and Molecular geometry (VSEPR theory) | 1, 2, 3, 5, 8, 9, 10, 12, 13, 15, 18, 19, 22, 23 |
| Hybrid Orbitals (Hybridization) | 11, 17 |
| Molecular orbitals | 6, 20, 24, 25 |
| Intermolecular forces of attraction | 7, 10 |
| Relationship between Lewis and VSEPR structures | 14, 17, 19, 25 |

*Analysis of the Two-Tier Test*

Criteria used by Coştu (2006) in his doctoral thesis were employed in the scoring of the items of the two-tier diagnostic test. Table 4 displays these criteria.

**Table 4. Used criteria in the evaluation of two-tier questions in concept tests.**

| Evaluation criteria | | |
|---|---|---|
| **Categories** | **Abbreviations** | **Score** |
| Correct Answer-Correct Reason | CC | 3 |
| Wrong Answer-Correct Reason | WC | 2 |
| Correct Answer-Blank | CB | 2 |
| Correct Answer-Wrong Reason | CW | 1 |
| Wrong Answer- Blank | WB | 0 |
| Wrong Answer - Wrong Reason | WW | 0 |
| Blank-Blank | BB | 0 |

Each item was scored according to the criteria shown in the Table 4 and the total scores that the students collected from the test were calculated by using these scores. The maximum score to be obtained from the test is 75**,** while the minimum score is 0. Frequency and percentage distribution table was created for each test item according to these criteria. Analyses were detailed with the model student answers given in the second tier of the two-tier diagnostic test. In this way, expressions containing wrong information and misconceptions obtained from the analysis of the test items were displayed in a table.

*Reliability of the Analysis*

For the reliability of the findings obtained in the research, categorization displayed in Table 4 was repeated by the researchers at different times and two instructors specialised in chemistry education were consulted about whether the categorization process had been carried out accurately. In the assessment criteria, "the answers containing all aspects of the valid reason" were accepted in the part of correct reason requested to be specified in the second tier of the two-tier test items**,** while "the answers containing wrong information" were accepted in the part of wrong reason (Karataş, Köse, & Coştu, 2003).

**Results of Research**

"What are the comprehension levels and misconceptions of the students studying Physics, Chemistry and Biology Teaching in the Faculty of Education in the subject of molecular geometry?" was the first question that the research sought answer for. Frequency and percentage distributions of the items of the two-tier diagnostic test developed to this end in the categories given in Table 4 were calculated. The data obtained for the items of the two-tier test at the end of the calculations are shown in Table 5.

**Table 5. Distribution of frequencies of the student answers according to the categories.**

| Categories | CC | | WC | | CB | | CW | | WB | | WW | | BB | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item No | f | % | f | % | f | % | f | % | f | % | f | % | f | % |
| I1 | 14 | 13 | 3 | 3 | 9 | 8 | 4 | 4 | 39 | 35 | 30 | 27 | 11 | 10 |
| I2 | 38 | 35 | 0 | 0 | 35 | 32 | 16 | 15 | 5 | 5 | 12 | 11 | 4 | 4 |
| I3 | 25 | 23 | 0 | 0 | 34 | 31 | 17 | 15 | 8 | 7 | 20 | 18 | 6 | 5 |
| I4 | 19 | 17 | 0 | 0 | 12 | 11 | 7 | 6 | 19 | 17 | 28 | 25 | 25 | 23 |
| I5 | 22 | 20 | 2 | 2 | 4 | 4 | 29 | 26 | 10 | 9 | 40 | 36 | 3 | 3 |
| I6 | 31 | 28 | 2 | 2 | 18 | 16 | 2 | 2 | 14 | 13 | 29 | 26 | 14 | 13 |
| I7 | 6 | 5 | 0 | 0 | 15 | 14 | 2 | 2 | 38 | 35 | 32 | 29 | 17 | 15 |
| I8 | 40 | 36 | 5 | 5 | 30 | 27 | 3 | 3 | 15 | 14 | 12 | 11 | 5 | 5 |
| I9 | 5 | 5 | 1 | 1 | 19 | 17 | 6 | 5 | 36 | 33 | 20 | 18 | 23 | 21 |
| I10 | 28 | 25 | 2 | 2 | 18 | 16 | 15 | 14 | 12 | 11 | 16 | 15 | 19 | 17 |
| I11 | 30 | 27 | 0 | 0 | 23 | 21 | 15 | 14 | 12 | 11 | 13 | 12 | 17 | 15 |
| I12 | 28 | 25 | 0 | 0 | 14 | 13 | 19 | 17 | 20 | 18 | 24 | 22 | 5 | 5 |
| I13 | 24 | 22 | 0 | 0 | 15 | 14 | 5 | 5 | 17 | 15 | 29 | 26 | 20 | 18 |
| I14 | 23 | 21 | 0 | 0 | 37 | 34 | 18 | 16 | 5 | 5 | 21 | 19 | 6 | 5 |
| I15 | 3 | 3 | 0 | 0 | 25 | 23 | 4 | 4 | 24 | 22 | 40 | 36 | 14 | 13 |
| I16 | 22 | 20 | 9 | 8 | 19 | 17 | 0 | 0 | 24 | 22 | 30 | 27 | 6 | 5 |
| I17 | 20 | 18 | 1 | 1 | 11 | 10 | 7 | 6 | 26 | 24 | 26 | 24 | 19 | 17 |
| I18 | 7 | 6 | 2 | 2 | 6 | 5 | 1 | 1 | 31 | 28 | 38 | 35 | 25 | 23 |
| I19 | 32 | 29 | 0 | 0 | 18 | 16 | 5 | 5 | 25 | 23 | 25 | 23 | 5 | 5 |
| I20 | 2 | 2 | 0 | 0 | 11 | 10 | 1 | 1 | 28 | 25 | 50 | 45 | 18 | 16 |
| I21 | 20 | 18 | 4 | 4 | 19 | 17 | 11 | 10 | 7 | 6 | 31 | 28 | 18 | 16 |
| I22 | 12 | 11 | 0 | 0 | 17 | 15 | 14 | 13 | 23 | 21 | 33 | 30 | 11 | 10 |
| I23 | 13 | 12 | 0 | 0 | 29 | 26 | 12 | 11 | 15 | 14 | 27 | 25 | 14 | 13 |
| I24 | 40 | 36 | 1 | 1 | 17 | 15 | 3 | 3 | 9 | 8 | 23 | 21 | 17 | 15 |
| I25 | 3 | 3 | 0 | 0 | 10 | 9 | 4 | 4 | 13 | 12 | 50 | 45 | 30 | 27 |

For each test item, the categorical value presenting the highest percentage is marked in bold in Table 5. When the Table 5 is examined, it is seen that the number of questions that students answer with correct reasons (questions 2, 6, 8, 10, 11, 12, 19 and 24) is lower than the number of questions that students answer with wrong reasons (questions 4, 5, 13, 15, 16, 17, 18, 20, 21, 22 and 25).

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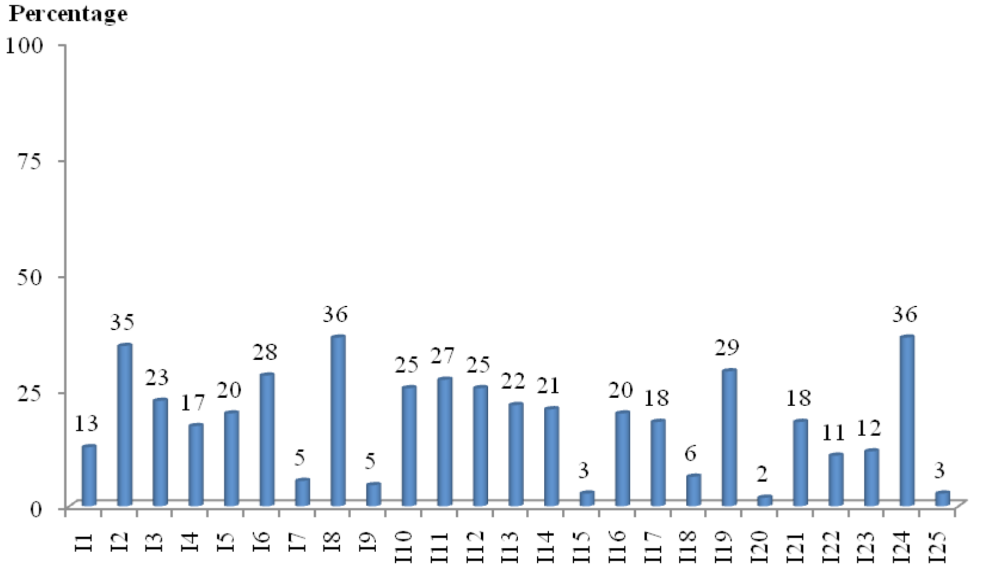


**Figure 1:** **The diagram showing the percentage distribution of correct answers-correct reasons (CC) given to test items.**

As it is seen in Figure 1, the percentage of being answered correctly among the test items (Correct Answer – Correct Reason) was below 50 %. In other words, the general success rate of the students in the test was low. The highest number of questions answered wrongly (questions 1, 7, 9, 15, 18, 20, 22, 23 and 25) and thus misconceptions were seen in the subjects of "Repulsion of electron pairs and Molecular geometry", "Molecular orbitals", "Intermolecular forces of attraction" and "The relationship between Lewis structures and VSEPR structure".

There exist misconceptions in the other categories [Correct-Wrong (CW) and Wrong-Wrong (WW)] other than the CC category in the two-tier test questions. Therefore, wrong reasons given in these categories for each question were examined in detail and relevant misconceptions were determined. Figure 2 shows the test items containing the highest amounts of misconceptions. With the data obtained through the analysis of the test items, the test items which had wrong reasons written under the categories and thus contained the highest number of misconceptions in the categories (CW-WW) were examined. When Figure 2 is considered, it is seen that the questions containing the highest number of wrong reasons are 5th, 15th, 18th, 20th and 25th questions.

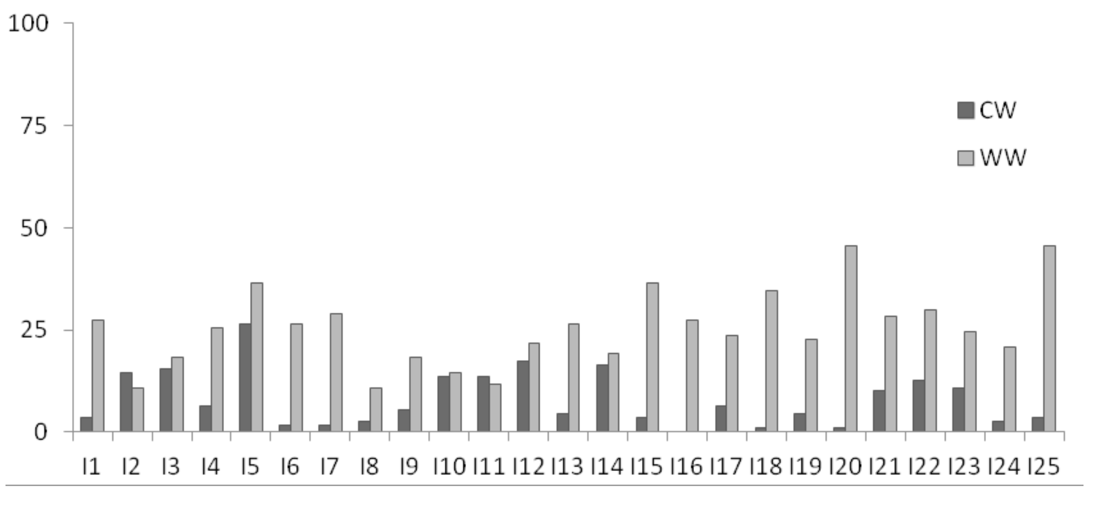


**Figure 2:** **Percentage distribution graph of the CW and WW categories of the test items.**

Table 6 gives the descriptive statistical values calculated for the data obtained from the two-tier diagnostic test items.

**Table 6. Descriptive statistical values of two-tier diagnostic test.**

| Department | N | $\bar{X}$ | SD | Max. score | Min. score |
|---|---|---|---|---|---|
| Chemistry 1 | 28 | 20.96 | 5.447 | 30 | 13 |
| Chemistry 2 | 27 | 21.52 | 10.807 | 40 | 4 |
| Physics | 26 | 25.88 | 7.230 | 40 | 3 |
| Biology | 29 | 30.79 | 10.455 | 52 | 12 |
| Total | 110 | 24.85 | 9.569 | 52 | 3 |

*N:Participant Number; $\bar{X}$: Average Value; SD: Standard Deviation*

When Table 6 is examined, it can be seen that the mean score collected in the test is low for each department. Mean success rate in the test was calculated to be 24.85 which corresponded to 33%. The mean scores of each department students were under the half of the maximum score. In terms of departments, the highest mean success rate belongs to the students of the department of biology teaching ($\bar{X}$=30.79), while the lowest mean success rate belongs to the freshmen studying in the department of chemistry teaching ($\bar{X}$=20.96).

The second question of the research was "Are there any differences between the comprehension levels of the freshmen and sophomores studying in the department of chemistry teaching in the subject of molecular geometry by their education levels?" To this end, independent sample t test was employed in order to examine whether there are any differences between the success levels of the freshmen and sophomores in the two-tier test.

**Table 7. Independent t test results of averages of total test scores of chemistry teaching students according to grades.**

| Dependent variable | Grade | N | $\bar{X}$ | SD | t | p |
|---|---|---|---|---|---|---|
| Total score | Chemistry 1 | 28 | 20.96 | 5.447 | 0.239 | 0.813 |
| | Chemistry 2 | 27 | 21.52 | 10.807 | | |

According to the analysis results shown in Table 7, there is no significant difference between the variable of class level and mean test scores of the students ($t=0.239$; $p>0.05$). It can be inferred from this result that the scores the freshmen and sophomores received from the two-tier test are not significantly different, in other words, the students still have difficulty in understanding the subject of molecular geometry even though this subject is taught at an advanced level in the course of Inorganic Chemistry in the second year.

When the written answers given in the second part where reasons are sought for the answers of all test items were examined, it was seen that the answers contained too many items of wrong information and misconceptions. The test items containing the highest number of misconceptions on the subjects specified in Table 3 were examined, and the expressions containing misconceptions in relation to these items were displayed in Table 8. Percentage analyses of the answers given in the second part were performed on the students except for those answering the relevant question correctly.

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**Table 8. Misconceptions written in the reasons part by the subjects in the two-tier diagnostic test.**

| Subjects | IN* | Expressions Containing Misconceptions |
|---|---|---|
| Resonance | 16 | For the concept of resonance, the students think that:<br>• Atoms move in the resonance structure (29%). |
| | 21 | • Since $N_2O$ molecule (molecule structure was shown as N—O—N in the answers) does not contain double bonds, it cannot display resonance structure (18%),<br>• Resonance structure cannot be seen in ionic compounds (8%),<br>• Resonance structure cannot be seen in $CH_3$—$CH_3$ structure of the benzene molecule as it does not contain double bonds (8%),<br>• Same atoms should be bonded for resonance (2%),<br>• At least two different groups are needed for resonance (2%). |
| Structures violating the Octet Rule | | No misconception was found. |
| Repulsion of electron pairs and Molecular geometry (VSEPR theory) | 15 | For $NH_3$ and $NF_3$ molecules;<br>• If the molecule geometries have a trigonal pyramidal shape, the bond angles cannot be different (22%),<br>• When the electron numbers on the atoms are the same, bond angles are the same as well (8%). |
| | 22 | In determining the central atom in compounds;<br>• Xe cannot form bonds as it is a noble gas (16%),<br>• Electronegative atom is the central atom (7%),<br>• The one with higher valence electron number is the central atom (4%). |
| Hybrid Orbitals (Hybridization) | 17 | For $BeBr_2$ and $SCl_2$ molecules;<br>• Lewis structures are the same and hybrid types are sp (10%),<br>• Their molecule geometries are linear and hybrid types are sp3 (12%),<br>• Hybrid types are the same since the bond numbers are the same (4%). |
| Molecular Orbitals | 20 | For the magnetic properties of $N_2$ and $O_2$ molecules;<br>• Both of them are paramagnetic. They have unpaired electrons in their orbitals (16%) (The answer was given in consideration of the atomic orbitals instead of molecular orbitals),<br>• O and N are non-metallic atoms. Thus, they are influenced by the magnetic field (4%),<br>• $N_2$ molecule is paramagnetic since it will form a single bond (2%),<br>• O and N are non-metallic atoms. Thus, they are diamagnetic (2%). |
| Intermolecular forces of attraction | 10 | In relation to $NH_3$, $H_2O$ and $CH_4$ molecules;<br>• The water ($H_2O$) boils most rapidly (7%),<br>• $CH_4$ molecule is polar as it contains dipole-dipole bond strengths (6%),<br>• Boiling points will reduce as the hydrogen number increases (3%),<br>• The molecule with the highest number of atoms is the weakest molecule (3%). |
| Relationship between Lewis and VSEPR structures | | No misconception was detected. |

***IN:** *Item Number*

Figure 3 presents some examples for the test items numbered 15 and 22 in which students gave answers containing misconceptions in the two-tier test. In Figure 3a, the student's answer for the 15th question contains the following expression for $NH_3$ and $NF_3$ molecules: "The angles will be the same considering the electron densities." This expression implies that the student think that bond angles of these molecules cannot be different since their molecule geometries are the same.

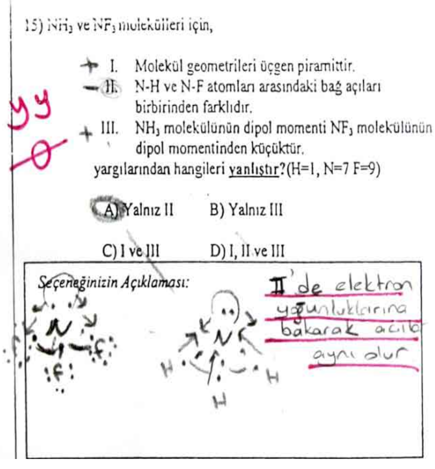
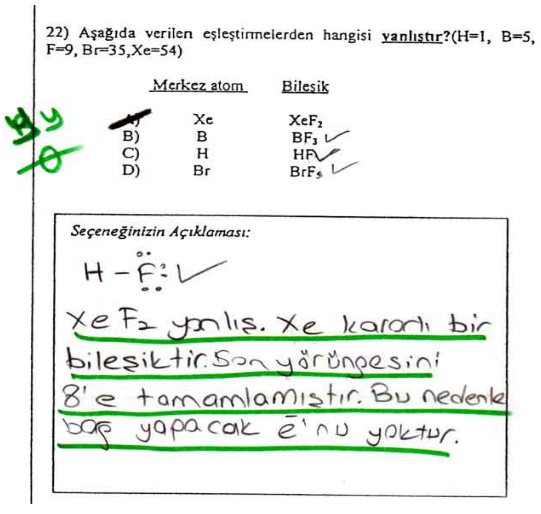
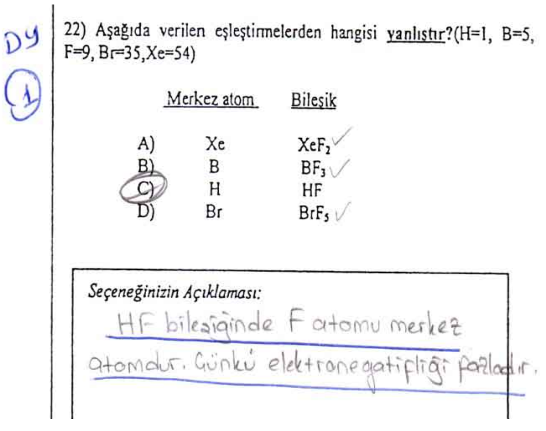
| | |
|---|---|
|  | 15) For $NH_3$ and $NF_3$ molecules,<br>I. Their molecular geometries are trigonal pyramid.<br>II. Their bond angles between the atoms N-H and N- F are different.<br>III. The dipole moment of $NH_3$ is lower than $NF_3$.<br>Which statements are **wrong?** (H=1, N=7, F=9)<br>A) Only II B) Only III C) I and III D) I, II and III |
| | *The student's statement:*<br>The II.statement explains that the bond angles of the molecules are same by taking into consideration the electron density among atoms. (Also see the drawings of the 41st student) |
| 3.a) 15th question – Chemistry teaching 41st student (in Turkish form) | 3.a) 15th question – Chemistry teaching 41st student (in English form) |
|  | 22) Which following pairing is **wrong?** (H=1, B=5, F=9, Br=35, Xe= 54)<br>Central atom Compound<br>A) Xe $XeF_2$<br>B) B $BF_3$<br>C) H HF<br>D) Br $BrF_5$ |
| | *The students' statement:*<br>$XeF_2$ is wrong. Xe is a stable compound. It completed its last orbital to 8. Thus, it hasn't got any bonding electron. (Also see the drawings of the 82nd student) |
| 3.b) 22nd question - Biology teaching 82nd student (in Turkish form) | 3.b) 22nd question - Biology teaching 82nd student (in English form) |
|  | 22) Which following pairing is **wrong?** (H=1, B=5, F=9, Br=35, Xe= 54)<br>Central atom Compound<br>A) Xe $XeF_2$<br>B) B $BF_3$<br>C) H HF<br>D) Br $BrF_5$ |
| | *The students' statement:*<br>F atom is the central atom in the HF molecule. Because the electronegativity of the F atom is high. |
| 3.c) 22nd question – Chemistry teaching 73rd student (in Turkish form) | 3.c) 22nd question – Chemistry teaching 73rd student (in English form) |

**Figure 3: (3a, 3b and 3c). Examples of students' misconceptions in items of the two-tier test.**

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In Figures 3b and 3c, two different examples of misconceptions concerning the question numbered 22. It was seen in Figure 3b that the student marked "A" as the correct answer and the explanation in relation to $XeF_2$ says: "Xe is a stable compound. It completes its last orbital to 8. So it does not have electrons to form bonds." It can be understood from this expression that the student thinks that Xe cannot form bonds as it is a noble gas. Therefore, the student cannot recognize the central atom on the molecule. The following expression is seen for the same question in Figure 3c: "F is the central atom in HF compound. This is because of the fact that it has a higher electronegativity." It can be concluded that the student has misconception concerning the concept of central atom, in fact the central atom should be the highest electropositivity atom and binary molecular compounds do not consider a central atom.

In Table 9, the items containing the highest level of wrong information were examined and examples were given.

**Table 9. Expressions containing wrong information in the reasons part by the subject areas of the items of the two-tier diagnostic test.**

| Subjects | IN* | Expressions containing wrong information |
|---|---|---|
| Structures violating the Octet rule | 4 | For the structure of $PCl_2F_3$, the students thinks that; • F atoms settle in axial site while Cl atoms settle in equatorial site (11%), • The structure will be trigonal pyramidal in the equatorial site (3%), • The angle between F and P atoms is 900 (4%), • Molecular geometry is regular tetrahedron (2%). |
| Repulsion of electron pairs and Molecular geometry (VSEPR theory) | 5 | For the structure of $ClF_3$; • It is trigonal pyramid (21%). • It is trigonal planar (13%). • Double bond exists between Cl and F atoms (12%). |
| | 15 | For $NH_3$ and NF3 molecules; • Their molecular geometries are different (2%). • Their structure is trigonal planar (11%). |
| | 18 | In $OF_2$ and $BeF_2$ molecules; • $\pi$ (pi) bonds exist in both of them (12%). • Molecular geometries are same in both of them (6%). • Both of them are linear in the structure of 2 2 0 (6%). |
| Molecular Orbitals | 20 | For the magnetic properties of $N_2$ and $O_2$ molecules; • Both of them are diamagnetic since they do not have unpaired electrons (8.5%). |
| | 6 | • Since the oxygen atom forms double bonds, its bonds will be weaker (4%). • Double bond consists of 2 $\pi$ bonds (4%). • In $COCl_2$ molecule, there exist 3 $\pi$ bonds and 1 $\sigma$ (sigma) bond (6%). |
| Relationship between Lewis and VSEPR structures | 19 | • The structure of $SO_2$ is linear (5%), • The structure of $CS_2$ is angular (AB2E2) (4%), • The structure of $BrF_5$ is trigonal pyramid rather than square pyramid (5%). |

***IN:** *Item Number*

## Discussion

It was concluded in the research that the two-tier test developed in relation to the molecular geometry was sufficiently reliable and valid to reveal the conceptual comprehension levels and misconceptions of the university students on this subject. The results of the item analysis of the test showed that discrimination and difficulty indices of the items were acceptable (see Table 2).

In the test designed as a two-tier scale, a total of 7 subjects including resonance, structures violating the octet rule, repulsion of electron pairs and molecular geometry (VSEPR), hybrid orbitals, molecular orbitals, intermolecular forces of attraction and the relationship between Lewis and VSEPR structures were studied. The subject areas where the students' answers contained wrong information and misconceptions at most were found to be "Repulsion of electron pairs and Molecular geometry", "Molecular orbitals", "Intermolecular forces of attraction" and "Relationship between Lewis structures and VSERP structures".

The general success rate in the two-tier test was determined to be 33 %. This rate suggests that university students have difficulty in the subject of molecular geometry. Many previous researches reveal such difficulties that the students have about understanding this subject (Birk & Kurtz, 1999; Butts & Smith, 1987; Harrison & Treagust, 2000). In the analyses conducted on the students studying in the department of chemistry teaching, whether there was any difference between freshmen and sophomores was examined, and it was determined that the class level did not affect the success rates of the students. However, the students studying chemistry teaching learn the subject of molecular geometry in the course of General Chemistry in the first year and in the course of Inorganic Chemistry in the second year. Despite the expectation that sophomores would be more successful on this subject area, no significant difference was found between the success rates of the freshmen and sophomores. Accordingly, it can be said that the difficulty experienced by the students in the first year continues in the second year. In parallel to this finding, it was reported in the studies related to the misconceptions of the pre-service Chemistry teachers that the misconceptions of the students persisted and could be changed hardly although they acquired more concept knowledge in the period of undergraduate education (Demircioğlu, Ayas, & Demircioğlu, 2005; Doğan & Demirci, 2011; Pabuçcu & Geban, 2006).

When the findings obtained from the explanations given in the two-tier test were examined, it was seen that students' expressions contained a great deal of wrong information and numerous misconceptions and these expressions were examined separately and grouped into sub-titles of the subject of molecular geometry (see Tables 8 and 9). When the expressions concerning the sub-title of resonance were considered, it was revealed that most of the students supposed that the concept of resonance occurs "with the replacement of the atoms". With regard to this concept, the students confuse the electron replacement with atom replacement, and thus, are mistaken. It was also detected that the students thought that resonance could not occur in such molecule structures as benzene ($C_6H_6$) and nitrous oxide ($N_2O$) due to the "lack of double bonds in the structure". This finding may imply that students have difficulty in forming the molecular structures and suggest incorrect structures and therefore, they make such mistakes. Similar to the problem experienced in the combination of the atoms in $N_2O$ molecule, it was reported in a study that both high school and undergraduate students made mistakes in the symbolic representation of water ($H_2O$) and methane ($CH_4$) molecules (Kern, Wood, Roehrig, Nyachwaya, & 2010; Nyachwaya et al., 2011).

In the example of $PCl_2F_3$ molecule, it was seen that students could not perceive the trigonal bipyramidal structure that the phosphorus atom formed, and thus, had wrong information about "the settlement, bond angles and molecule geometry" of the atoms found in this structure. The finding that the students had difficulty in comprehending such structures violating the octet rule is in parallel with the findings of other studies (Taber, 2003).

In the questions where the students are expected to estimate the structures of the molecules according to VSEPR theory, the students suggested different structures for $ClF_3$ structure by ignoring the "number of non-bonding electrons" in the central atom, argued that the structures of $NH_3$ and $NF_3$ molecules would be "trigonal planar" by ignoring the "unpaired electrons" in a similar way, and thought that bond angles would be the same although two different atoms were connected to the atom in the same structure. In a different question, similar misconceptions were obvious in relation to the molecular geometries of $OF_2$ and $BeF_2$. A similar misconception was found in another research with the expression of "non-bonding electron pairs have no function in the detection of the location of the atoms in the molecules or ions (Yılmaz & Morgil, 2001).

Students' misconceptions about hybridization showed that "the students could not identify the type of hybrid" since they could not identify the structure of the molecules correctly. They reported in the relevant question that the "types of hybrid would be the same" since the bond numbers of the molecules were equal. Nakiboğlu (2003) reported in his study on hybridization that the students could comprehend that the geometries of the molecules could be determined with the types of hybrids. Since the students could not specify the geometries of the molecules given correctly despite having comprehended the relationship between the types of hybrids and molecular geometries, it can be said that they are mistaken on this subject area. In the same question, the students also stated that both of $BeBr_2$ and $SCl_2$ molecules had linear structures. While this expression is correct for $BeBr_2$ molecule, it is not correct for $SCl_2$ molecule. Likewise, the expression containing the misconception of "Since the repulsive forces between the bonding and non-bonding electron pairs in $SCl_2$ molecule are equal, the molecular geometry is linear" was reported in another research (Canpolat, Pınarbaşı, & Sözbilir, 2003; Demircioğlu & Baykan, 2011).

In the question related to the molecular orbitals, the students were asked to determine the magnetic properties of $N_2$ and $O_2$ molecules. In relation to this concept, it was detected that a great majority of the students considered the "atomic orbitals (s, p, d, f …) of these molecules rather than their molecular orbitals (σ and π)". In parallel with this finding, Taber (2001) reported in his study that teaching the atomic structure through the settlement on the electron shells might prevent the learning of the concepts of orbital, molecular structure and molecular orbital. Besides, the findings related to this concept showed that the students "associated the magnetic property of the molecule with the metallic property of the atom". This finding may imply that the students have misconception related to associating the magnetic property of the molecule with an "atom's being metallic or non-metallic".

In the question related to $COCl_2$ molecule, the students expressed their misconceptions about sigma (σ) and pi (π) bonds included in the molecule. They wrongly thought that "double bonds are weaker than single bonds"; "a double bond consists of two pi bonds". It was also seen that they "confused the concept of sigma bond with the concept of pi bond". Nakiboğlu (2003) addressed the importance of comprehending the hybridization correctly in the comprehension of sigma and pi bonds.

When the findings related to the comprehension levels of the students about the intermolecular forces of attractions were examined, it was seen that this subject could not be comprehended correctly and the relevant questions were mostly answered on the basis of the daily experiences. Likewise, it was reported in other studies that the students could not identify the intermolecular forces of attraction and confused intermolecular bonds with intramolecular bonds (Peterson & Treagust, 1989; Peterson, Treagust, & Garnett, 1989; Goh, Khoo, & Chia, 1993; Boo, 1998). In the findings of the present study, the students expressed that "$CH_4$ molecule is polar since it contains dipole-dipole bond forces". Thus, it can be said that the students confuse "molecule polarity with bond polarity due to the polar covalent bond structure" although the molecule has a nonpolar structure. In another study, it was reported that the students expressed misconceptions about the molecule polarity in the molecules of $SiF_4$, $CO_2$, $PCl_3$, $C_2H_6$ which are similar to the molecule of $CH_4$ (Yılmaz & Morgil, 2001).

In the subject of molecule geometry, the students have difficulty in determining the relationship between Lewis and VSEPR structures. While determining the molecular geometries, the students determined the structures incorrectly by ignoring the numbers of unpaired electrons and bonding and non-bonding electrons. This finding may suggest that the students could not visualise the three dimensional structures of the molecules correctly and projected these structures two dimensionally on the paper. Other studies reported similar findings as well (Wang, 2007). In the study conducted by Wu, Krajcik and Soloway (2001), it was reported that the structures of the molecules should be presented to the students visually so that they could learn and compare them in two dimensional and three dimensional forms.

**Conclusions**

Examining the results of the study in general, it is observed that students have lower levels of determining the resonance, hybridization, molecular orbitals, intermolecular forces of attraction, and Lewis and VSEPR structures of the molecule and they have relevant misconceptions in these subjects. These acquired results are thought to have archetypal qualities in terms of conducting studies regarding this field. This information could be used on a large scale, especially in the stage of realizing the conceptual change, which is among the applications aimed at removing the misconceptions.

As in the present study, misconceptions of the students on many different subjects of chemistry may be detected through the two-tier diagnostic tests. At the same time, the awareness levels of the students about their own knowledge can also be raised via these tests. In this way, the students may be more successful in establishing cause and effect relations while structuring the information. The students who can establish cause and effect relations can internalize the concepts and reach scientific truths. Besides, the nature of the information that the students have on a specific subject and their misconceptions can be revealed in detail during the education through two-tier diagnostic tests. By this means, the instructors may develop their instructional plans with alternative methods in consideration of the misconceptions determined. It was detected with the two-tier diagnostic test developed in this research that university students had a great deal of wrong information and numerous misconceptions on the subject of molecule geometry. Picture, drawing and text-aided materials, audible animations to be prepared in computer and such generative multimedia learning environment tools as PowerPoint presentations may unearth the misconceptions in the subjects of resonance, hybridization, VSEPR and Lewis theories, in particular. The misconceptions detected can be eliminated via argumentation-based learning process in the learning environments. Experiments can be carried out in the laboratories in order to enable the students to comprehend the magnetic properties of the molecules in the subject of molecular orbitals and the misconceptions related to this subject can be eliminated with the help of the scientific process skills such as observation, analysis and assessment to be acquired in the experiments. In order to ease the comprehension of intermolecular forces of attraction, concrete examples from the real life can be provided, and the subject can be taught with discussions on the depth of the subject with the questions of what, why and how. Programs containing two dimensional and three dimensional animations can be developed for students to better comprehend different types of molecular geometry (for instance, linear, angular, trigonal pyramid etc.), and activities can be developed with the method of modelling. Activities can also be held at different cognitive levels by taking the characteristics of the students into account so as to facilitate the process of learning in the subjects about which the students have misconceptions.

**References**

Anderson, D. L., Fisher, K. M., & Norman, G. J. (2002). Development and evaluation of the conceptual inventory of natural selection. *Journal of Research in Science Teaching*, *39* (10), 952-978.

Ayas, A., & Demirbaş, A. (1997). Turkish secondary students' conception of introductory chemistry concept. *Journal of Chemical Education, 74* (5), 518-521.

Azizoğlu, N., Alkan, M., & Geban, O. (2006). Undergraduate pre-service teachers' understandings and misconceptions of tier equilibrium. *Journal of Chemical Education, 83* (6), 947-953.

Bernhisel, S. M. (1999). *Measuring preservice and in-service biology teachers' understanding of selected biological concepts*. (Doctoral Dissertation). Utah State University, Utah.

Birk, J. P., & Kurtz, M., J. (1999). Effect of experience on retention and elimination of misconception about molecular structure and bonding. *Journal of Chemical Education, 76* (1), 124-128.

Boo, H. K. (1998). Students' understandings of chemical bonds and the energetics of chemical reactions. *Journal of Research in Science Teaching, 35* (5), 569-581.

Butts, B., & Smith, R. (1987). HSC chemistry students' understanding of the structure and properties of molecular and ionic compounds. *Research in Science Education*, *17*, 192-201.

Büyüköztürk, Ş. (2007). *Experimental Designs.* Ankara: PegemA Publishing.

Büyüköztürk, Ş., Çakmak, E. K., Akgün, Ö. E., Karadeniz, Ş., & Demirel, F. (2008). *Scientific research methods.* Ankara: PegemA Publishing.

Canpolat, N., Pınarbaşı, T., & Sözbilir, M. (2003). Kimya öğretmen adaylarının kovalent bağ ve molekül *yapıları* ile ilgili kavram yanılgıları [Chemistry pre-service teachers' misconceptions related to covalent bonding and molecular shape]. *Çukurova University Faculty of Education Journal, 2* (25), 66-72.

Case, M. J., & Fraser, D. M. (1999). An investigation into chemical engineering students' understanding of the mole and the use of concrete activities to promote conceptual change. *International Journal of Science Education, 21* (12), 1237-1249.

Chen, C. C., Lin, H. S., & Lin, M. L. (2002). Developing a two-tier diagnostic instrument to assess high school students' understanding-the formation of images by a plane mirror. *Proceedings of the National Science Council, 12* (3), 106-121.

Coll, R. K., & Treagust, D. F. (2003). Investigation of secondary school, undergraduate, and graduate learners' mental models of ionic bonding. *Journal of Research in Science Teaching, 40* (5), 464–486.

Coştu, B. (2006). *Determining students' conceptual change levels: Evaporation, condensation and boiling*. (Unpublished Doctoral Dissertation). Karadeniz Technical University, Institute of Science, Trabzon, Turkey.

Coştu, B., Ayas, A., & Ünal, S. (2007). Misconceptions about boiling and Their possible reasons. *Kastamonu Education Journal, 15* (1), 123-136.

Çakır, M., & Aldemir B. (2011). Developing and validating a two tier Mendel genetics diagnostic test. *Mustafa Kemal University Journal of Social Sciences Institute*, *8* (16), 335-353.

Dale, G. L. (2006). *Student construction of small molecule models using Spartan model to explore polarity.* (Doctoral Dissertation). The University of Southern Mississippi, USA.

Demircioğlu, G., & Baykan, F. (2011). Kimya ve fen bilgisi öğretmen adayları ile lise 11.sınıf öğrencilerinin kimyasal bağlanma kavramına yönelik algılamalarının karşılaştırılması, 2nd International Conference on New Trends in Education and Their Implications, 27-29 April, Antalya, Turkey, 1083-1090.

Demircioğlu G., Ayas A., & Demircioğlu, H. (2005). Conceptual change achieved through a new teaching program on acids and bases. *Chemistry Education Research and Practice, 6* (1), 36-51.

Doğan, D., & Demirci, B. (2011). High school chemistry students' and prospective chemistry teachers' misconceptions about ionic bonding. *İnönü University Journal of the Faculty of Education, 12* (1), 67-84.

Fergus, S., & Hitch, G. (2014). Assessing the status of fundamental chemistry knowledge using a visually displayed chemistry diagnostic test. *New Directions, 10* (1), 50-58. doi: 10.11120.

Furió, C., & Calatayud, M. L. (1996). Difficulties with the geometry and polarity of molecules: Beyond misconceptions. *Journal of Chemical Education, 73,* 36-41.

Furió, C., Calatayud, M. L., Bárcenas, S. L., & Padilla, O. M. (2000). Functional fixedness and functional reduction as common sense reasonings in chemical equilibrium and in geometry and polarity of molecules. *Science Education, 84*, 545-565.

Gabel, D., (1998). The complexity of chemistry and implications for teaching. In B.J. Fraser and K.G. Tobin (Eds.), *International handbook of science education* (pp. 233-248). London, Great Britain: Kluwer Academic Publishers.

ISSN 1648–3898

Garnett, P.J., & Treagust, D. F. (1992). Conceptual difficulties experienced by senior high school students of chemistry: Electrochemical (galvanic) and electrolytic cells. *Journal of Research in Science Teaching, 29* (10), 1079-1099.

Griffard, P. B. (2001). The two-tier instrument on photosynthesis: What does it diagnose? *International Journal Science Education, 23* (10), 1039-1052.

Goh, N. K., & Sai, C. L. (1992). Students' learning difficulties on covalent bonding and structure concepts. *Teaching and Learning, 12* (2), 58-65.

Goh, N. K., Khoo, L. E., & Chia, L. S. (1993). Some misconceptions in chemistry: A cross-cultural comparison and implications for teaching. *Australian Science Teachers Journal, 39* (3), 65-68.

Harrison, A. G., & Treagust, D. (2000). Learning about atoms, molecules, and chemical bonds: A case study of multiple model use in grade 11 chemistry. *Science Education, 84,* 352-381.

Haslam, F., & Treagust, D. F. (1987). Diagnosing secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument. *Journal of Biological Education, 21* (3), 203-211.

Jang, N. H. (2003). *Developing and validating a chemical bonding instrument for Korean high school students.* (Unpublished Doctoral Dissertation). The Faculty Graduate School University, Missouri.

Johnson, R. B., & Christensen, L.B. (2000). E*ducational research: Quantitative and qualitative approaches.* Boston: Allyn and Bacon.

Kabapınar, F. (2003). The differences between misconception assessment scale and knowledge- comprehension level indicator. *Educational Administration-Theory and Practice*, *35,* 398-417.

Karadeniz Bayrak, B. (2013). Using two-tier test to identify primary students' conceptual understanding and alternative conceptions in acid base. *Mevlana International Journal of Education (MIJE), 3* (2), 19-26.

Karataş, F. Ö., Köse, S., & Coştu, B. (2003). Öğrencilerin yanılgılarını ve anlama düzeylerini belirlemede kullanılan iki aşamalı testler. *Pamukkale University Journal of Education, 13* (1), 54-69.

Kern, A. L., Wood N. B., Roehrig G. H., & Nyachwaya, J. M., (2010). A qualitative report of the ways high school chemistry students attempt to represent a chemical reaction at the atomic/molecular level. *Chemistry Education Research and Practice*, *11*, 165-172.

Kılıç, D., & Sağlam, N. (2009). Development of a two-tier diagnostic test to determine students' understanding of concepts in genetics. *Eurasian Journal of Educational Research, 36*, 227-244.

Kousathana, M., & Tsaparlis, G. (2002). Students' errors in solving numerical chemical equilibrium problems. *Chemical Education: Research and Practice in Europe, 3,* 5-17.

Levy Nahum, T., Hofstein, A., Mamlok-Naaman, R., & Bar-Dov, Z. (2004). Can final examinations amplify students' misconceptions in chemistry? *Chemistry Education: Research and Practice in Europe, 5* (3), 301 –325.

Mann, M., & Treagust, D. F. (1998). A pencil and paper instrument to diagnose students' conception of breathing, gas exchange and respiration. *Australian Science Teachers Journal, 44* (2), 55-59.

Meyer, P. G. (2005). *A study of how precursor key concepts for organic Chemistry success are understood by general chemistry students.* (Doctoral Dissertation). Western Michigan University, Kalamazoo, Michigan.

Nakiboğlu, C. (2003). Instructional misconceptions of Turkish prospective chemistry teachers about Atomic orbitals and hybridization. *Chemistry Education Research and Practice, 4* (2), 171-188.

Nakhleh, M. (1992). Why some students don't learn chemistry: Chemistry misconceptions. *Journal of Chemical Education, 69* (3), 191-196.

Nicoll, G. (2001). A report of undergraduates' bonding misconceptions. *International Journal of Science Education, 23*, 707-730.

Nyachwaya, J. M., Mohamed, A. R., Roehrig, G. H., Wood, N. B., Kern A. L., & Schneider, J. L. (2011). The development of an open-ended drawing tool: An alternative diagnostic tool for assessing students' understanding of the particulate nature of matter. *Chemistry Education Research and Practice, 12*, 121-132.

Odom, A. L., & Barrow, L. H. (1995). Development and application of a two-tier diagnostic test measuring college biology students' understanding of diffusion and osmosis after a course of instruction. *Journal of Research in Science Teaching, 32* (1), 45-61.

Özmen, H. (2004). Some student misconceptions in chemistry: A literature review of chemical bonding. *Journal of Science Education and Technology, 13,* 147–159.

Pabuçcu, A., & Geban, Ö. (2006). Remediating misconceptions concerning chemical bonding through conceptual change text. *Hacettepe University Journal of Education, 30,* 184- 192.

Peterson, R. F., & Treagust, D. F. (1989). Grade-12 students' misconceptions of covalent bonding and structure. *Journal of Chemical Education, 66* (6), 459-460.

Peterson, R. F., Treagust, D. F., & Garnett, P. (1989). Development and application of a diagnostic instrument to evaluate grade 11 and 12 students' concepts of covalent bonding and structure following a course of instruction. *Journal of Research in Science Teaching, 26* (4), 301-314.

Peterson, R., Treagust, D., & Garnett, P. (1986). Identification of secondary students' misconceptions of covalent bonding and the structure concepts using a diagnostic instrument. *Research in Science Education, 16,* 40-48.

Punch, F. K. (2009). *Introduction to research methods in education.* London: Sage Publication.

Raviolo, A. (2001). Assessing students' conceptual understanding of solubility equilibrium. *Journal of Chemical Education, 78* (5), 629-31.

Schmidt, H. J. (1997). Students' misconceptions: Looking for a pattern. *Science Education, 81,* 123-135.

Taber, K. S. (1999). Ideas about ionization energy: A diagnostic instrument. *School Science Review, 81* (295), 97-104.

Taber, K. S. (2001). Building the structural concepts of Chemistry: Some considerations from educational research. *Chemistry Education: Research and Practice in Europe, 2,* 123-158.

Taber, K. S. (2003). Mediating mental models of metals: Acknowledging the priority of the learner's prior learning. *Science Education, 87,* 732-758.

Tan, K. C. D., Goh, K. N., Chia, S. L., & Treagust, D. F. (2002). Development and application of a two-tier multiple choice diagnostic instrument to assess high school students' understanding of inorganic chemistry qualitative analysis. *Journal of Research in Science Teaching, 39* (4), 283-301.

Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. *International Journal of Science Education, 10* (2), 159-169.

Treagust, D. F., & Haslam, F. (1986). Evaluating secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier diagnostic instrument. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (59th, San Francisco, CA, March 28-31, 1986).

Tsai, C. C., & Chou, C. (2002). Diagnosing students' alternative conceptions in science through a networked two-tier test system. *International Journal of Computer Assisted Learning, 18* (2), 157-165.

Tyson, L., Treagust, D. F., & Bucat, R. B. (1999). The complexity teaching and learning chemical equilibrium. *Journal of Chemical Education, 76* (4), 554-558.

Ünal, S., Coştu, B., & Ayas, A. (2010). Secondary school students' misconceptions of covalent bonding. *Journal of Turkish Science Education, 7* (2), 3-29.

Wang, C. (2007). *The role of mental-modelling ability, content knowledge and mental models in general chemistry students' understanding about molecular polarity.* (Doctoral Dissertation). The Faculty of the Graduate School University of Missouri, Columbia.

Voska, K. W., & Heikkinen, H. W. (2000). Identification and analysis of student conception used to solve chemical equilibrium problems. *Journal of Research in Science Teaching, 37* (2), 160-176.

White, R. T., & Gunstone, R. F. (1992). *Probing understanding*, The Falmer Press, London.

Wu, H. K., Krajcik, J. S., & Soloway, J. S. (2001). Promoting understanding of chemical representations: Students' use of a visualization tool in the classroom. *Journal of Research in Science Teaching, 38*, 821-842.

Yılmaz, A., & Dinçol Özgür, S. (2012). **T**he effect of generative multimedia learning environment on teacher candidates' achievement, attitude and retention according to their learning styles. *Hacettepe University Journal of Education, 42,* 441-452.

Yılmaz, A., & Morgil, İ. (2001). Identification of misconception of university students on chemical bonds. *Hacettepe University Journal of Education, 20,* 172 -178.

Yin, R. K. (2003). *Case study research: Design and methods.* (3rd Ed.). Thousand Oaks, CA: Sage Publishing.

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