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Journal Name

ARTICLE

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Accepted 00th January 20xx

DOI: 10.1039/x0xx00000x

www.rsc.org/

This study sought to determine the levels of conceptual understanding of undergraduate students regarding organic compounds within different functional groups. A total of 60 students who were enrolled in the Department of Secondary Science and Mathematics Education of a Faculty of Education at a state university in Turkey and who had followed an Organic Chemistry Laboratory Course participated in the study. The data were collected using two tools: functional group worksheets and concept maps. Both qualitative and quantitative evaluations were used in analyzing the data. The findings showed that the students generally had low levels of understanding of concepts relating to functional groups, and they exhibited a considerable number of misconceptions. Considering the findings more fully, it was determined that students have remarkable misconceptions and low levels of understanding about certain topics regarding functional groups, including the physical properties of functional groups, intermolecular bonds, acidity and basicity, reduction and oxidation, stereoisomerism and structural isomerism, and aromaticity and aliphaticity, as well as other organic chemistry concepts (e.g. decarboxylation, oxyacide, phenol). The results suggest that, since students are unable to adequately comprehend the subjects of general chemistry, such as intramolecular and intermolecular bonds, acidity and basicity, oxidation and reduction and determination of molecular structures, they fail to accurately transfer their knowledge to learning about organic chemistry. In order to promote students' understanding of functional groups and prevent related misconceptions, it is recommended that basic chemistry topics should be reinforced, and the relationship between students' current knowledge and the new information to be learned in organic chemistry should be emphasized with the help of activities in which various forms of thinking are used.

Introduction

Learning is an active configuration process involving a dynamic interaction between a number of factors (Piaget, 1964; Vosniadou and Ioannides, 1998). Conceptions are the central form of knowledge in this process. As Schwartz (1993) states, an important aspect of acquiring new knowledge is understanding the relationships between various concepts. Likewise, Deci *et al.* (1991) define learning as a mixture of conceptual understanding and flexible use of knowledge. In this sense, modern teaching approaches indicate that permanent learning depends on conceptual understanding (Driver and Erickson, 1983), in line with Ausubel's (1968) emphasis on the necessity for individuals to correlate the concepts they encounter for meaningful learning to take place. When we use the concepts accurately and establish convenient, hierarchical relationships between the concepts being learned, this will lead to the effective structuring of knowledge. In his film *Minds of our Own*, Sadler (1997) made the following comment regarding conceptual understanding: "If the meaning of the term is not fully understood, then everything involving that term that the subject encounters tends to have problems" (as cited in Meyer 2005). The problems that emerge when a relationship is not established between the concepts that are the units of thoughts and the constituents of knowledge cause not only a failure in

learning, but also the formation of misconceptions (Nakhleh, 1992).

Misconceptions are encountered in a number of areas. One area in which concepts often cannot be learned effectively, and where misconceptions are encountered at the highest rate is the physical sciences. Studies carried out on science learning in the last several decades have revealed that students fail to comprehend many concepts within the physical sciences, and that misconceptions are frequently detected (Bodner, 1991; Coştu *et al.*, 2010; Galley, 2004; Mintzes *et al.*, 1997; Wasacz, 2010). It is asserted in the literature that misconceptions in chemistry are mainly caused by lack of information, incorrect strategies being applied during instruction, misconceptions of teachers, and in the prior understanding of students, as well as past experiences and memorization-oriented learning (Taber, 2001). Misconceptions formed for all or any of these reasons may negatively affect subsequent learning (Palmer, 2001). Thus, it is essential to determine which incorrect ideas are held by students in order to enable them to reach scientifically accepted understandings and learn the related concepts effectively (Osborne and Freyberg, 1985). As Case and Fraser (1999) also indicate, it is necessary to determine the existing misconceptions in order to remove them and enable conceptual learning. Unless this process is carried through, it is thought that the teaching strategies being applied and students' new experiences will not be sufficient to reach the desired outcomes. In this respect, it is very important to understand the conceptual learning and misconceptions that may occur in courses in organic chemistry, which is

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3 considered one of the physical sciences and has a broad
4 subject area (Driver and Easley, 1978; Duffy, 2006; Duis,
5 2011).

6 Organic chemistry, which was believed to be presented in
7 the structure of living organisms and was known as "carbon
8 compounds" until the beginning of the 19th century, has
9 always had an important place in our daily lives. According to
10 Yong (1994), organic chemistry is an indispensable part of
11 daily life. This entwinement of organic chemistry in our lives
12 and the need for scientific progress necessitate constant
13 attention to education in the field. However, researchers have
14 made it clear that students have great difficulty in
15 understanding organic chemistry (Birk and Kurtz, 1999;
16 Childs and Sheehan, 2009; Gaddis, 2001; Graulich, 2015;
17 O'Dwyer and Childs, 2011; Taagepera and Noori, 2000;
18 Wasacz, 2010). In fact, students have attributed different
19 meanings to this academic course due to its difficulties, and it
20 has gained a reputation as a "rite of passage" (Pungente and
21 Badger, 2003), a "killer course" (Grove *et al.*, 2008),
22 "gatekeeper" (McClary, 2010) and "dreaded wash-out" (Katz,
23 1990, as cited in O'Dwyer and Childs, 2011). When students
24 were asked why they found organic chemistry to be difficult,
25 they answered that it was an abstract, onerous task and a
26 memorization-oriented subject with many details to be learnt
27 (Bhattacharyya and Bodner, 2005; O'Dwyer and Childs,
28 2011).

29 On the other hand, a number of studies have shown that
30 students fail to learn organic chemistry primarily due to their
31 lack of conceptual understanding, as in other areas of
32 chemistry (Duffy, 2006). Bhattacharyya and Bodner (2005)
33 demonstrated that even with high performance in terms of
34 solving problems in organic chemistry, graduate students
35 have very low levels of conceptual understanding, which has
36 been mainly associated with a memorization-oriented
37 approach to learning. It has also been observed that a reason
38 they are unable to learn these concepts is that they apply an
39 algorithmic approach, using a limited number of problems
40 with gradually-progressing solutions, to understand organic
41 chemistry; and they are thus not able to generate alternative
42 ways of thinking (Nakhleh, 1993; Sanger, 2005). Ferguson
43 (2003) contends that rather than answering the questions of
44 "how" and "why" in interpreting reactions in organic
45 chemistry, students focus solely on initial products and the
46 products that may be formed.

47 In order to address this issue, researchers have drawn
48 attention to the teaching of the granular structure of matter,
49 conducting studies aimed at the development of spatial and
50 reasoning ability in students (Fleming *et al.*, 2000; Liu, 2005;
51 Nandagopal, 2008). Bhattacharyya (2004) emphasizes the
52 necessity for students to focus on the visualization of
53 molecules, reactions and even 'non-visual' particles in order
54 to understand the concepts involved in organic chemistry.
55 Some researchers have determined that students are able to
56 understand basic concepts in organic chemistry through
57 macro-micro-symbol and sub-micro representations
58 (Ferguson and Bodner, 2008; Nakhleh, 1993; Reid and Yang,
59 2002). Additionally, to counteract misconceptions Kozma
60 *et al.* (2000) emphasize that it is possible to make a connection
between these representations with the help of alternative

ways of thinking. The relationships between representations
are not algorithmic; while using these four representations,
students tend to apply alternative ways of thinking between
each of them without pursuing an order. Duffy (2006) notes
that conceptual learning depends on the ways of thinking
deployed. According to her, conceptual understanding occurs
when the students create viable and scientific pathways in
order to obtain the correct answers. She suggests that
terminological representation plays an active role in
developing conceptual understanding and increases the
comprehensibility of organic chemistry. Since the students
may misuse or misunderstand the specific chemical concepts,
or use vocabulary either non-scientifically or inconsistent
with the chemical definitions, she denotes the presence of a
non-referential use of terminology (NRT) way of thinking.
Robinson and Nurrenbern (n.d.), have also touched upon the
types of problem related to organic chemistry in conceptual
learning and emphasized the necessity for using algorithmic-
A and recall-R methods, as well as the conceptual-C method
(Raker, 2011).

In light of all these studies, it can be understood that
organic chemistry may only be learned through acquisition of
conceptual knowledge. We think that conceptual
understanding is not merely about knowing the definition of
the concepts or defining them, but also about seeing the
relationship between concepts and the ways in which
concepts are constructed in the minds of students. Moreover,
conceptual understanding occurs when new knowledge is
connected with existing knowledge using alternative ways of
thinking in a logical way. Thus, it is essential to determine the
misconceptions of students in order to promote meaningful
learning and to plan instruction accordingly (Driver and
Easley, 1978). Accordingly, the first step in improving the
teaching of these concepts is to carry out an analysis
regarding what misconceptions students have (Tennyson,
1983, as cited in Ülgen, 2004).

According to Ausubel *et al.* (1978), the most important
factor affecting learning is students' available knowledge (as
cited in Köseoğlu and Tümay, 2013). However, in terms of
national and international research, only a limited number of
studies have been conducted regarding students'
misconceptions in the field of organic chemistry. In one of the
existing studies, Rushton *et al.* (2008) examined the
conceptual understandings of fourth-year university chemistry
students regarding the basic concepts of organic chemistry. In
another study, Cruz-Ramirez de Arellano and Towns (2014)
investigated students' understanding of alkyl halide reactions
in undergraduate organic chemistry. In this interview study,
the questions related to predicting the product that might be
formed depending on certain reactives, writing the best
mechanism to describe the organic reactions, and explaining
the basic concepts of organic chemistry. Likewise, in his
exploratory study, Duis (2011) conducted interviews with 23
organic chemistry educators; their answers revealed that
students have misconceptions in the basic concepts of organic
chemistry. In particular, her participants reported that students
had difficulty with reaction mechanisms, acid-base chemistry,
synthesis reactions, stereochemistry, and resonance and
functional groups, as well as their properties.

Another study relating to the determination of misconceptions concerning organic chemistry was conducted with 60 students from a junior college in Singapore (Bryan, 2007). According to the results, the students had learning difficulties in determining the presence of chiral carbon atoms, cis-trans isomerism, optical isomerism, reactivity of alkenes, and activity of organic compounds consisting of functional groups like alcohols and carboxylic acids. Likewise, as a result of a diagnostic test applied with 276 university students, O'Dwyer and Childs (2011) determined that students had an average success rate of 53% in organic chemistry. The researchers concluded that students primarily had difficulties in understanding the subjects of reaction and mechanism, as well as in classifying organic compounds and understanding their properties.

Aside from the studies related to determining students' misconceptions, the literature regarding organic chemistry includes studies that were primarily aimed at teaching approaches and reaction mechanisms as a subject (Bauer, 1998; Cruz-Ramirez de Arellano and Towns, 2014; Evans, 2013; Gaddis, 2001; McClary, 2010; Nandagopal, 2008; Pakhira, 2012; Schroeder, 2008; Shatila, 2007). However, there is a very limited number of studies concerning students' level of understanding of functional groups, which are among the most important subjects related to organic chemistry. In fact, functional groups play an important role in both the classification of organic compounds according to their reactivities and in the characteristic chemical reactions of molecules. Therefore, it is necessary to investigate the extent to which students learn the concepts of organic compounds with functional groups and the extent of the convenient, hierarchical relationships between these concepts, and to reveal their degree of understanding. In this study the authors wish to foster an awareness of misconceptions regarding functional groups. Developing and promoting such an awareness may be useful for teachers and educators in structuring their teaching more productively. Additionally, the results of this research may contribute to subsequent studies. Accordingly, this study aims to determine the learning levels of undergraduate students regarding organic compounds with different functional groups, as well as their misconceptions, if present. Thus, answers have been sought for the following questions:

- What are the undergraduate students' levels of conceptual understanding regarding functional groups?
- What are the undergraduate students' misconceptions regarding functional groups?

Method

Research Design

This study aims to determine the misconceptions concerning functional groups of undergraduate students followed in the Organic Chemistry Laboratory Course in the spring semester. A case study design was used to draw attention to the specific circumstances related to the participants' understanding of functional groups. The study was carried out over 12 weeks in the spring semester. During this period various experiments relating to the subject of functional groups were performed.

Following each experiment, worksheets related to the concepts mentioned in the experiment were given to the students, and the students were asked to complete them. At the end of the 12-week period of study, the researchers instructed the students in concept mapping techniques during 1 week's class hours (4 hours weekly). The content of this program included types of concept maps, the methods for writing propositions between concepts, and the directions in which arrows should be drawn. Following this instruction, each student was asked to build a concept map related to the subject of functional groups.

The Study Group

The total of 60 students who cooperated with this research were enrolled in the Department of Secondary Science and Mathematics Education of a Faculty of Education at a state university in Turkey. Among these students, 32 were female and 28 were male. Students took the Organic Chemistry Laboratory Course in the spring term; they had also followed the Organic Chemistry I and Organic Chemistry II during two previous academic years. The subject of functional groups was taught within the scope of the Organic Chemistry II course, and these theoretical lessons were conducted in parallel with laboratory lessons. Throughout the study, the students carried out experiments regarding functional groups (molecule models of alcohols and ethers, aldehydes and ketones, carboxylic acids and esters, maleic and fumaric acid output, and iodoform output) under the guidance of the researchers. Furthermore, the authors of this article, who were also the lead researchers, have a combined experience of 8 years in teaching the Organic Chemistry Laboratory courses.

The researchers explained the research procedures and potential consequences accurately and in sufficient detail to the students in the laboratory environment. All the students were asked to participate in the study and gave their informed consent before participating in research and the researchers use individuals' existing data for research purposes. Students had a right to make a free choice over whether to contribute to the study or not (British Educational Research Association, 2011; as cited in Taber, 2014). Data were obtained solely by two researchers and they were stored in a secure location. All data and the identities of the individuals were kept anonymous. In order to maintain confidentiality, the participants' names were not revealed; the students were referenced using the code "S" and a number (e.g. S1).

Data Collection and Instruments

Two data collection tools were used in the study: functional group worksheets and concept maps. All of the data were collected in Turkish. The study data were translated into English by two English experts, and finally, the researchers checked the translations for the accuracy of chemistry-related terminology.

Functional Group Worksheets. The worksheets were prepared and developed by the researchers in order to use the concepts being mentioned in each experiment. In determining the concepts to be used, a literature review was carried out, as

well as soliciting the views of expert academics (two in the field of organic chemistry and two in chemistry education). Table 1 illustrates the concepts involved in the worksheets and in the objectives of the experiments.

The worksheets included the concepts mentioned in the experiments, as well as the concepts that were thought to be related to those concepts; that is to say, a concept mentioned in one experiment that could also be related to another experiment was mentioned in the worksheet related to that experiment as well. For instance, the dipole-dipole bond, Van der Waals bond, hydrogen bond, nucleophile, aromatic and aliphatic could be given as examples of the common concepts that were used in this way.

Table 1 Concepts involved in worksheets and the objectives of experiments

As shown in Table 2, the students were asked to define the concept and make statements about the relationships between the subjects studied with regard to the concepts in the worksheets. Open-ended questions regarding the concepts were prepared in a manner that enabled the students to freely express how they had structured the concepts and their relationship in their minds, and thus to reveal their misconceptions (Palmer, 1998). The worksheets also included the option “I don’t know”. This option was offered in order to assist in determining whether the students had remembered the concepts mentioned in the subject.

Table 2 Worksheet order

Table 2 shows examples of 3 different ways of answering about the concept of the structural isomer in the worksheets. Among these examples, the student in this case marked the option “I don’t know” in the first example, as he had no understanding of the concept. In the second example, the student only wrote the definition of the concept and was unable to indicate its relation to the subject; and in the third example, he defined and associated the concept accurately. The definitions and associations of students regarding the concepts may not always include accurate statements; thus, the researchers attempted to reveal the levels of understanding and misconceptions of the students with the aid of any incorrect statements written on the worksheets.

Analysis of the Functional Group Worksheets. In order to evaluate the levels of conceptual understanding of the students and to present the data in an organized and uniform manner, the written answers obtained from the worksheets were analyzed according to 5 categories: “sound understanding”, “partial understanding”, “specific misconceptions”, “no understanding” and “no response”. Similar categorization processes for determining students’ levels of understanding are frequently encountered (e.g. Abraham *et al.* 1994; Çalık, 2005; Ünal *et al.*, 2010). The explanations of these categories are provided in Table 3.

In order to establish the reliability of the coding process, the researchers coded the data in the worksheets separately at different times. Following this coding process, the researchers

checked the coherence between them and determined the match percentage as 90% (0.90). The fact that this value was higher than 0.75 shows that the analyses were reliable and demonstrated “excellent coherence” (Fleiss *et al.* 2003).

Table 3 Categories used in the analysis of the written answers acquired from the worksheets and their coding criteria

Concept Maps. Concept maps are graphical materials used for revealing the relationships between the main and subsidiary concepts that exist in the cognitive structures of students. They have been widely used in the studies in order to reveal students’ cognitive structures, conceptual understanding and misconceptions (Jennings, 2012; Nakiboğlu and Ertem, 2010; Ruiz-Primo, 2004).

In this study, the students were instructed in concepts relating to the functional groups and were asked to form a concept map using these concepts. The process of preparing the concept maps provided the students with cognitive freedom and enabled them to visualise the associations they had formed. A total of 50 concepts were selected relating to the subject of functional groups. These concepts are displayed in Table 4. Otherwise, the students were exposed to no influence and were free to use any concepts in order to demonstrate their structures of cognition. Accordingly, they used other concepts and examples in addition to the concepts given on the maps.

Table 4 Concepts involved in the concept maps

The concept maps were prepared in approximately 60-90 minutes. In order to encourage the students to individually reflect their knowledge about the concepts, they were prohibited from communicating with each other or using outside resources in the process of preparation. The students were permitted to give different concepts or examples aside from the concepts given in the maps they prepared. At the end of this process, a total of 60 concept maps were collected.

Analysis of the Concept Maps. Both qualitative and quantitative evaluations were used in analyzing the concept maps. The analysis methods suggested by McClure *et al.* (1999) consist of 6 types: holistic, holistic with expert map, relational, relational with expert map, structural, and structural with expert map. This study used the relational method in the analysis of the concept maps prepared by the students. This method examines in detail how the relationships between concepts are established. The suggestions about the relationships between the concepts could be evaluated both qualitatively and quantitatively by this scoring method, which uses three criteria as a base: a) whether there is a relationship between the concepts or not; b) the accuracy of the proposition; and c) the direction of the arrow indicating the relationship. The propositions about the concepts are scored from 0 to 3 based on accuracy. The total score is determined after scoring all of the propositions displayed on the map (McClure *et al.*, 1999). In the relational analysis method, Yin *et al.* (2005) evaluated both the presence and the quality of relationships and suggested a scoring method accordingly. Related studies show that it is

possible to determine the misconceptions and conceptual understanding levels of students regarding any subject with the help of concept map analyses conducted using the relational method (Francisco *et al.*, 2002; Ross and Munby, 1991).

The scales developed by McClure and Bell (1990) and adapted by McClure *et al.* (1999) were taken into consideration in scoring the concept maps. The propositional statements among the concepts were taken into consideration during the qualitative evaluation of the concept maps. The propositions where the relationship between the concepts was indicated with arrows were evaluated with the following scoring criteria: scientifically accurate propositions and the direction of the arrow, accurate propositions, incorrect propositions, and those involving no scientific statements were assigned a value of 3 points, 2 points, 1 point and 0 points respectively. The findings used in this study consist of the incorrect propositions acquired from the qualitative analysis of the concept maps. These incorrect propositions involve statements with misconceptions.

Interrater reliability of the concept maps. In order to establish the reliability of the study, the concept maps were analyzed and scored by two independent researchers at different times. Following this scoring, the agreement percentage was calculated to determine interrater reliability (Miles and Huberman, 1994). The agreement percentage was determined as 94% (0.94), indicating that the coding was reliable and the coherence excellent (Fleiss *et al.*, 2003). Table 5 shows the average values acquired by both researchers as a result of scoring the concept maps. The coding reliability of the concept maps was determined based on the correlation value between these average values.

Table 5 Interrater reliability of the concept maps

The Pearson product-moment correlation coefficient of the scorers was calculated as 0.976 ($p < 0.01$) via the SPSS 15.0 program. The high correlation value does not signify that both researchers had given the same score to the same map; the scores given to the concept maps show some variation. However, the correlation coefficient shows that there was a significant, high and positive relationship between the scorers; therefore, it can be asserted that the evaluations of the concept maps were both valid and reliable.

Results

Results Acquired from the Analysis of the Worksheets

The concepts relating to each experiment were analyzed separately in the worksheets that were prepared to determine the level of understanding and misconceptions of students regarding functional groups. The analysis was evaluated according to five categories: Sound Understanding (SU), Partial Understanding (PU), Specific Misconception (SM), No Understanding (NU) and No Response (NR). Table 6 shows the findings acquired from the analyses of the worksheets.

Table 6 Analysis of the responses given by students to concepts

As shown in Table 6, the worksheets involved the understanding levels and misconceptions of students regarding a total of 61 concepts. The concepts indicated with an asterisk (*) in the table were associated with each of the experiments and were therefore included in the worksheets for all of the experiments. An examination of the table reveals that the students had the highest levels of understanding of the concepts of alcohol and its various types, such as monoalcohol, dialcohol, trialcohol, hydroxyl groups, and ether; as well as carboxylic acid types, such as monocarboxylic acid, dicarboxylic acid and tricarboxylic acid. A level of partial understanding was observed in relation to the concepts such as polarity, structural isomer, dipole-dipole interaction, solubility, boiling point, aromatic, nucleophile, amphoteric property, geometrical isomer, and reduction. On the other hand, there were some concepts, such as tautomeri, oxyacide etc. that were generally left blank by students, as they had no connotation or correlation regarding the functional groups (see Table 6). Specific misconceptions as related to these concepts are given in Table 7 in detail.

Table 7 shows the concepts that had the greatest misconceptions in terms of experimental subjects in the worksheets according to their frequencies and percentages. The table also illustrates on a separate line the misconceptions regarding common concepts in the worksheets. The reason for including these common concepts separately was that the same misconceptions were encountered on each worksheet. The frequency and percentage values of the errors relating to the common concepts in worksheets were attained by averaging the frequency and percentage values in all worksheets. While the frequency values indicate the number of students expressing the misconception, the percentage values indicate the percentage value among the 60 students who participated in the study. Concepts involving the misconceptions were not evaluated for frequency values of less than 3.

Table 7 also shows the statements of students regarding concepts in relation to which they had the greatest number of errors. According to these statements, they confused the Van der Waals and dipole-dipole interactions and both intramolecular and intermolecular bonds in the concepts of hydrogen bond; they were also unable to associate the bond structures of the molecules. In addition, they confused concepts that are usually used together, such as oxidizer and reducer and nucleophile and electrophile, and they were unable to define them accurately. The students also made erroneous statements about concepts such as optical isomer, chiral and enantiomer in the subject of isomery.

Table 7 Statements of students with misconceptions acquired from worksheets

Quantitative Results Acquired from the Analysis of the Concept Maps

The data in the study were acquired from a total of 60 concept maps that were prepared by the students. The concept maps

were scored by the researchers according to the relational scoring method. Figure 1 shows the distribution of findings that were acquired as a result of the scoring.

Fig. 1 Distribution of scores obtained from the concept maps

The scores obtained from the concept maps varied between 34 and 180. In order to interpret these scores, the scores were categorized equally in order to have an interval value of 36 using the SPSS 15.0 program. Table 8 shows the frequency and percentage distribution of the numbers of students in 4 categories (excellent, good, average, poor) that were obtained as a result of the process of categorization. Examples of two students' concept maps categorized good and poor are given in the Appendix.

Table 8 Scale codes of concept map scores and distribution of students

According to Table 8, it can be seen that the students had low levels of conceptual understanding regarding functional groups.

Table 9 illustrates in detail the levels of understanding of the students regarding the concepts in the concept maps. The data from the concept maps are presented separately as the number of concepts, total number of propositions used, number of accurate propositions used and number of incorrect propositions. The relationships between the concepts included in the column of concepts in incorrect propositions (IPC) is shown in Table 9; however, there is an error concerning the propositions between these concepts that were written by the students. The incorrect propositions among these concepts are specified in the qualitative analysis of the concept maps.

Table 9 Quantitative analysis of concept maps

Qualitative Findings Acquired from the Analysis of the Concept Maps

Table 10 involves the misconceptions acquired from incorrect propositions that were displayed by the majority of the students. Table 10 shows the frequency and percentage distribution of these misconceptions according to students.

Table 10 Misconceptions identified from concept maps

As shown in Table 10, as a result of the analysis of the students' concept maps, the students were observed to have various misconceptions regarding concepts in the functional groups, particularly with regard to structural isomer, phenol, chiral, achiral, geometrical isomer, oxyacide, aliphatic, intermolecular bonds (Van der Waals, dipole-dipole, H bond), diastereomer, enantiomer, optical isomer, oxidizer, nucleophile and solubility (see Table 10). In addition, the students were observed to have problems in determining the oxidation and reduction products of functional groups, classifying mono-alcohols and determining the electrophile or nucleophile groups.

Discussion

This study has attempted to reveal students' levels of understanding and their misconceptions regarding the concepts concerning functional groups, which are among the most important subjects of organic chemistry. The understanding levels and misconceptions of students were identified from worksheets that were prepared by the researchers and from concept maps that were prepared by the students. All of the findings indicate that the students generally had low levels of understanding of concepts regarding functional groups, and they had a considerable number of related misconceptions.

Considering the findings acquired from the worksheets, it was observed that the students had good levels of understanding of concepts of *“alcohol, ether, aldehyde, ketone, ester, carboxylic acid and its variations”* (see Table 6). This indicates that students are able to discern the compounds within this functional group. However, it was also observed that the students had low levels of understanding of concepts relating to *“solubility, nucleophile, electrophile, melting point, acid regulation, diastereomer, optical isomer, reduction and oxidizer.”* On the other hand, the students had the greatest misconceptions regarding *“hydrogen bond, number of branchings, dipole-dipole bond, Van der Waals bond, nucleophile, electrophile, decarboxylation, chiral, oxidizer and reducer.”* Considering these findings, it can be determined that the students generally had misconceptions about certain topics regarding functional groups, as well as low levels of understanding in relation to *“physical properties of functional groups, intermolecular bonds, acidity and basicity, reduction and oxidation, stereoisomerism and structural isomerism, aromaticity and aliphaticity, as well as other organic chemistry concepts being encountered (such as decarboxylation, oxyacide, phenol)”*.

Physical Properties of Functional Groups of Organic Compounds

An examination of the findings shows that students had difficulty in understanding the concepts relating to solubility, amphoteric property, melting point, crystal structure and acid regulation. These concepts are related to the physical properties of functional groups of organic compounds. Even though students were able to discern the functional groups, it can be seen that they were not able to sufficiently understand and correlate the concepts regarding their properties. Misconceptions concerning solubility and boiling point were also observed in the concept maps. For instance, some students (16.7% in the worksheets and 5.0% in the concept maps – see Table 7 and Table 10) associated the increase of the boiling point in compounds comprising the functional groups such as alcohol with an increase in the number of branchings. This misconception could have been caused by the students confusing the number of branchings with the size of the molecules. An example relating to solubility is that, since the molecular structure of ether resembles water, its solubility is higher than that of alcohol (6.7% in the worksheets - see Table 7). This condition indicates that students also had problems with the intermolecular hydrogen bonds that exist in alcohol. In their study conducted with

students enrolled in a department of organic chemistry, Henderleiter *et al.* (2001) determined that students could form definitions about the hydrogen bond and explain the formation of the hydrogen bond; however, they could not make interpretations regarding how the hydrogen bond would affect the physical properties of molecules, and they had misconceptions regarding boiling point and solubility.

Intermolecular Bonds in Functional Groups

One of the most important findings of the current study is that the students had particular misconceptions regarding the definitions of the concepts of hydrogen bond, Van der Waals interaction and dipole-dipole bond, which are among the intermolecular bonds, as well as their association with functional groups. The majority of the students (18.3% on the concept maps and 21.7%, 11.7% and 15.0% respectively among the common concepts in the worksheets - see Table 7 and Table 10) defined these bonds as intramolecular bonds and failed to consider intermolecular bonds. Examining the literature, it is observed that students have a number of misconceptions regarding chemical bonds (Birk and Kurz, 1999; Nicoll, 2001; Othman *et al.*, 2008; Peterson and Treagust, 1989; Taber and Coll, 2002).

The results obtained from the concept maps in the present case show that 15% of the students had misconceptions regarding "the existence of a hydrogen bond between the oxygen and hydrogen atoms in a hydroxyl group". This result is in parallel with the results obtained by Gaddis (2001) and Meyer (2005). In a study performed in an organic chemistry laboratory with organic chemistry students, Gaddis (2001) posed a question about intermolecular forces. According to the answers, 32% (N=22) of students confused the hydrogen bond with the intramolecular covalent bond.

Similarly, Meyer (2005) determined that the majority of students were unable to understand the nature of intermolecular forces and that they confused them with intramolecular covalent bonds. For instance, in one of the interview questions, the students were asked to show the intermolecular bond on the structures of water molecules; some of the students pointed to the covalent bond between the hydrogen and oxygen atom in the structure of the water molecule. Moreover, in their study conducted with college students in an organic chemistry course, Taagepera and Noori (2000) observed an error regarding the fact that the "hydrogen bonds contain the covalent bond". In this present case, some of the students (38.3% in the worksheets - see Table 7) also defined the hydrogen bond as "the attraction force between the efficient particles in aldehydes". Accordingly, they stated: "as aldehydes contain the hydrogen atom, they provide an intermolecular hydrogen bond". Furthermore, the students noted that "the first four members of aldehydes and ketones make up the hydrogen bond". This error could have been caused by confusion with the following information: "In particular, the first four members of aldehydes and ketones that have a small molecular mass make up the hydrogen bond with the help of water molecules when they dissolve in water".

Apart from this, while some students (18.3% in the worksheets - see Table 7) were observed to "ground the existence of the Van der Waals bond in aldehydes and ketones on the aliphatic structure", others (13.3% in the worksheets - see Table 7) stated that "the Van der Waals bond exists in apolar molecules". Regarding the dipole-dipole interaction, some students (15.0% in the worksheets - see Table 7) stated: "alcohols have higher dipole-dipole interactions compared to ethers, which is caused by the apolar structure of ethers". Such a misconception could be caused by failure to understand the concept of polarity in alcohol and ether, as well as failure to comprehend the fact that alcohols have stronger bonds, since they involve each intermolecular bond in comparison to ethers.

In fact, the findings acquired from the worksheets suggest a failure of the students to sufficiently understand the concept of polarity. Accordingly, it is observed that while some students (8.3% in the worksheets - see Table 7) had misconceptions regarding polarity, others (20.0% in the worksheets - see Table 6) had lower levels of sound understanding. Students with misconceptions regarding polarity (8.3% in the worksheets - see Table 7) state in particular that "ethers that are the compounds of functional groups are not polar due to their molecular structure". At this point, it can be observed that students also experienced problems concerning molecular structures outside of bonds and molecular polarity. From this point of view, it is possible to assert that students had either deficiencies or errors in their prior chemistry knowledge. When students with such deficiencies encounter more complex molecules bearing a functional group in organic chemistry, they are unable to determine the molecular polarity and have greater difficulty with this subject.

The related literature indicates that students are generally unable to recognize intramolecular electron distributions and use non-bonding "lone pair" electrons in determining molecular structure, and that therefore they fail to understand molecular polarity (Birk and Kurtz, 1999; Harrison and Treagust, 1996; Peterson *et al.*, 1989; Taagepera *et al.*, 2002). As a result of interviews conducted with 56 university students, Nicoll (2001) likewise concluded that students have a number of misconceptions, especially with regard to bonds and polarity, in organic chemistry.

Considering other misconceptions regarding the dipole-dipole interaction, which is among the intermolecular bonds, some students (11.7% in the worksheets - see Table 7) noted that "while the esters involve the dipole-dipole interaction, the carboxylic acids do not involve the dipole-dipole interaction, as they have a hydrogen bond". This error could be caused by the failure of students to consider other intermolecular forces, as the hydrogen bond is the strongest intermolecular bond. Apart from this, some students (13.3% in the worksheets - see Table 7) stated that "while the maleic acid, which is among the carboxylic acids, involves the dipole-dipole interaction, the fumaric acid does not"; this could indicate students' confusion about the dipole-dipole interaction and the dipole moment.

Acidity and Basicity in Functional Groups

Another finding of the study relates to misconceptions about "electrophile" and "nucleophile". For instance, while some of the students (16.7% in the worksheets - see Table 7) used the statement, "a carbon atom with a relatively positive charge" regarding the concept of nucleophile, others (11.7% in the worksheets - see Table 7) used the statement, "electron-rich carbon atom in the iodoform compound". In addition, the students (11.7% among the common concepts in the worksheets - see Table 7) defined the concept of nucleophile as "structures showing a tendency to receive electrons", "positive-end parts" and "electron-poor groups". Considering these errors, it can be seen that the students confused the concept of nucleophile with the concept of electrophile. Similarly, considering the misconceptions of students regarding the electrophile, some of them (21.7% in the worksheets - see Table 7) gave the following definitions: "structures showing a tendency to give electrons", "electron-rich molecules" and "negatively-charged parts". Considering the findings from the concept maps, on the other hand, some of the students (10.0% in the concept maps - see Table 10) exhibited a misconception that "the group OH is electrophilic"; others (15.0% in the concept maps - see Table 10) had a misconception that "the maleic anhydride molecule being used in the formation of maleic acids is nucleophilic". In this respect, the students were observed to have problems with both defining and discerning the processes of developing these concepts.

Within the secondary school curriculum in Turkey, students are acquainted with the concepts of nucleophile and electrophile in organic chemistry for the first time in the 12th grade. Although the students in this case realized the properties of these two concepts in the reactions of displacement and participation on the theoretical level, as well as in a few examples, they were unable to learn the reaction mechanism and its functions and properties in detail. At the university level, on the other hand, the students were taught the concepts of nucleophile and electrophile in the organic chemistry course on the basis of reaction mechanisms. However, the past misunderstanding of students affected their subsequent learning. Moreover, students may fail to sufficiently understand these concepts due to the fact that the substances of nucleophile and electrophile are associated with the concepts of acid and base, and this relation cannot be transferred from previous learning experiences. Considering the findings derived from the worksheets, it can be observed that the level of sufficient understanding of these concepts was very low (See Table 6), which could be caused by the failure of students to precisely understand the concepts of acid-base at the level of general chemistry.

According to the related literature, the subjects of acidity and basicity are very important in understanding reaction mechanisms in organic chemistry; comprehending the behaviour of reactive substances in a reaction; estimating the products in chemical reaction and understanding the concepts of nucleophile and electrophile (Bhattacharyya and Bodner, 2005; Ferguson and Bodner, 2008; Fishback, 2010; McClary, 2010). As a result of interviews conducted with 14 students, Cartrette and Mayo (2011) identified the relationship between

the concepts of acid and base and the concepts of nucleophile and electrophile in organic chemistry, as well as the levels of understanding of students. Although some of the students could explain the concepts of nucleophile and electrophile, they remained unable to explain the relationship of these to acids and bases. Similarly, the students also had difficulties in determining the nucleophile and electrophile substances in organic chemistry reactions. According to Ferguson and Bodner (2008), students are unable to estimate the flow of electrons during reaction mechanisms in solving problems about reaction mechanisms; they contend that this is caused by students' deficient conceptual understanding regarding acidity, acidity strength and acidity constant. In their qualitative investigation with university students in an organic chemistry course, Cruz-Ramirez de Arellano and Towns (2014) observed that students confused the concepts of base and/or nucleophile and were unable to determine the strengths of basic and/or nucleophilic substances such as iodide and methanol or the strengths of basic and/or electrophilic substances. Therefore, the students could not determine how to assess electron-deficient and electron-rich areas in molecules. This inability was associated with their failure to understand bonds and molecular polarity. In this respect, McClary (2010) points out that students need to have a deeper conceptual understanding regarding acids and bases in order to understand the relationship between the nucleophilic and basicity.

Similarly, Anderson (2009) reported that university students interpreted the concepts of nucleophile and electrophile in reactions as a result of activities that were performed to develop their mechanistic problem-solving skills, and they were able to achieve conceptual understanding as a result of this process. Thus, it can be concluded that it is important to clearly present the subjects of acid and base types and properties, as well as acidity and basicity strengths, in order for students to understand the concepts of nucleophile and electrophile. It is also recommended that the concepts of acid and base be taught through various learning techniques by associating them with the concepts of nucleophile and electrophile with respect to the subject of reaction mechanisms.

Reduction and Oxidation in Functional Groups

Another important finding of this study concerns the concepts of "oxidation", "reduction", "oxidizer" and "reducer". It was observed that the students had a partial understanding in explaining these concepts in general (see Table 6). They also had misconceptions regarding these concepts, which is highly interesting. Examining Table 7, it can be seen that students confused the definitions of oxidizer and reducer through statements such as "atoms receiving electrons" and "a structure that is reduced by receiving hydrogen" for the concept of "reducer" (20.0% in the worksheets); and the statements "atoms giving electrons" and "a structure that is oxidized by giving hydrogen" for the concept of "oxidizer" (20.0% in the worksheets). This suggests that the students had a problem with both defining and discriminating in the process of developing these concepts. In addition, considering

the concept maps, it can be seen that the students encountered difficulty in explaining the products of oxidation and reduction in the functional groups. For instance, a portion of the students (5.0% in the concept maps - see Table 10) had the misconception that "when all the alcohols are oxidized, a carboxylic acid will be formed".

What is remarkable here is that students were not able to soundly comprehend the oxidation products of primary, secondary and tertiary alcohols, which are among the mono-alcohols. This could be caused by their generalization of alcohol oxidation, as excessive generalization in the process of developing concepts may lead to errors. Another misconception regarding this subject is illustrated by the statements of some of the students (5.0% in the concept maps - see Table 10) that "esters are formed when ketones are oxidized". This misconception may be caused by the fact that students consider the oxidation of a secondary alcohol, which is the reduction product of ketone, to be similar to the oxidation of a primary alcohol. Apart from this, while some of the students (11.7% in the concept maps - see Table 10) evidenced a misconception that "diols are formed when ketones are oxidized", others (6.7% in the concept maps - see Table 10) had the misconception that "ketones are formed when polyalcohols are oxidized". Here, the students confused the oxidation and reduction products of ketone with diol and polyalcohol, instead of mono-alcohol.

Due to these related misconceptions, it may be asserted that students primarily have difficulties in understanding the subject of oxidation and reduction. Similarly, it is reported in the literature that students have very low levels of understanding of the subject, as well as various misconceptions (Childs and Sheehan, 2009; Garnett and Treagust, 1992; Lin *et al.*, 2002; Sanger and Greenbowe, 1997; Silverstein, 2011). When studying organic chemistry, students are taught about oxidation-reduction reactions and organic syntheses via functional groups such as alcohol, aldehyde, ketone, carboxylic acid and ester. When students encounter the subject of oxidation and reduction, which they often do not understand soundly in their general chemistry courses, as well as in their organic chemistry courses, they try to establish a relationship between these concepts via organic molecules. The resulting deficiencies and/or errors regarding the development of relevant concepts in their prior learning affect their subsequent learning experiences as well (Palmer, 2001).

According to the findings of the present study, the students had difficulties in understanding the oxidation and reduction reactions of functional groups, as well as the concepts encountered during the reactions. Anselme (1997) suggests that it has been difficult for students to understand the concepts of oxidation and reduction in organic chemistry for years, and that these concepts occasionally become traumatic experiences. In addition, students fail to gain conceptual understanding due to their failure to transfer these concepts to their courses in organic chemistry. Various scholars have suggested different approaches to increase students' conceptual understanding (Shibley *et al.*, 2010). Menzek (2002) suggested a new approach in teaching the concepts of oxidation and reduction in organic chemistry

reactions. According to this approach, the oxidation and reduction of compounds in organic chemistry can be easily understood by assigning average oxidation numbers to carbon atoms in small or conjugate organic molecules. Other studies have emphasized the importance of providing macroscopic, submicroscopic, and symbolic representations in order to increase conceptual understanding in oxidation-reduction reactions (Brandriet and Bretz, 2014; Nieves *et al.*, 2012). In line with all these studies, it can be argued that it is necessary to use alternative methods in order to develop better understanding of the conceptual process of oxidation-reduction reactions.

Stereoisomerism and Structural Isomerism in Functional Groups

Some of the other remarkable findings acquired from the concept maps and worksheets include the students' failure to understand the subject of stereoisomers in functional groups. Considering the findings acquired from the worksheets, it can be seen that the students had very low levels of understanding of the concepts of "chiral", "enantiomer", "diastereomer" and "optical isomer"; in fact, a great number of students failed to provide definitions for these concepts. The students also demonstrated a number of misconceptions regarding these concepts (see Table 6). For instance, some of the students (11.7% in the worksheets) applied the statement "structures with conflicting mirror images" to the concept of "chiral", confusing it with the concept of "achiral" (see Table 7). A similar finding could also be found in the concept maps (see Table 10). In teaching the concept of chiral, the verbal use of definitions like "conflicting with mirror images" and "structures that don't conflict" may cause confusion and a failure to soundly understand the subject, as students may be unable to visualize the concept in this way. Another error regarding the concept of "chiral" relates to the following statement: "If four different atoms are bonded to the carbon atom, then it is a chiral". A similar error was found in the study of Bryan (2007), where he investigated the misconceptions of second-year university students in organic chemistry. In his study, the students revealed the following error: "In determining the presence of chiral carbon atoms, look for carbon atoms that are bonded to four different atoms".

A further misconception was observed in this case in the concept of "optical isomer"; namely, a portion of the students (10.0% in the worksheets) applied the statement, "maleic acid and fumaric acid that display a geometrical isomer are also the optical isomers of each other" with respect to the maleic and fumaric acid molecules within the carboxyl group. In addition, the error, "a type of isomer formed by molecules with a plane of symmetry" was also encountered in the students' definition of the concept of "optical isomer". Likewise, in his study on symmetry and chirality, Klein (1999) suggested that some school books include the following error: "a molecule is required to be an asymmetric molecule in order to be optically active". Considering these errors, students mistakenly believe that molecules primarily displaying a geometrical isomer may also display an optical

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3 isomer. Furthermore, they also believe that there is a plane of
4 symmetry for molecules with an optical isomer, which could
5 be yet another indicator of their difficulty regarding the
6 concepts of chirality and achirality. This condition may be
7 caused by difficulties in visualizing the mirror images of the
8 structures of maleic acid and fumaric acid, as well as their
9 failure to soundly understanding the concepts of optical
10 isomer and chirals. According to Hassan *et al.* (2004),
11 students are unable to visualize the concept of optical isomer,
12 which is due to their failure to perceive the molecules three-
13 dimensionally.

14 In terms of functional groups, one of the most remarkable
15 findings regarding stereoisomerism is that a number of the
16 students (35.0% in the worksheets - see Table 6) were unable
17 to provide definitions or relations concerning the concept of
18 "enantiomer" and the concept of "diastereomer" (41.7% in
19 the worksheets - see Table 7). Moreover, with respect to the
20 concept maps, it can be seen that a number of students
21 confused the concepts of "enantiomer" and "diastereomer"
22 (see Table 10). This suggests that students had difficulties
23 with the process of defining, which one of the processes in
24 developing conceptual understanding. Considering their
25 misconceptions, on the other hand, some of the students
26 (6.7% in the worksheets - see Table 7) made the following
27 errors regarding the concept of "enantiomer": "An isomer
28 originating from the cis-trans property" and "maleic acid is
29 the enantiomer of the fumaric acid". Here, the students
30 appeared to believe that molecules displaying the cis-trans
31 isomer are also enantiomers; this may be due to their failure
32 to visualize the organic molecules on a spatial ground. To
33 address this issue, Harrison and Treagust (2000) emphasize
34 the necessity to develop multiple mental models in order to
35 enable students to imagine the three-dimensional structures of
36 organic molecules, and thus to understand the concept of
37 enantiomer. Written, physical and computer-aided three
38 dimensional models were applied in their study, enabling the
39 students to make interpretations. Taking an alternative
40 approach, in her study on stereochemistry, Strange de Soria
41 (2001) asked students to draw sample molecules with a chiral
42 and achiral atom in order to determine how they understood
43 the molecular structures and achieved their conceptual
44 understandings. She also asked them about the enantiomer
45 and diastereomer structures of molecules. She then observed
46 the methods (e.g. the Spartan computer modeling program,
47 dimensional analysis notation, physical molecular model kits,
48 Fisher Projection, Newman Projection, Sawhorse Projection)
49 that were used by the students in the process of learning.

50 A further misconception observed in the concept maps
51 was the statement: "An isomer containing double bonds is a
52 geometrical isomer". The fact that several of the students
53 (16.7% in the concept maps - see Table 10) have such a
54 misconception could be associated with the fact that they had
55 only been taught using sample molecules containing double
56 bonds in geometrical isomer. When students encounter such
57 examples in school books, this may lead to incorrect learning,
58 causing them to make the generalization that the concept of
59 the geometrical isomer exists in molecules with double bonds.
60 However, the geometrical isomer can also be realized around
a single bond. In this sense, Hassan *et al.* (2004) reported that

a great majority of students in their study had difficulty in
finding the geometric isomers of molecules.

It is frequently reported in the literature that students have
difficulties in understanding the subject of stereoisomerism
(Bryan, 2007; Childs and Sheehan, 2009; Duffy, 2006; Duis,
2011; Hassan *et al.*, 2004). Cruz-Ramirez de Arellano and
Towns (2014) and Rushton *et al.* (2008) consider
stereochemistry, which involves stereoisomerism and the
three-dimensional structure of molecules, to also be among
the subjects where misconceptions are frequently encountered
in organic chemistry. In this sense, they believe that
stereochemistry is a very important and compelling subject in
understanding both isomery and reaction mechanisms. If
students improperly assimilate the relevant concepts, it will
be difficult for them to understand these concepts in the
future. Thus, it is necessary for them to understand the
molecular structures in order to comprehend the concepts
related to stereoisomerism.

To improve comprehension in this area, researchers have
emphasized the positive effects of developing the ability of
spatial visualisation (e.g. Collins and Easdon, 2001; Duffy,
2006; Lujan-Uptan, 2001; Strange de Soria, 2001), because,
conceptual understanding requires students to visualize the
three-dimensional shapes of organic compounds. Gaddis
(2001) and Abraham *et al.* (2010) similarly emphasize the
importance of computer simulations in achieving conceptual
understanding in stereochemistry. Dori and Barak (2001), on
the other hand, suggest the use of concrete and visual models
in order to increase comprehension of the concept of isomery
in functional groups.

Another misconception of students observed in the
concept maps relates to "structural isomer". A significant
proportion of the students (18.3% in the concept maps - see
Table 10) suggested that "primary, secondary and tertiary
alcohols are the structural isomers of each other". This
misconception may be caused by students' consideration of
chain branching isomerism, which is a type of structural
isomer. It can be inferred here that the students considered the
primary, secondary and tertiary alcohols to be the branched
forms of one another, and thus they believed that they are
structural isomers of each other. Furthermore, all of the
aforementioned alcohols are mono-alcohols. By generalizing
about mono-alcohols, students may believe that these
molecules have the same structure, and thus, that they are
structural isomers of each other. A further misconception
based on students' generalizations was the statement that
"dialcohols have structural isomer with ethers". Some of the
students (6.7% in the concept maps - see Table 10) evidenced
the misconception that, aside from mono-alcohols, alcohols
also have structural isomer with ethers, which implies that the
students considered every alcohol type to have structural
isomer with ethers. This is supported by Hassan *et al.* (2004),
who asked students about the structural isomer of ethyl,
methyl and ether molecules and determined that only 33% of
students gave correct responses and thus had difficulty with
these concepts. Similarly, Schmidt (1992) determined that
students had misconceptions regarding the structural isomer
of functional groups.

Aromaticity and Aliphaticity in Functional Groups

Some of the other misconceptions encountered in the students concerned "aromaticity" and "aliphaticity". It was observed that the students had only a partial understanding regarding these concepts, and 11.7% of them were unable to give a response to the concept of "aliphatic", while 6.7% were unsure of the concept of "aromatic" (see Table 6). With respect to the errors of students regarding the concept of "aliphatic", the statement that "aldehydes and ketones are aliphatic compounds" was expressed by some of the students (10.0% in the worksheets - see Table 7). In addition, the concept maps show that a considerable number of students (21.7%) made this error. This could be caused by the failure of students to consider functional groups like aldehydes and ketones as aromatic groups, as well as lack of experience with examples of aromatic aldehydes and ketones during their lessons. The misconception regarding "aromaticity" is shown in the statement of some students (11.7% among the common concepts in the worksheets - see Table 7) that "cyclical structures are aromatic compounds". This error indicates that students perceive organic compounds with a functional group in every cyclical structure as aromatic. In this sense, it may be asserted that the students confused the concept of "aromatic" with the concept of "cyclo". In addition, the students were observed to fail to comprehend that free electrons moving in a cyclical structure form an aromatic structure.

In a study that was conducted with high school and university students using a descriptive survey method, Topal *et al.* (2007) examined the misconceptions of students regarding aromaticity. The most remarkable misconception found in their study is "every cyclic compound is aromatic". Their misconception is supported by the misconception seen in the present study. Similarly, as a result of their study on how students classified organic compounds, Domin *et al.* (2008) determined that students mainly used the concept of "cyclic" in their definitions regarding the concept of aromatic.

There are various other studies on the understanding of students regarding the concept of aromaticity in the literature arguing that students have difficulties and various misconceptions regarding this subject (Duffy, 2006; Ealy and Hermanson, 2006; Fishback, 2010; Gaddis, 2001; Rushton *et al.*, 2008). For example, as a result of quizzes that were prepared for their study, Ealy and Hermanson (2006) determined that students did not have sufficient information about the concept of aromaticity, which could be associated with their failure to apply information learned in general chemistry about the placement of electrons, as well as the placement of electrons in bonds and hybridization according to the law of octet, to aromatic compounds.

Kuwajima (1984) emphasizes the importance of having sufficient knowledge about the valence bond theory encountered in general chemistry in order to soundly understand the concept of aromaticity. These results indicate that the students failed to develop their comprehension of the concept of aromaticity and that there were related misconceptions. In her study on the understanding of students regarding aromaticity and electrophilic aromatic substitution reactions, Duffy (2006) underlines the necessity of redefining

their conceptual understanding. Accordingly, she asserts that how terminology is used is also important to students' conceptual understanding.

Other Concepts Encountered in Functional Groups

Finally, the findings demonstrate that a significant number of students failed to respond to concepts like "carbaldehyde", "dimeric structure", "oxyacide", "decarboxylation", "anhydride" and "lactone" in the functional groups (see Table 6). Examining their apparent misconceptions, problems were found in terms of the concepts of "oxyacide", "decarboxylation" and "phenol". For instance, with regard to the concept of "oxyacide", the following misconception: "carboxylic acids containing oxygen atoms" were encountered in both the worksheets and the concept maps (10.0% in the worksheets and 18.3% in the concept maps - see Table 7 and Table 10). In terms of the misconceptions regarding "decarboxylation", the students (11.7% in the worksheets and in the concept maps) were seen to have the following misconception: "Decarboxylation is an event where the carboxyl group (-COOH) separates from the carboxylic acid" (see Table 7 and Table 10). Apart from this, another misconception regarding "phenol" is demonstrated by the following statement of some students (26.7% in the concept maps and 6.7% in worksheets - see Table 7 and Table 10): "Phenol is a cyclical structure of monoalcohols". That is, they were unable to understand the nature of a phenol compound and confused it with alcohol. A number of students failed to respond to these concepts at all, which could be due to the fact that they first encounter them in organic chemistry, and thus they were unable to understand them after a relatively short time. Students encountering new concepts may not be able to correctly interpret the facts that are required to assimilate them, and consequently, they may be unable to internalize the concepts. Memorizing these concepts may also lead to misconceptions, as with the study of Henderleiter *et al.* (2001) that found that students were unable to explain certain events and concepts and make interrelations, and thus they tried to learn through memorization alone.

Conclusions

Considered in general terms, this study is a pioneer in the field, as there are only a limited number of misconceptions regarding functional groups that have been established in the existing literature. Evaluating all the results, it has been established that undergraduate students following the Organic Chemistry Laboratory Course had low levels of conceptual understanding regarding functional groups, as well as a considerable number of misconceptions, in spite of just having completed a course in organic chemistry. This result could be primarily associated with their deficient and erroneous knowledge of general chemistry, as is indicated in the title of this paper. Since students have been unable to fully learn subjects related to general chemistry such as intramolecular and intermolecular bonds, acidity and basicity, oxidation and reduction and determination of molecular structures, they fail to accurately transfer their knowledge to organic chemistry. Thus, they have difficulties in

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3 understanding and explaining concepts regarding functional
4 groups. Indeed, the American Chemical Society (ACS)
5 considers bonds, molecular structure and reactivity,
6 stereochemistry, Lewis and Bronsted acidity and basicity
7 among the basic subjects necessary to understanding both
8 functional groups and organic chemistry in general (as cited
9 in Duis, 2011).

10 Likewise, as a result of interviews conducted in her study,
11 Wasacz (2010) contended that the achievements of students in
12 organic chemistry are associated with their achievements in
13 general chemistry. Therefore, she underscores the necessity
14 for instructors to review information related to general
15 chemistry with students before beginning instruction in
16 organic chemistry. This approach, she argues, may enable
17 students to reach the level of relevant comprehension and
18 affect their attitudes towards organic chemistry in a positive
19 manner.

20 At this point in time, it should be possible to examine the
21 principal subjects being taught in general chemistry at the
22 university in previous years and emerging in the study in
23 detail and support them with different teaching activities.
24 Also, in organic chemistry lessons including the subject of
25 functional groups, it should now be possible to apply
26 assessments – evaluations questioning the extent of
27 knowledge of the principle topics in chemistry – in order to
28 facilitate the learning of organic chemistry. According to the
29 results of these assessments, lesson plans and the learning
30 goals of organic chemistry lessons could be reformulated.
31 This would remove the deficiencies and mistakes by
32 determining students' levels of conceptual understanding in
33 advance. In addition to this, these deficiencies, could be
34 specifically targeted in introductory organic chemistry lessons
35 within the curriculum.

36 In addition to poor understanding of the concepts of
37 general chemistry, inappropriate teaching strategies used by
38 instructors may also generate misconceptions. To counter this
39 issue, it is suggested that teachers should create an active
40 learning environment that enables students to develop their
41 conceptual understanding. For instance, it is recommended
42 that students be asked to perform various experiments and
43 activities in laboratories in order to explore concepts
44 regarding functional groups, explain these concepts and adapt
45 them into different situations. The inclusion of activities that
46 increase critical thinking, reasoning and spatial thinking
47 abilities may lead to a more effective understanding of the
48 functional groups in organic chemistry. As such, the
49 researchers emphasize the importance of using three-
50 dimensional visual representations such as animation effects
51 and molecular modelling in the representation of organic
52 molecules (as with Bhattacharyya, 2004; Fleming *et al.*, 2000;
53 Gaddis, 2001), as students first need to visualize the particles
54 and manipulate them in their minds in order to understand the
55 dynamics of the processes.

56 Furthermore, it is important to encourage different ways
57 of thinking in students in order to enable them to understand
58 concepts regarding functional groups. Thus, the use of
59 symbolic, microscopic and submicroscopic representations, as
60 well as terminological discussions, is recommended. The
'terminologically' level in chemistry refers to both chemical

vocabulary and the uses of common language in the scientific
sense. This use of "multi-relational representations" provides
a way of scientific thinking and communicating that develops
an understanding of functional groups. Mandl and Levin
(1989) assert that the recognition of concepts via language-
based communication such as words, statements and texts
alone places a burden on the mental coding system, whereas
pictorial representations are coded as images as well as also
enabling verbal coding.

With this in mind, both language-based communication and
pictorial representations may enable students to understand
the concepts regarding functional groups more effectively
within the scope of their interaction. Moreover, examining the
results further under the headings of *intermolecular bonds*,
acidity and basicity, *reduction and oxidation*,
stereoisomerism and structural isomerism, it may be further
asserted that students are not able to thoroughly learn the
inorganic systems that explain the behaviours of atoms, ions
and molecules in reality. As McMurry (2000) asserts, "The
same principles that explain the simplest inorganic systems
also explain the most complex organic ones" (p. 2). Thus, it is
very important to also understand the inorganic systems that
explain the behaviours of atoms, ions and molecules and the
extent to which they are learned in understanding the
phenomena of organic chemistry. At this point, emphasis
should be placed on some of the topics being taught in
Inorganic Chemistry at the university in previous years in
order to support future lessons in Organic Chemistry. For
instance, we could conduct more effective teaching in valence
bond theory, resonance and hybridization in order to enable
the students to understand the aromatic compounds;
symmetry in molecular structures to understand stereoisomer
and structural isomerism; and interparticular attractions to
understand the physical properties of functional group
compounds.

Rather than improving the levels of conceptual
understanding of undergraduate students regarding functional
groups and removing the misconceptions, this case study is
aimed at revealing the present condition of this knowledge. It
also approaches all the functional groups. Future studies
could thus be conducted in how to improve students'
conceptual understanding by using the results found here.

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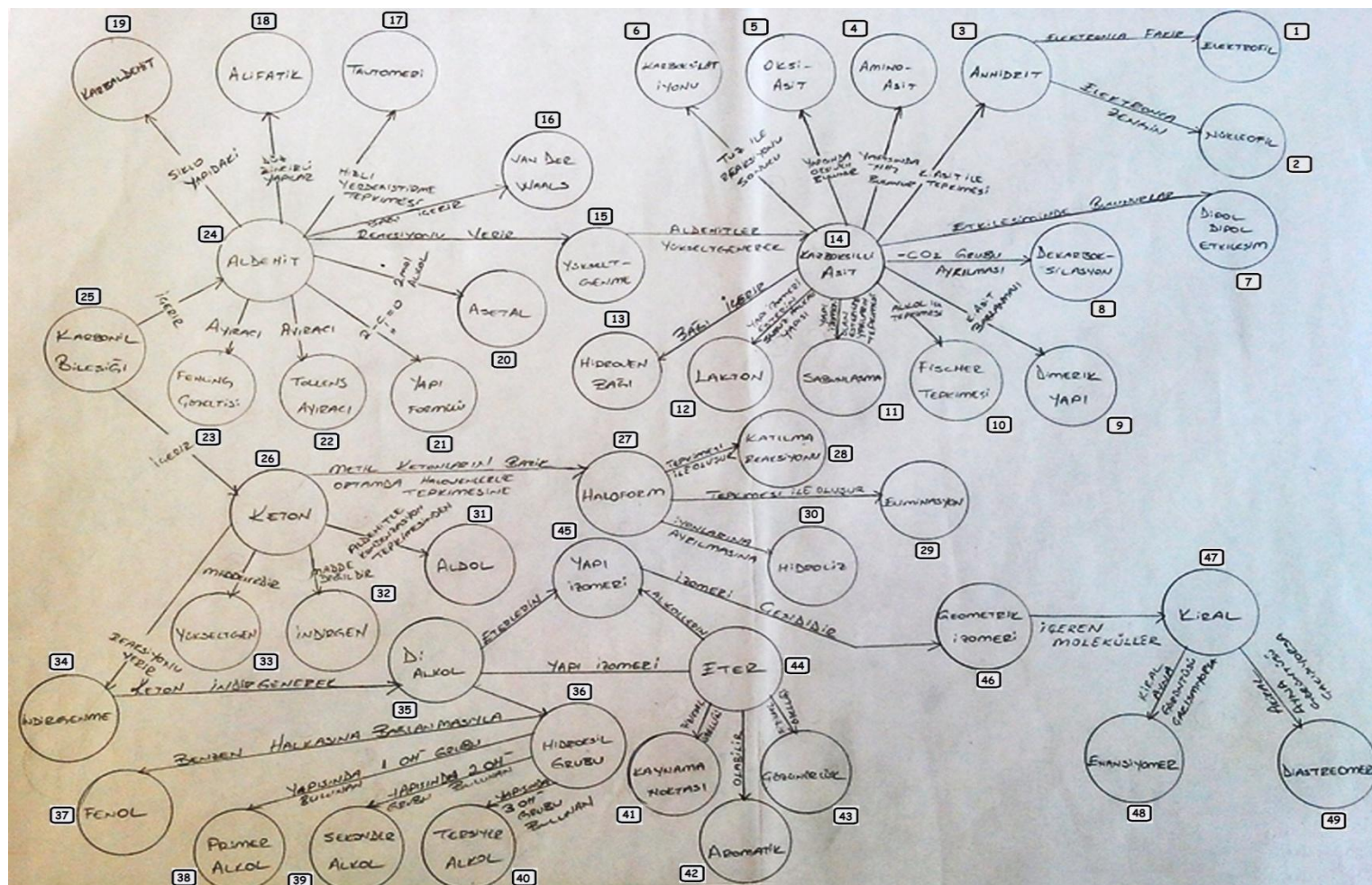
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Appendix



Translation of concepts and examples from Turkish to English	
1. Electrophile	26. Ketone
2. Nucleophile	27. Haloform
3. Anhydride	28. Participation rxn.
4. Amino acid	29. Elimination
5. Oxyacide	30. Hydrolysis
6. Carboxylate ion	31. Aldol
7. Dipole-dipole interaction	32. Reducer
8. Decarboxylation	33. Oxidizer
9. Dimeric structure	34. Reduction
10. Fischer reaction	35. Dialcohol
11. Saponification	36. Hydroxyl group
12. Lactone	37. Phenol
13. Hydrogen bond	38. Primary alcohol
14. Carboxylic acid	39. Secondary alcohol
15. Oxidation	40. Tertiary alcohol
16. Van der Waals	41. Boiling point
17. Tautomeri	42. Aromatic
18. Aliphatic	43. Solubility
19. Carbaldehyde	44. Ether
20. Acetal	45. Structural isomer
21. Structure Formula	46. Geometrical isomer
22. Tollens reagent	47. Chiral
23. Fehling solution	48. Enantiomer
24. Aldehyde	49. Diastereomer
25. Carbonyl compound	

Fig. 2 An example of a student concept map categorized as good (S16)

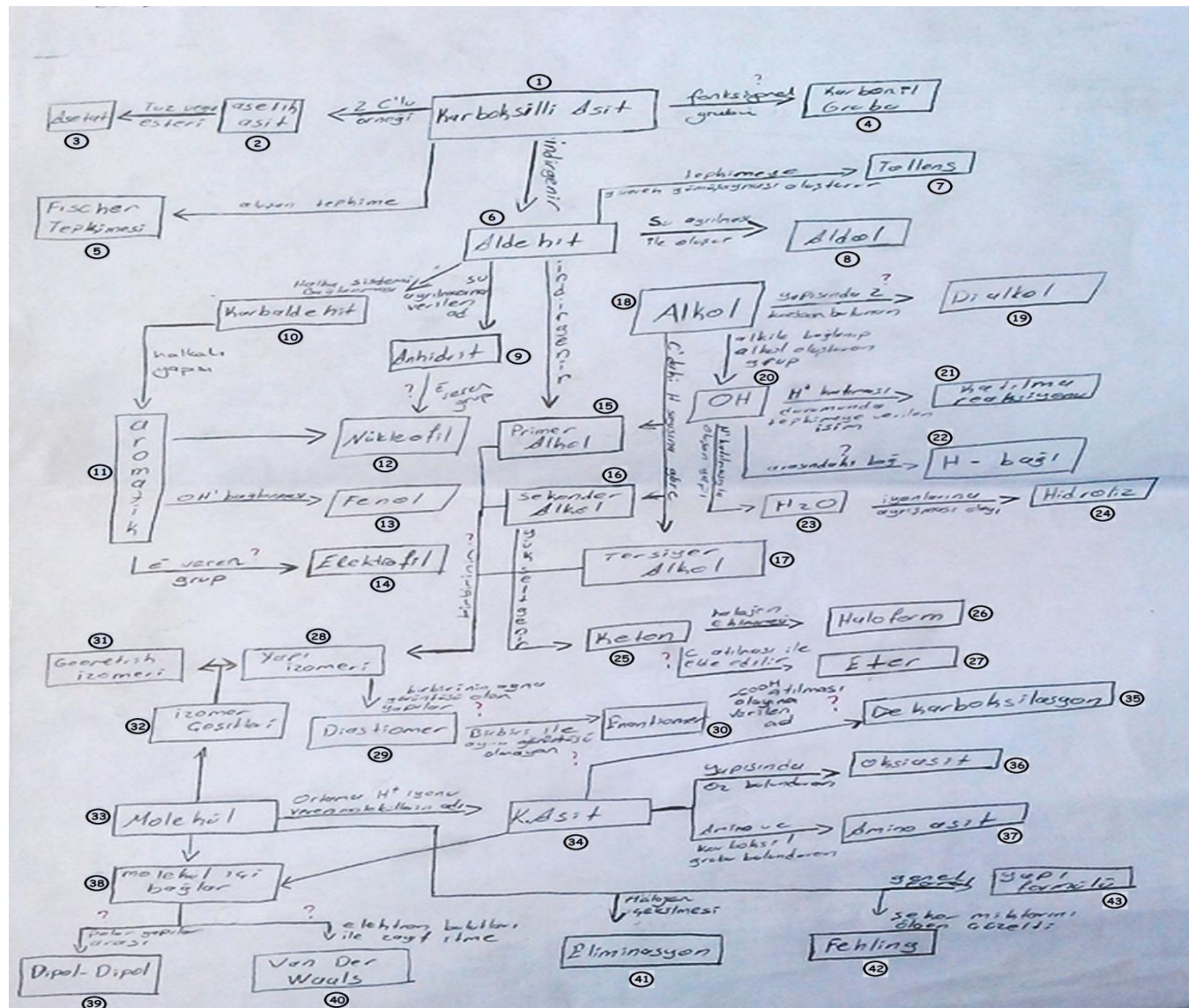


Fig. 3 An example of a student concept map categorized as poor (S23)

Translation of concepts and examples from Turkish to English	
1. Carboxylic acid	26. Haloform
2. Acetic acid	27. Ether
3. Acetate	28. Structural isomer
4. Carbonyl group	29. Diastereomer
5. Fischer reaction	30. Enantiomer
6. Aldehyde	31. Geometrical isomer
7. Tollens	32. Isomer types
8. Aldol	33. Molecule
9. Anhydride	34. Carboxylic acid
10. Carbaldehyde	35. Decarboxylation
11. Aromatic	36. Oxyacide
12. Nucleophile	37. Amino acid
13. Phenol	38. Intramolecular bonds
14. Electrophile	39. Dipole-dipole
15. Primary alcohol	40. Van der Waals
16. Secondary alcohol	41. Elimination
17. Tertiary alcohol	42. Fehling
18. Alcohol	43. Structure Formula
19. Dialcohol	
20. OH	
21. Substitution rxn	
22. H bond	
23. H ₂ O	
24. Hydrolysis	
25. Ketone	

Table 1 Concepts involved in worksheets and the objectives of experiments

Name of the experiment	Goal of the experiment	Concepts
Molecule Models of Alcohols and Ethers	Examine the physical and chemical properties of the 3-dimensional structures of alcohols and ethers with the help of the molecule modeling method	Alcohol, phenol, primary alcohol, secondary alcohol, tertiary alcohol, monoalcohol, dialcohol, trialcohol, hydrogen bond, hydroxyl group, number of branchings, polarity, structural isomer, ether, dipole-dipole, Van der Waals, boiling point, solubility, structure formula
Molecule Models of Aldehydes and Ketones	Examine the physical and chemical properties of the 3-dimensional structures of aldehydes and ketones with the help of the molecule modeling method	Aldehyde, ketone, aromatic, aliphatic, carbonyl group, carbaldehyde, nucleophile, electrophile, hemiacetal, acetal, structural isomer, Van der Waals, hydrogen bond, dipole-dipole, tautomeri
Molecule Models of Carboxylic Acids and Esters	Examine the physical and chemical properties of the 3-dimensional structures of carboxylic acids and esters with the help of the molecule modeling method	Carboxylic acid, ester, dimeric structure, oxyacide, dicarboxylic acid, tricarboxylic acid, amphoteric property, structure formula, mono carboxylic acid, dipole-dipole, Van der Waals, acidic property, amino acid, decarboxylation, aliphatic, aromatic, anhydride, hydrogen bond, lactone, saponification
Maleic and Fumaric Acid Output	Learn the physical properties of the concept of isomery and isomer types in functional groups, as well as organic molecules in the hydrolysis experiment	Geometrical isomer, substitution reaction, elimination, physical property, melting point, chiral, carboxylic acid, dipole-dipole, Van der Waals, nucleophile, crystal, solubility, acid regulation, structural isomer, enantiomer, diastereomer, optical isomer
Iodoform Output	Learn the oxidation and reduction reactions in functional groups	Oxidation, reduction, oxidizer, reducer, primary alcohol, secondary alcohol, tertiary alcohol, aldehyde, ketone, carboxylic acid, ester, haloform, nucleophile

Table 2 Worksheet order

Name of the experiment		Alcohols and Ethers		
Way of answering	Concept	I don't know	What does it mean to you?	What is the relation to the subject?
Example 1	Structural isomer	X		
Example 2	Structural isomer		Compounds with the same closed formula and a different structural formula are called structural isomers of each other.	
Example 3	Structural isomer		Compounds with the same closed formula and different structural formula are called the structural isomers of each other.	Alcohols and ethers are structural isomers of each other.

Table 3 Categories used in the analysis of the written answers acquired from the worksheets and their coding criteria

Categories	Coding criteria
Sound Understanding (SU)	Responses that include all components of the acceptable responses
Partial Understanding (PU)	Responses that include at least one of the components of the acceptable response
Specific Misconception (SM)	Responses that include descriptive, incorrect or illogical information
No Understanding (NU)	Repeats part or all of the question and uncodable responses
No Response (NR)	Blank or I don't know

Table 4 Concepts involved in the concept maps

Concepts	Acetal	Carboxylic acid	Ester	Mono alcohol	Reducer
	Achiral	Chiral	Ether	Nucleophile	Saponification
	Alcohol	Decarboxylation	Geometrical isomer	Optical isomer	Secondary alcohol
	Aldehyde	Dialcohol	Haloform	Oxidation	Stereoisomerism
	Aliphatic	Diastereomer	Hemiacetal	Oxidizer	Structural isomer
	Amino acid	Dimeric structure	Hydrogen bond	Oxyacide	Structure Formula
	Anhydride	Dipole-dipole	Hydroxyl group	Participation reaction	Solubility
	Aromatic	Electrophile	Isomery	Phenol	Tautomeri
	Boiling point	Elimination	Ketone	Polyalcohol	Tertiary alcohol
	Carbonyl group	Enantiomer	Lactone	Primary alcohol	Van der Waals

Table 5 Interrater reliability of the concept maps^a

Raters	N	\bar{X}	Sd	r
1.Rater	60	78.339	25.799	0.976 ^b
2.Rater	60	78.710	22.925	

^a \bar{X} : Mean points of the concept maps, Sd: Standard deviation, r: Correlation coefficient

^bCorrelation is significant at the 0.01 level (2-tailed).

Table 6 Analysis of the responses given by students to concepts^a

Concept Number	Concepts involved in worksheets	SU		PU		SM		NU		NR	
		f	%	f	%	f	%	f	%	f	%
1	Alcohol	51	85.0	6	10.0	1	1.7	1	1.7	1	1.7
2	Phenol	30	50.0	13	21.7	4	6.7	5	8.3	8	13.3
3	*Primary alcohol	34	56.6	18	30.0	3	5.0	2	3.3	3	5.0
4	*Secondary alcohol	33	55.0	16	26.7	5	8.3	3	5.0	3	5.0
5	*Tertiary alcohol	32	53.3	17	28.3	5	8.3	3	5.0	4	6.7
6	Mono alcohol	52	86.6	5	8.3	0	0	1	1.7	2	3.3
7	Dialcohol	50	83.3	3	5.0	3	5.0	1	1.7	3	5.0
8	Triolcohol	51	85.0	1	1.7	2	3.3	1	1.7	5	8.3
9	*Hydrogen bond	18	30.0	25	41.7	13	21.7	2	3.3	5	8.3
10	Hydroxyl group	43	71.7	14	23.3	1	1.7	0	0	2	3.3
11	Number of branchings	18	30.0	24	40.0	10	16.7	5	8.3	3	5.0
12	Polarity	12	20.0	36	60.0	5	8.3	3	5.0	4	6.7
13	*Structural isomer	12	20.0	38	63.3	1	1.7	5	8.3	4	6.7
14	Ether	47	78.3	9	15.0	0	0	1	1.7	3	5.0
15	*Dipole-dipole interaction	15	25.0	30	50.0	7	11.7	2	3.3	6	10.0
16	*Van der Waals interaction	13	21.7	30	50.0	9	15.0	3	5.0	5	8.3
17	*Boiling point	25	41.7	27	45.0	4	6.7	2	3.3	2	3.3
18	*Solubility	10	16.7	32	53.3	4	6.7	11	18.3	3	5.0
19	*Structure formula	21	35.0	27	45.0	1	1.7	4	6.7	7	11.7
20	*Aldehyde	32	53.3	18	30.0	2	3.3	3	5.0	5	8.3
21	*Ketone	33	55.0	16	26.7	2	3.3	3	5.0	6	10.0
22	*Aromatic	13	21.7	38	63.3	3	5.0	2	3.3	4	6.7
23	*Aliphatic	13	21.7	35	58.3	3	5.0	2	3.3	7	11.7
24	Carbonyl group	30	50.0	17	28.3	3	5.0	3	5.0	7	11.7
25	Carbaldehyde	26	43.3	3	5.0	2	3.3	8	13.3	21	35.0
26	*Nucleophile	9	15.0	32	53.3	7	11.7	1	1.7	11	18.3
27	Electrophile	6	10.0	25	41.7	13	21.7	3	5.0	13	21.7
28	Hemiacetal	21	35.0	7	11.7	2	3.3	8	13.3	22	36.7
29	Acetal	21	35.0	5	8.3	2	3.3	6	10.0	26	43.3
30	Tautomeri	15	25.0	25	41.7	0	0	3	5.0	17	28.3
31	*Carboxylic acid	28	46.7	24	40.0	3	5.0	0	0	5	8.3
32	*Ester	26	43.3	21	35.0	3	5.0	4	6.7	6	10.0

33	Dimeric structure	21	35.0	12	20.0	0	0	4	6.7	23	38.3
34	Oxyacide	21	35.0	11	18.3	6	10.0	4	6.7	18	30.0
35	Dicarboxylic acid	49	81.7	4	6.7	2	3.3	0	0	5	8.3
36	Tricarboxylic acid	50	83.3	3	5.0	2	3.3	0	0	5	8.3
37	Amphoteric property	6	10.0	38	63.3	3	5.0	3	5.0	10	16.7
38	Mono-carboxylic acid	45	75.0	6	10.0	0	0	1	1.7	8	13.3
39	Acidic property	19	31.7	34	56.7	0	0	2	3.3	5	8.3
40	Amino acid	25	41.7	23	38.3	2	3.3	7	11.7	3	5.0
41	Decarboxylation	20	33.3	8	13.3	7	11.7	4	6.7	21	35.0
42	Anhydride	21	35.0	14	23.3	1	1.7	6	10.0	18	30.0
43	Lactone	28	46.7	7	11.7	0	0	6	10.0	19	31.7
44	Saponification	28	46.7	19	31.7	0	0	5	8.3	8	13.3
45	Geometrical isomer	21	35.0	33	55.0	0	0	4	6.7	2	3.3
46	Substitution reaction	20	33.3	31	51.7	0	0	2	3.3	7	11.7
47	Elimination	18	30.0	25	41.7	1	1.7	3	5.0	13	21.7
48	Physical property	7	11.7	37	61.7	1	1.7	10	16.7	5	8.3
49	Melting point	12	20.0	29	48.3	1	1.7	5	8.3	13	21.7
50	Chiral	19	31.7	21	35.0	7	11.7	3	5.0	10	16.7
51	Hydrolysis	12	20.0	25	41.7	6	10.0	5	8.3	12	20.0
52	Crystal structure	7	11.7	34	56.7	0	0	5	8.3	14	23.3
53	Acid regulation	2	3.3	20	33.3	0	0	11	18.3	27	45.0
54	Enantiomer	13	21.7	19	31.7	4	6.7	3	5.0	21	35.0
55	Diastereomer	7	11.7	20	33.3	1	1.7	7	11.7	25	41.7
56	Optical isomer	5	8.3	34	56.7	6	10.0	3	5.0	12	20.0
57	Oxidation	10	16.7	40	66.7	6	10.0	1	1.7	3	5.0
58	Reduction	8	13.3	41	68.3	6	10.0	2	3.3	3	5.0
59	Oxidizer	6	10.0	37	61.7	12	20.0	2	3.3	3	5.0
60	Reducer	4	6.7	39	65.0	12	20.0	2	3.3	3	5.0
61	Haloform	19	28.3	19	31.7	0	0	6	10.0	18	30.0

^a f: Number of students, %: Percentage value of students

Table 7 Statements of students with misconceptions acquired from worksheets

Concept	Misconception	f	%
Boiling point	As the number of branchings increases, the boiling point increases.	4	6.7
Number of branchings	As the number of branching increases in alcohols, the solubility decreases.	10	16.7
	As the number of branchings increases, the boiling point increases, since the molecules grow.		
Polarity	No polarity due to the ether structure.	5	8.3
	There is polarity between metal atoms.		
Primary alcohol	Only one carbon (C) atom in the primary alcohol structure.	3	5.0
Secondary alcohol	Alcohols containing two hydrogens in the centre carbon atom.	5	8.3
Tertiary alcohol	Alcohols containing two hydroxyl groups (-OH).	5	8.3
Solubility	The process where the bonds of a molecule are torn with the help of another solvent.	4	6.7
	Homogeneous distribution of compounds within one another.		
Phenol	Since the molecular structure of ether resembles the water molecule, it dissolves in water better. Alcohol, on the other hand, dissolves less.	4	6.7
	It is an alcohol type which has an aromatic ring.		
Hydrogen bond	Intramolecular bonds. Since alcohol contains the OH group, they form intramolecular hydrogen bonds.	10	16.7
Dipole-dipole interaction	Alcohols contain higher rates of dipole-dipole interactions compared to ethers. Because ethers are more apolar.	9	15.0
Van der Waals interaction	Since alcohols contain the hydroxyl group, they have a stronger Van der Waals interaction compared to ethers.	11	18.3
Dialcohol	Alcohols with two hydroxyl groups (OH) bonded to the same carbon atom.	3	5.0

Journal Name				
Molecule Models of Aldehydes and Ketones	Carbonyl group	Compounds containing the COOH group. Attraction force between efficient particles in aldehydes.	3	5.0
	Hydrogen bond	The first four members of aldehydes and ketones contain a hydrogen bond.	23	38.3
		Since aldehydes contain a hydrogen atom, they have intermolecular hydrogen bonds.		
	Nucleophile	In the carbonyl group, a carbon atom with a relatively positive charge is called nucleophile.	10	16.7
		Structures showing a tendency to give electrons. Electron-rich molecules.		
	Electrophile	Negatively (–) charged parts.	13	21.7
An oxygen atom with a negative charge in the carbonyl group is called an electrophile.				
Van der Waals interaction	Since aldehydes and ketones have a straight chain structure, they contain Van der Waals.	11	18.3	
Aliphatic	Aldehydes and ketones are aliphatic compounds.	6	10.0	
Molecule Models of Carboxylic Acid and Esters	Oxyacide	Carboxylic acids contain an oxygen atom.	6	10.0
	Hydrogen bond	Esters are polar and form hydrogen bonds.	5	8.3
	Decarboxylation	An event occurring when the carboxyl group (–COOH) goes out.	7	11.7
	Amphoteric property	Carboxylic acids have an amphoteric property.	3	5.0
		Both metal and non-metal elements.		
	Van der Waals interaction	Very weak intermolecular interaction observed on apolar molecules. It is not observed on carboxylic acids.	8	13.3
Dipole-dipole interaction	It is observed on esters and not on carboxylic acids as they contain hydrogen bonds.	7	11.7	
Maleic – Fumaric Acid Output	Chiral	Structures with conflicting mirror images.	7	11.7
		If four different atoms are bonded to the carbon atom, then it is chiral.		
	Dipole-dipole interaction	Maleic acid contains the dipole-dipole interaction, whereas the fumaric acid does not.	8	13.3
	Solubility	Since fumaric acid is stable, it has a higher solubility than maleic acid.	4	6.7
	Optical isomer	Both maleic and fumaric acids displaying a geometrical isomer are also optical isomeries of each other.	6	10.0
		A type of isomer formed by molecules with a plane of symmetry.		
	Enantiomer	An isomer caused by the cis-trans property.	4	6.7
Maleic acid is the enantiomer of the fumaric acid.				
Hydrolysis	A reaction causing water (H ₂ O) in the environment as a result of a reaction.	6	10.0	
Iodoform Output	Secondary alcohol	Aldehydes are formed when it is oxidized.	4	6.7
	Tertiary alcohol	Ketones are formed when it is oxidized.	4	6.7
		Carboxylic acids are formed when it is oxidized.		
	Ester	Ketones are formed when the ester is reduced.	3	5.0
	Carboxylic acid	Carboxylic acids are formed when the ketone is oxidized.	3	5.0
	Oxidation	An event where the ion receives electrons during the reaction.	6	10.0
		Oxidation occurs by giving Hydrogen atom.		
	Reduction	An event where the ion gives electrons during the reaction.	6	10.0
		Reduction occurs by receiving Hydrogen atom.		
	Oxidizer	Atoms that give electrons.	12	20.0
A structure being oxidized by giving Hydrogen atom.				
Reducer	Atoms that receive electrons.	12	20.0	
	A structure being reduced by receiving Hydrogen atom.			
Common concepts	Hydrogen bond	The electron-rich carbon atom in iodoform compound displays a nucleophilic property.	7	11.7
		The bond formed by a carbon (C) atom with the hydrogen (H) atom is called hydrogen bond.		
		A bond formed between hydrogen atoms. Strong intramolecular bonds.		

ARTICLE

Journal Name

	Intramolecular bonds.		
Dipole-dipole interaction	Bonds caused by electron exchange.	7	11.7
	Bonds that are formed by electron sharing.		
	Short-duration intramolecular bonds.		
Van der Waals interaction	Bonds that are formed by electron sharing.		
	Attraction force between apolar molecules.	9	15.0
	Established between non-metal atoms.		
	The weakest intramolecular bond.		
Nucleophile	Structures showing a tendency to receive electrons.	7	11.7
	Positively (+) charged parts.		
	Electron-poor groups.		
Aromatic	Cyclical structures are aromatic compounds.	7	11.7

Table 8 Scale codes of concept map scores and distribution of students^a

Scale Codes	Intervals of score	f	%
Excellent	143-180	2	3.3
Good	107-142	6	10.0
Average	71-106	26	43.3
Poor	34-70	26	43.3
Total		60	100

^af: Number of students, %: Percentage value of students

Table 9 Quantitative analysis of concept maps^a

SN	TCN	Score	TPN	CPN	IPN	IPC
S1	47	105	40	36	4	Aldehyde→Hydroxyl group; Secondary alcohol→Ether; Primary alcohol→ Boiling point; Phenol→Secondary alcohol
S2	29	49	19	17	2	Alcohol→ Solubility; Anhydride→Nucleophile
S3	36	49	18	15	3	Carboxylic acid → Hydroxyl group; Alcohol → Haloform; Ether → Solubility
S4	48	180	68	62	6	Alcohol → Carboxylic acid; Ether→Boiling point; Ester→ Aromatic; Anhydride → Nucleophile; Anhydride →Elimination; Aldehyde→Tautomerizm
S5	19	73	32	27	5	Anhydride → Nucleophile; Geometric isomer→Chiral; Alcohol→ Primary alcohol; Alcohol→Secondary Alcohol; Alcohol→Tertiary alcohol
S6	38	81	35	27	8	Carboxylic acid → Carbonyl group; Isomery → Geometrical isomer; Primary, secondary, tertiary alcohol → Structural isomer; Ketone→Ether; Aldehyde→Aldol; Aldehyde→ Anhydride
S7	32	82	32	27	5	Isomery → Dicarboxylic acid; Anhydride → Carboxylic acid; Aldehyde→Aldol; Ketone→Ether; Anhydride → Nucleophile
S8	23	51	17	15	2	Alcohol→Primary alcohol; Carboxylic acid → Oxyacide
S9	25	47	20	17	3	Alcohol→ Aldehyde; Alcohol→ Carboxylic acid; Aldehyde→Aliphatic
S10	28	69	25	22	3	Carboxylic acid →H bond; Stereoisomer→Diastereomer; Ether→ Carbonyl compound
S11	30	90	35	26	9	Alcohol→Mono alcohol, Dialcohol, Trialcohol; Alcohol→Haloform; Ether→ Carbonyl compound; Optical isomer→Chiral, Achiral; Stereoisomer→ Geometrical isomer, Optical isomer
S12	35	57	33	27	6	Enantiomer→Achiral; Diastereomer→Chiral; Carboxylic acid → Decarboxylation; Aldehyde→Aliphatic; Ketone → Aliphatic; Ketone → Dialcohol
S13	45	110	43	35	8	Hydroxyl group →Oxidizer; Tertiary alcohol→Reduction; Ketone→ Carbonyl group; Carbonyl group → hydrolysis; Carboxyl group → Decarboxylation; Aldehyde→ Acetal; Aldehyde→Aliphatic; Carboxylic acid → Aliphatic
S14	32	86	34	28	6	Stereoisomerism→Chiral; Ketone→Ester; Ketone→Dialcohol; Alcohol→Primary alcohol, Secondary alcohol, Tertiary alcohol
S15	37	59	24	18	6	Achiral → Geometrical isomer; Ether→Solubility; Alcohol→Phenol; Alcohol→Secondary alcohol; Alcohol→Tertiary alcohol; Carboxylic acid → Hydroxyl group
S16	46	116	42	36	6	Ketone→Dialcohol; Dialcohol→Ether; Geometrical isomer →Chiral; Chiral→Diastereomer; Chiral → Enantiomer; Haloform → hydrolysis
S17	41	61	27	17	10	Ketone→Ether; Alcohol→Primary alcohol; Alcohol→Dialcohol; Alcohol→Phenol; Carboxylic acid → Carbonyl group; Carbonyl compound → Hemiacetal; Carboxylic acid → Oxyacide; Carboxylic acid →Dipole-dipole, Van der waals, H bond
S18	41	114	41	37	4	Ether→Solubility; Aliphatic→Ketone; Aliphatic→Aldehyde; Ketone→Ester
S19	22	60	21	19	2	Ether→ Solubility; Isomery → Geometrical isomer
S20	30	51	22	16	6	Diastereomer→Chiral; Enantiomer →Chiral; Ester→H bond; Alcohol→Primary alcohol, Secondary alcohol, Tertiary alcohol
S21	35	59	27	16	11	Carboxylic acid → Van der waals, Dipole-dipole, H bond; Carboxylic acid → Oxyacide; Isomery → Geometrical isomer; Structural isomer →Primary, secondary, tertiary alcohol; Ketone→Ether; Ketone→ Decarboxylation; Hydroxyl group →H bond
S22	41	77	33	22	11	Carboxylic acid → Oxyacide; Carboxylic acid →Van der waals, dipole-dipole, H bond; Carbonyl compound → Hemiacetal; Alcohol→Dialcohol; Alcohol→Phenol; Structural isomer →Primary, secondary, tertiary alcohol; Hydroxyl group →H bond
S23	37	62	29	16	13	Carboxylic acid → Carbonyl group; Alcohol→Dialcohol; Hydroxyl group →H bond; Ketone→ Ether; Carboxylic acid → Decarboxylation; Carboxylic acid → Van der waals, dipole-dipole; Anhydride → Nucleophile; Aromatic →Electrophile; Diastereomer→ Enantiomer; Structural isomer → Primary, secondary, tertiary alcohol
S24	35	51	26	23	3	Aldehyde→Aliphatic; Carboxylic acid →Aliphatic; Ether→ Carbonyl group
S25	32	79	30	26	4	Aldehyde→ H bond; Secondary alcohol→Tertiary alcohol; Ester→ Aromatic ; Isomery→ Geometric isomer
S26	37	88	34	24	10	Alcohol→Dialcohol; Hydroxyl group →H bond; Carboxylic acid → Oxyacide; Carboxylic acid →Van der waals, dipole-dipole; Isomery→ Geometrical isomer; Ketone→Ether; Structural isomer → Primary, secondary, tertiary alcohol
S27	46	146	49	45	4	Mono alcohol→Dimeric structure; Aldehyde→H bond; Aldehyde→ Van der waals; Alcohol→Phenol
S28	43	109	38	35	3	Enantiomer →Achiral; Enantiomer →Chiral; Polyalcohol→Ketone
S29	28	71	27	24	3	Amino acid→ Decarboxylation; Enantiomer →Achiral; Diastereomer→Chiral
S30	27	65	25	20	5	Alcohol→Phenol; Aldehyde→H bond; Structural isomer → Primary, secondary, tertiary alcohol
S31	20	41	15	9	6	Carboxylic acid → Decarboxylation; Alcohol→Ether; Carboxylic acid → Oxyacide; Aldehyde→H bond; Diastereomer→Chiral; Enantiomer →Achiral
S32	34	86	30	25	5	Mono alcohol → Dimeric structure; Alcohol→Phenol; Anhydride → Nucleophile; Aldehyde→Aliphatic; Ketone→Ether
S33	31	77	26	19	7	Dialcohol→Ether; Alcohol→Phenol; Enantiomer →Achiral; Diastereomer→Chiral; Structural isomer → Primary, secondary, tertiary alcohol
S34	31	65	22	17	5	Dialcohol→Ether; Carboxylic acid →Ester; Ketone→Tautomerism; Hydroxyl group → Electrophile; Anhydride → Nucleophile
S35	27	58	21	16	5	Phenol→Secondary alcohol; Primary, secondary, tertiary alcohol→ Structural isomer; Ester→Aromatic

ARTICLE

Journal Name

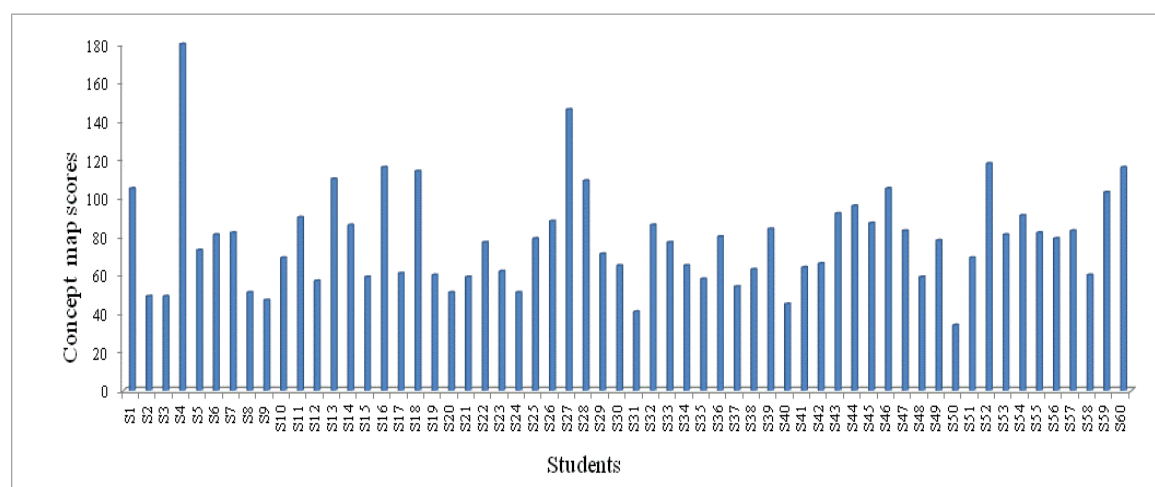
S36	33	80	26	21	5	Carboxylic acid → Decarboxylation; Geometrical isomer → Chiral; Chiral → Diastereomer; Alcohol → Phenol; Aldehyde → H bond
S37	19	54	14	12	2	Hydroxyl group → H bond; Dialcohol → Ketone
S38	29	63	31	26	5	Mono Alcohol → Phenol; Aliphatic → Ketone; Aliphatic → Aldehyde; Stereoisomerism → Geometrical isomer, Optical isomer
S39	43	84	41	31	10	Primary, secondary, tertiary alcohol → Structural isomer; Diastereomer → Chiral; Enantiomer → Achiral; Alcohol → Phenol; Ester → H bond; Anhydride → Nucleophile; Carboxylic acid → Oxyacide; Hydroxyl group → H bond
S40	19	45	17	13	4	Aldehyde → Van der waals, dipole-dipole; Polyalcohol → Ketone; Isomer → Geometrical isomer
S41	25	64	20	16	4	Enantiomer → Achiral; Enantiomer → Chiral; Aliphatic → Ketone; Aliphatic → Aldehyde
S42	22	66	19	16	3	Ester → Aromatic; Hydroxyl group → Oxidizer; Carboxylic acid → Oxyacide
S43	34	92	36	28	8	Hydroxyl group → H bond; Geometrical isomer → Chiral; Chiral → Diastereomer; Structural isomer → Primary, secondary, tertiary alcohol; Ketone → Ether; Ketone → Dialcohol
S44	34	96	39	35	4	Alcohol → Phenol; Carboxylic acid → Van der waals, Dipole-dipole; Ether → Carbonyl group
S45	37	87	34	29	5	Alcohol → Phenol; Aldehyde → Hydroxyl group; Ester → Aromatic; Isomery → Geometrical isomer; Ketone → Dialcohol
S46	43	105	47	43	4	Ketone → Ether; Carboxylic acid → Oxyacide; Enantiomer → Achiral; Diastereomer → Chiral
S47	32	83	27	22	5	Aldehyde → Ketone; Carboxylic acid → Ester; Carboxylic acid → Decarboxylation; Aldehyde, Ketone → Aliphatic
S48	20	59	23	20	3	Alcohol → Secondary alcohol; Phenol → Secondary alcohol; Hydroxyl group → Electrophile
S49	22	78	30	25	5	Dialcohol → Ketone; Aldehyde → Anhydride; Isomery → Geometrical isomer; Aliphatic → Ketone, Aldehyde
S50	19	34	14	12	2	Alcohol → Carboxylic acid; Ether → Solubility
S51	23	69	33	31	2	Hydroxyl group → H bond; Mono Alcohol → Phenol
S52	45	118	44	36	8	Structural isomer → Primary, secondary, tertiary alcohol; Alcohol → Secondary alcohol; Anhydride → Nucleophile; Carboxylic acid → Oxyacide; Hydroxyl group → H bond; Enantiomer → Achiral
S53	32	81	28	26	2	Aldehyde → Aliphatic; Ketone → Aliphatic
S54	33	91	40	37	3	Carboxylic acid → Van der waals, dipole-dipole, H bond
S55	28	82	31	24	7	Alcohol → Phenol; Structural isomer → Primary, secondary, tertiary alcohol; Ketone → Ether; Hydroxyl group → Electrophile; Ester → H bond
S56	33	79	27	22	5	Polyalcohol → Ketone; Enantiomer → Achiral; Enantiomer → Chiral; Dialcohol → Ether; Ester → Aromatic
S57	31	83	30	25	5	Aldehyde → Ketone; Ether → Boiling point; Ether → Solubility; Carboxylic acid → Decarboxylation; Carboxylic acid → Oxyacide
S58	26	60	30	26	4	Alcohol → Phenol; Aldehyde → Boiling point; Ester → Aromatic; Ketone → Ester
S59	36	103	38	35	3	Alcohol → Ether; Hydroxyl group → Electrophile; Anhydride → Nucleophile
S60	42	116	47	42	5	Aldehyde → Aliphatic; Carboxylic acid → Aliphatic; Structural isomer → Primary, secondary, tertiary alcohol

^aSN: Student Number, TCN: Used Total Concept Number, TPN: Used Total Proposition Number, CPN: Used Correct Proposition Number, IPN: Used Incorrect Proposition Number, IPC: Concepts used in Incorrect Propositions

Table 10 Misconceptions acquired from concept maps^a

Misconceptions acquired from concept maps	f	%
Primary, secondary and tertiary alcohols are structural isomers of each other.	11	18.3
Phenol is a secondary alcohol.	3	5.0
Phenol is a cyclical structure of mono alcohols.	16	26.7
Boiling point increases in parallel with the increase of the number of branchings in functional groups.	3	5.0
Carboxylic acids are formed when all the alcohols are oxidized.	3	5.0
A structure with conflicting mirror images is chiral.	12	20.0
Ether is formed by removing C from the ketone.	11	18.3
An isomer containing a double bond is a geometrical isomer.	10	16.7
A carboxylic acid containing an oxygen molecule (O ₂) is an oxyacide.	11	18.3
Ethers contain the carbonyl group.	4	6.7
Chiral molecules with non-conflicting mirror images are the diastereomers of each other.	10	16.7
Achiral molecules with conflicting mirror images are the enantiomers of each other.	10	16.7
When the carboxyl group (-COOH) goes out of the carboxylic acid, this event is called decarboxylation.	7	11.7
OH group is an oxidizer (electrophile) group.	6	10.0
Esters are formed when ketones are oxidized.	3	5.0
Ethers have a high solubility in water.	6	10.0
Diols are formed when ketones are reduced.	7	11.7
Dialcohols and ethers are structural isomers of each other.	4	6.7
Van der Waals, dipole-dipole interactions and hydrogen bonds are intramolecular bonds.	11	18.3
Ketones are formed when polyalcohols are oxidized.	4	6.7
Alcohols are separated as primary-secondary-tertiary according to the number of OH.	9	15.0
Anhydride molecule is an electron-rich nucleophile.	9	15.0
Aldehydes contain hydrogen bonds.	5	8.3
Hydroxyl group contains hydrogen bond between O-H atoms.	9	15.0
Aldehydes, ketones and carboxylic acids are aliphatic compounds.	13	21.7
Dialcohol structure is the bicarbureted form of alcohol.	6	10.0
Functional group of carboxylic acids is the carbonyl group.	3	5.0

^a f: Number of students, %: Percentage value

**Fig. 1** Distribution of scores obtained from the concept maps