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Omani twelfth grade students' most common misconceptions in chemistry

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Abstract

The current study, undertaken in the Sultanate of Oman, explored twelfth grade students' common misconceptions in seven chemistry conceptual areas. The sample included 786 twelfth grade students in Oman while the instrument was a two-tier test called Chemistry Misconceptions Diagnostic Test (CMDT), consisting of 25 items with 12 items incorporating visual representations and eight items used sub-microscopic representations. In addition, nine items required participants to study the visual diagram(s) in order to answer the questions. The results confirmed several misconceptions that had been identified in previous studies, as higher percentages of the misconceptions were recorded compared to the findings of previous studies. Misconceptions receiving the highest percentages were associated with combustion, chemical equilibrium, and electrochemistry. The results also indicated that twelfth graders had a difficulty dealing with visual test items. These findings are serious alerts to the practice of chemistry education at the secondary level in Oman. Recommendations are given to improve the teaching of chemistry by taking research-diagnosed misconceptions into account when designing instructional materials and classroom activities.

Key words: *atomic structure, chemical bonding, chemical equilibrium, chemistry misconceptions, combustion, electrochemistry, oxidation and reduction, two-tier test*

Introduction

Twelfth grade is the last pre-university grade in Oman. The gaining of chemical concepts cumulates through middle and secondary grade levels. And hence the twelfth graders' understanding of these chemical concepts reflects cumulative knowledge resulted from different epistemological experiences throughout different grade levels. Exploring this conceptualisation reflects the successes and pitfalls of pedagogical practices in chemistry throughout the school grade levels. In addition, uncovering conceptions held reveals the misconceptions that students internalize while studying chemistry. Uncovering learners' misconceptions allows them to be challenged and avoids them being integrated into learners'

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conceptualization, thus preventing interference with subsequent learning (Lin, Yang, Chiu, & Chou, 2002; Treagust, 2006).

The literature has shown that misconceptions are constructed in different areas of chemistry. Examples are atomic structure (Nakiboglu, 2003; Park & Light, 2009; Stefani & Tsaparlis, 2009), chemical bonds (Coll & Treagust, 2001; Dhindsa & Treagust, 2009; Unal, Costu, & Ayas, 2010), chemical equilibrium (Bilgin, 2006; Cheung, Ma, & Yang, 2009), electrochemistry (Ahtee, Asunta, & Palm, 2002; Lin, et al., 2002; Özkaya, Üce, & Şahin, 2003), oxidation and reduction (Barke, Hazari, & Yitbarek, 2009) and acids and bases (Cetingul & Geban, 2005; Kousathana, Demerouti, & Tsaparlis, 2005; Lin & Chiu, 2007). Being aware of misconceptions associated with these concepts gives researchers a better understanding of learners' cognitive processing associated with their conceptualizations. It also facilitates improving the instructional practices, students' modeling experience in chemistry and textbook illustrations of chemical concepts.

To explore students' misconceptions in chemistry, the current study uses a two-tier diagnostic test method. Each item in this type of paper-and-pencil tests has two tiers. The first tier is a content question with two to four choices, while the second tier presents four to five possible justifications for all potentially possible answers in the first tier (Tan, Goh, Chia, & Treagust, 2002; Treagust, 2006; Wang, 2004). This approach has several advantages such as (a) it allows identifying students' justifications for their beliefs (Lin, 2004; Treagust, 2006; Wang, 2004), (b) it is convenient to administer and is not time consuming (Tan et al., 2002; Treagust, 2006), and (c) a wide range of scientific concepts can be explored in a short time. Nevertheless, a limitation of the two-tier diagnostic tests can be that they provide "forced choices" which can reflect a distorted image of students' conceptions (Lin, 2004).

Students' Misconceptions in Chemistry

The current study explores seven major chemical concepts, based on the twelfth grade chemistry textbook in Oman. These concepts are: atomic structure, the structure of compounds, chemical bonding, chemical equilibrium, electrochemistry, combustion, and oxidation and reduction. Table 1 summaries the related literature on students' misconceptions associated with these concepts discussed in the Omani textbook.

Purpose of Study

The purpose of the current study was to diagnose twelfth grade students' common misconceptions in chemistry. In particular, the study focused on the following chemical concepts: atomic structure, the structure of compounds, chemical bonding, chemical equilibrium, electrochemistry, combustion, and oxidation and reduction.

Methodology

Participants

The study was conducted with 786 twelfth grade students who were enrolled in 34 twelfth grade classes which were chosen randomly from four governances of the 11 major governances in Oman. These were: Al-Dhakheliah, Al-Sherqyah North, Al-Batina North and Al-Batinah South. The sample consisted of 425 female students and 361 male students.

Table 1. A summary of students' misconceptions associated with different chemical concepts

Misconceptions	References
Atomic Structure heat may change the size of the atom, atoms may be alive, collisions between atoms may change their size and atoms may be seen under the microscope. the atomic orbital: 1) is a shell where electrons are embedded, 2) represents a pair of electrons, 3) is a region where there is a high probability of an electron being found and moving in a constant motion, and 4) looks like a cloud of specific shape. the atom in an excited state, with an electron promoted from an inner shell to 'fill' the outer shell, is to be more stable than same atom in the ground state.	Park & Light, 2009; Stefani & Tsaparlis, 2009; Taber, 2009
The Structure of Compounds when water evaporates, it decomposes to hydrogen molecules and oxygen molecules or to hydrogen atoms and oxygen atoms. the structure of ionic compounds, such as NaCl, are molecules each of which are composed of one sodium atom and one chlorine atom.	Barke et al., 2009; Kelly & Jones, 2007; Taber, 2002; Tan & Treagust, 1999
Chemical Bonding the polarity of that molecule is only determined by the electronegativity differences between its atoms, ignoring the role of the molecular shape. bonds are material links rather that forces. electrons in metals only move while conducting heat or electricity. ionic bonds only form between alkali metals and halogens.	Acar & Tarhan, 2008; Dhindsa & Treagust, 2009; Ozmen, 2008; Pabuccu & Geban, 2006
Chemical Equilibrium the forward reaction increases when a reaction approaches equilibrium. the forward reaction reaches completion before the reverse reaction begins. at equilibrium, the concentration of reactants is equal to the concentration of products.	Kousathana & Tsaparlis, 2002; Niaz, 1998
Electrochemistry electrons can flow through aqueous solutions without ions. electrons enter the electrolyte at the cathode, move through the electrolyte and are released at the anode to complete the circuit. only negatively charged ions constitute a flow of current in the electrolyte and the salt bridge. the charge of the cathode and the anode is determined by the physical placement of the half-cells, regardless of the type of electrolyte they are in. the function of the salt bridge is to supply electrons to complete the circuit.	Acar & Tarhan, 2007; Dindar, Bektas, & Celik, 2010
Combustion the weight of metals remains the same after combustion, ignoring the role of oxygen. when gases are produced from a combustion reaction of a liquid and a solid, the total mass decreases, even if the system is closed. if two substances are mixed and react to produce one substance, then the total mass decreases because one substance is produced from two substances	Chang, Lee & Yen, 2010; Ozmen & Ayas, 2003
Oxidation and Reduction When asked to explain the formation of a copper-coloured coating on iron nails when dipped into a copper sulphate solution, some students believe that the iron nails rust after being dipped into the solution. Some also refer to the magnetic ability of iron nails which, they think, attract copper atoms.	Barke, et al., 2009

The school system in Oman is composed of two major stages: basic education (grades 1-10) and secondary education (grades 11 and 12). One national science curriculum is used for grades 1-10 in public schools in Oman. And the same is for grades 11 and 12. All schools in Oman use identical textbooks, assessment tools and final exams for grades 10 through 12. Science teachers undergo similar in-service training programmes. Therefore, it is assumed students in all schools in the country are expected to have undergone a homogeneous learning experience. Thus, the representative aspect of the sample was not affected by choosing the sample from these four major governances in the country. Furthermore, the population in these four governances represented approximately 60.5% of the whole population of the country.

Instrument

This study uses a two-tier diagnostic test, called Chemistry Misconceptions Diagnostic Test (CMDT). Research shows that this type of paper-and-pencil tests allows taking students' reasoning behind their choices into account (Lin, 2004; Treagust, 2006; Wang, 2004). Some CMDT items are modified items used by other researchers (e.g. Barke et al., 2009; Harrison & Treagust, 1996). The test is developed using the following steps:

1. identifying the content boundaries of the test based on the chemistry textbook used in the twelfth grade in Oman;
2. collecting information on students' misconceptions from the literature regarding the chemical concepts to be included in the test;
3. constructing the test items;
4. reviewing the test by a panel of experts;
5. piloting the test on 26 twelfth grade students; and
6. finalizing the final version of the test.

Validation of the instrument was completed by a panel of six experts. Two of them were science educators who taught in a public university in Oman, one expert was a chemistry professor working in the same university and two experts were supervisors of twelfth grade chemistry teaching working in the Ministry of Education. The last member of the panel was a chemistry teacher who had 13 years of experience in teaching chemistry to twelfth graders in public schools in Oman. This process of validation resulted in rephrasing of different items to be more intelligible to participants, or to be more scientifically accurate.

The piloting of the CMDT aimed at verifying the suitability of the reading level to twelfth grade students. The 26 students were asked to mark any terminology that was not familiar to them. Different linguistic modifications resulted from this process. They were also asked to write other justifications for their choice from the first tier of the test. This process helped the improvement of the justifications listed in the second tier of each item in the test. Also, this piloting process helped in determining the time required to complete the test which was 90 minutes on average. Regarding the reliability of the test, the Cronbach alpha reliability coefficient was calculated to be 0.772.

The final version of the CMDT consists of 25 items, each of which has two tiers:

(1) a content question with two to four choices, and

(2) four to five possible justifications for all potentially possible answers in first tier. Appendix 1 illustrates items 2, 16, 21 and 24. Acknowledging the importance of visual representations in chemistry (Bucat & Mocerino, 2009; Cheng & Gilbert, 2009; Treagust, Chittleborough, & Mamiala, 2003; Wu, Krajcik, & Soloway, 2001; Wu & Shah, 2004), visual representations are incorporated into 12 items of the CMDT. The visual representations, associated with eight items, are sub-microscopic representations. Also for nine items, participants need to study the visual diagram(s) to answer the questions.

Since the official language of instruction in Oman is Arabic, the original instrument was written in Arabic. Then, the test was translated into English by a chemistry education professor who was fluent in both Arabic and English. A chemist, who was also fluent in both

Arabic and English, checked whether the translation was accurate. Only minor linguistic changes were undertaken on the translated version.

Data Collection

The CMDT was administered to participants at the end of the spring semester in their classrooms. The time given to complete the test was 90 minutes. Four research assistants, one in each governance, assisted in administering the test.

Data Analysis

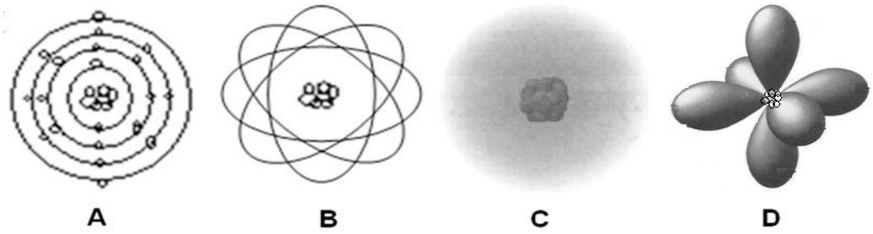
The frequencies and percentages of students' choices in both tiers in each item listed in the CMDT were calculated. The resulted percentages helped in deciding on the most common misconceptions. In the current study, a misconception was considered as a common misconception if 20% or more of the sample believed in it. The same cut off point was used by Dhindsa and Treagust (2009, p. 37) and this was originally suggested by Gilbert (cited in Dhindsa & Treagust, 2009). A list of the most common misconceptions was produced for each of the major chemical concept explored by the CMDT.

Results and Discussions

Atomic Structure

In the CMDT, twelfth graders were presented with four different models (Figure 1) of the atom: the solar system model (model A), the overlapping ovals model (model B), the electron cloud model (model C) and the orbitals model (model D). As shown in Figure 1, the participants thought that the solar system model was the most accurate representation for the atom and the electron cloud model was the least. In their justifications for their choices of the atomic models, as illustrated in Table 2, most of the participants thought that electrons go around the nucleus in circular orbits.

These results were incorborated by previous studies on Omani students which observed that the solar system model was the most vivid mental model for the atom imagined by Omani college chemisty students (Al-Balushi, 2009). Also, more students rejected the electron cloud model than they did other scientific models (Al-Balushi, 2011, 2012). When Harrison and Treagust (1996) studied grades 8-10 students' mental models of the atom, the overlapping ovals model came first and the orbitals model came last. In the current study, students were in a higher grade level than the sample of Harrison and Treagust's study. Nevertheless they chose a simpler model than did the participants of Harrison and Treagust's study. This might be justified partially by their experience with different atomic models in their science textbooks across different grade levels. The overlapping ovals model, the orbitals model and the electron cloud model were introduced to Omani students in their grade ten science textbook one time only. These models never appeared again in grades 11 and 12. On the other hand, the solar system model appeared several times in the grade ten textbook and very few times in grades 11 and 12. Additionally, there was no treatment for the topic of "electron configurations" in the chemistry textbooks at these grade levels.



58.8% 35.5% 5.1% 0.6%

Figure 1. Percentages of participants who chose different atomic models presented in the CMDT

Table 2. Common misconceptions related to participants' justifications for their choices of atomic models

Misconception	Percentage
1.1. Electrons orbit the nucleus in circular orbits as the planets orbit the sun.	60.4
1.2. Electrons are organized in shells around the nucleus in a certain order.	22.9

Structure of Compounds

Misconceptions regarding the structure of three compounds were investigated in the CMDT. These were lithium bromide, water and sulfur trioxide. Table 3 illustrates the most common misconceptions reported in the current study regarding the structure of these three compounds.

Figure 2 illustrates the percentages of participants who chose each representation given for lithium bromide in the CMDT. Although 42.1% reasoned that lithium bromide was a crystal compound and that the bonds between lithium atoms and bromine atoms were ionic, not all of them managed to select the right choice (the lattice shape). The misconception of representing ionic compounds as molecules has been reported in previous research (Barke et al., 2009; Kelly & Jones, 2007; Taber, 2002; Tan & Treagust, 1999). Also, in the current study, about one third of the sample thought that lithium bromide was a linear chain of lithium bromide "molecules." This misconception, to the authors' knowledge, is identified for the first time in the current study. Having studied the structural representations of different organic compounds in their chemistry textbook, twelfth graders might be influenced to view a chain-like structure for lithium bromide. This misconception of claiming organic structural characteristics in inorganic compounds resembled the historical believe that coordination compounds were chain-like compounds; an idea which was greatly influenced by the study of organic chemistry (Rodgers, 1994, pp. 12-15). Additionally, students might be ignorant of the fact that lithium is a metal and bromine is a non-metal; a condition for forming ionic compounds. However, a hint was given to participants in the statement of this question; that lithium was located in the first group of the periodic table and bromine was located in the seventh group. This piece of information was intended to guide them to conclude that lithium bromide was an ionic compound formed from a metal and a nonmetal.

Table 3. Common misconceptions related to the structure of compounds

Misconception	Percentage
Lithium Bromide	
2.1. The most precise representation for lithium bromide is a molecular structure in which one atom of lithium is connected to one atom of bromine.	48.8
2.2. The bond type between bromine and lithium in lithium bromide is covalent.	38.5
2.3. The most precise representation of lithium bromide is a linear chain of lithium bromide molecules.	30.7
Water Molecule	
2.4. When water evaporates (in a closed container), it turns into individual atoms that have no bonds between them.	39.2
Sulphur Trioxide	
2.5. Sulphur trioxide is composed of two sulfur atoms each of which is bonded to three oxygen atoms (not able to recognize the function of the coefficient (2) in 2SO3 as a part of the equation of SO3 formation).	31.8
2.6. Sulphur trioxide is composed of three sulphur atoms each of which is bonded to two oxygen atoms (not able to differentiate between the subscript (3) and the coefficient (2) in 2SO3 in the equation of SO3 formation).	20.0

Students are expected to realize that state change in water only affects the intra-molecular bonds and the inter-molecular distance, not bonding within molecules. Figure 3 illustrates students' expectations of what would happen if water evaporates in a closed container. Students with misconceptions regarding this issue represent almost 60% of the sample. The most dominant misconception is the belief that water molecules will turn into individual oxygen and hydrogen atoms. Similar misconceptions were reported by Mulford and Robinson (cited in Barke et al., 2009).

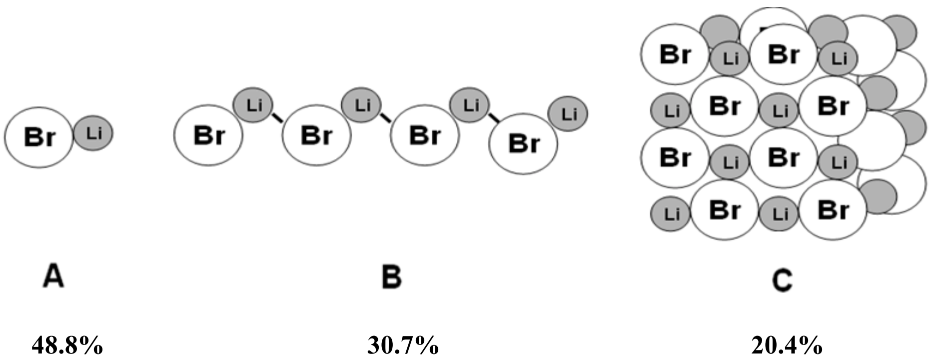


Figure 2. Percentages of participates who chose different structural models for lithium bromide

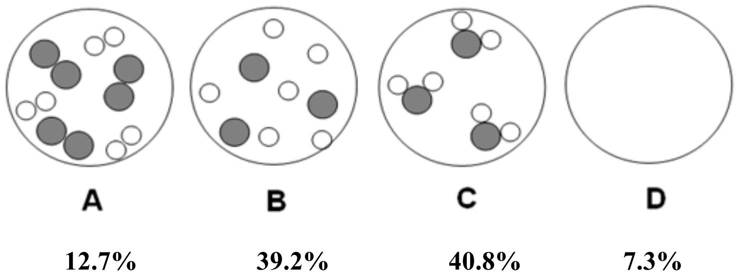


Figure 3. Percentages of participates' expectations of what would happen if water evaporates in a closed container

The third compound in the CMDT was sulphur trioxide. This item intended to test students' ability to differentiate between the coefficients and the subscripts in a chemical equation and how these numbers predicted atoms ratios in the compound. Findings presented in Figure 4 gave participants' predictions of the visual representation of sulfur trioxide which resulted from the following equation:

$$2S(g) \quad + \quad 3O_2(g) \quad \rightarrow \quad 2SO_3(g)$$

Only 37.7% of participants managed to predict the correct representation of sulphur trioxide. Similar results were documented by Mulford and Robinson (cited in Barke et al., 2009). This result might suggest students' inability to differentiate between the coefficients and the subscripts in the chemical equation. Omani science and chemistry textbooks in grades 10 and 12 have provided students with opportunities to know the chemical equation and its main components, and to practice balancing chemical equations. However, predicting the visual sub-microscopic representations of the chemical species in the chemical equation might be a different realm. Literature has shown that students were weak when it came to transference between the three levels of chemistry: macroscopic, sub-microscopic and symbolic (Johnstone, 2006; Tan, Goh, Chin, & Treagust, 2009; Treagust & Chandrasegaran, 2009; Wu et al., 2001).

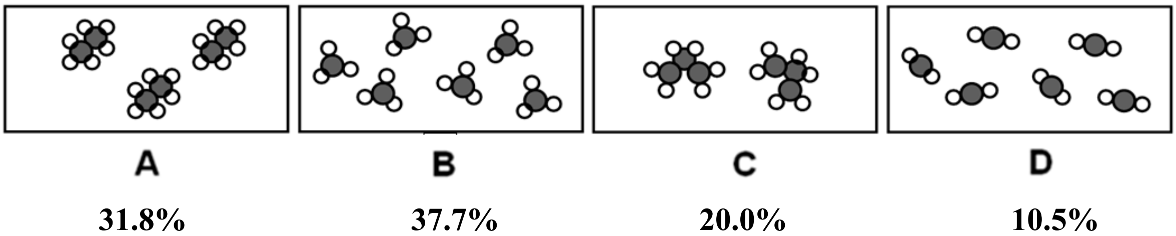


Figure 4. Percentages of participates' predictions of sub-microscopic representations of SO_3

Chemical Bonding

Table 4 illustrates common misconceptions regarding chemical bonding diagnosed by CMDT. The first category of misconceptions deals with chemical bonding in general. More than one third of the sample thinks that bonds could be broken into two parts. Participants in Ozmen's (2008) study also believe that covalent bonds are broken when the shape of the substance changes. Some participants in the current study reason that bonds are physical (material) links between atoms. This belief in the materialized nature of chemical bonds is also reported by Pabuccu and Geban (2006).

On the other hand, some participants in the current study did not think that bonds are affected. To justify this belief, some participants thought that bonds are very small to be affected. Omani textbooks, when describing the concept of chemical bonding, provide students with examples and exercises with regards to different types of bonds. However, they rarely mention that bonds are electromagnetic forces and never explicitly explain that they are not physical joints between atoms. This may partially justify students' misconceptions regarding this topic.

Table 4. Common misconceptions related to chemical bonding

Misconception	Percentage
Chemical Bonds	
3.1. When a stick is broken, the bonds at the broken area are not affected.	44.0
3.2. When a stick is broken, then the bonds at the broken area are divided into two parts, one part of which is on each side.	38.0
3.3. Bonds are too small to be affected when a stick is broken.	33.6
3.4. Bonds are physical (material) links between atoms.	27.9
Covalent Bond	
3.5. There is an equal attraction of shared electrons from atoms participating in the covalent bond. This is valid for all types of the covalent bonds.	41.9
3.6. The ionization of sulphuric acid into ions in water supports the expectation that the bond type between the oxygen and sulphur atom in sulphuric acid is ionic (or hydrogen bond.)	41.5
3.7. The type of bond between oxygen atom and sulphur atom in sulphuric acid is an ionic bond.	39.8
3.8. Water is partially polar, because oxygen has high electronegativity and attracts the shared electrons between it and the two hydrogen atoms.	35.4
3.9. In all covalent bonds, each atom shares the same number of electrons, so the attraction of electrons from atoms participating in the bond is equal.	30.6
3.10. There is a hydrogen bond between the oxygen atom and the sulphur atom in H2SO4.	28.4
3.11. Water is a non-polar compound.	25.4
Ionic Bond	
3.12. There is a covalent bond between the calcium atom and the chlorine atom in CaCl2.	28.9
3.13. In calcium chloride, each calcium atom contributes one electron and each chlorine atom contributes seven electrons.	24.1
3.14. Calcium is considered to be a metal which has free electrons, which bond calcium and chlorine atoms together in the calcium chloride.	21.8

The majority of participants (68.2%) could not identify the correct covalent bonding between sulphur and oxygen in the sulphuric acid. Some of them reasoned that sulphuric acid ionized completely in water. This clearly signified students' knowledge deficiency regarding the formation of chemical bonds. Participants were not able to 1) identify that both sulphur and oxygen were non-mental and, therefore, did not form ionic bonds; 2) realize that hydrogen should be a part of a hydrogen bond; and 3) appreciate that when sulphuric acid ionizes, sulphur and oxygen stay together, the ionization could not be a rational justification for the bond between sulphur and oxygen.

Some participants thought that there was equal attraction of shared electrons between the two bonds involved in the covalent bonds. Some justified that by stating each atom shares the same number of electrons. It seemed that they ignored the influence that electronegativity had on an atom's attraction of shared electrons in covalent bonds. This particular misconception of equal sharing of electrons in covalent bonds had been encountered widely in the literature (Dhindsa & Treagust, 2009; Ozmen, 2008; Pabuccu & Geban, 2006), thus suggesting that chemistry texts and chemistry teachers did not provide students with adequate treatment of this topic.

Not all participants believed that water was a polar molecule. Some participants justified that oxygen had high electronegativity which attracted the shared electrons. This might not be a misconception, yet it did not cover the whole story about the polarity of molecules. Only 35.1% chose the correct justification that the shape of the water molecule made the net dipole for all covalent bonds in the molecule unequal. Students' reliance on electronegativity only to predict the polarity of molecules might mislead them. This incomplete evaluation of the factors influencing molecular polarity was also reported by Dhindsa and Treagust (2009).

Participants' inability to identify the type of bonding in ionic compounds was evident with another compound, beside lithium bromide which was discussed above in misconceptions no. 2.1, 2.2 and 2.3. Approximately one third of participants believed that there was a covalent bond between calcium and chlorine in calcium chloride. Some thought that each calcium atom contributed one electron and each chlorine atom contributed seven electrons. Some also thought that there were metallic bonds between calcium atoms and chlorine atoms. They reasoned that calcium free electrons bonded calcium and chlorine atoms together in calcium chloride. Comparing misconceptions 3.12 and 2.2, it was noted that less students thought there was a covalent bond in calcium chloride than those who thought there was a covalent bond in lithium bromide. This might be partially because calcium chloride is a more familiar compound than lithium bromide. Science textbooks used calcium and chlorine as examples in different occasions more frequently than lithium and bromine. For instance, chlorine appeared as a part of the ionic bonding in sodium chloride in tenth grade science textbook and eleventh grades chemistry textbook and also to illustrate the ionization of the same compound in water in the same textbooks. Therefore, this familiarity might help some students to correctly predict the type of chemical bond in calcium chloride.

Chemical Equilibrium

Participants hold different misconceptions regarding chemical equilibrium. The most common misconceptions are listed in Table 5. Regarding the completion of the reversible reactions, more than half of the sample thinks that the forward reaction concludes before the reverse reaction. The two most preferable reasons for this belief by the participants from the second tier of the CMDT are (a) the reverse reaction cannot begin until the forward reaction is complete, and (b) the forward and reverse reactions are complete only at equilibrium. Similar misconceptions were reported by Niaz (1998).

Table 5. Common misconceptions related to chemical equilibrium

Misconception	Percentage
4.1. In reversible reactions, the forward reaction concludes before the reverse reaction.	59.0
4.2. If water is added to the blue solution that results from the following equilibrium reaction, then the blue solution will be diluted: $[Co(H_2O)_6]^{2+}_{(aq)} + 4Cl^-_{(aq)} \rightleftarrows [CoCl_4]^{2-}_{(aq)} + 6H_2O_{(l)}$ (pink) (blue)	48.0
4.3. In reversible reactions, the reverse reaction cannot begin until the forward reaction completes.	34.9
4.4. The forward and reverse reactions complete only at equilibrium.	34.8
4.5. Before equilibrium, the rate of producing reactants is higher than the rate of producing products.	33.3
4.6. At equilibrium, the concentration of reactants is equal to the concentration of products.	33.1
4.7. The reason behind point 4.2 is that water usually dilutes solutions.	30.4
4.8. Achieving equilibrium requires that the concentrations of reactants are equal to the concentrations of products.	28.3
4.9. Before reaching equilibrium, the rate of the forward reaction is equal to the rate of the reverse reaction.	22.5

Regarding the concentrations of reactants and products, one third of the sample believes that at equilibrium, the concentration of the reactants is equal to the concentration of the products. This misconception is also reported by Kousathana and Tsaparlis (2002). In the current study, participants reason that achieving equilibrium requires that the concentrations of reactants equal to the concentrations of products. Participants also held misconceptions about the rate of the forward and the reverse reactions. Some believe that before equilibrium, the rate of producing reactants is higher than the rate of producing products, while others believe that before reaching equilibrium, the rate of the forward reaction is equal to the rate of the reverse reaction.

One interesting misconception diagnosed by the CMDT in the current study is no. 4.2 in table 5. Almost one half of the sample believed that the addition of water to the shown reversible reaction would dilute the blue colour of the solution, instead of changing it to pink by reversing the direction of the reaction. They justified their response by indicating that water usually dilutes solutions. This misconception was also reported by Barke and his colleagues (2009).

Electrochemistry

Table 6 lists participants' misconceptions in electrochemistry. The most prevailing misconception is the notion that electrons circle the whole electrochemical cell. More than half of the sample believes that electrons move from the anode and back again to it through the wires, the cathode and its solution, the salt bridge, and finally through the solution of the anode. More than one third of the participants think that this path is important to complete the circuit in the electrochemical cell. A similar misconception is reported by other researchers (Acar & Tarhan, 2007; Özkaya et al., 2003).

Table 6. Common misconceptions related to electrochemistry

Misconception	Percentage
5.1. Electrons move from the anode to the cathode through wires. They are then released to the solution that contains the cathode. After that they transfer to the solution that contains the anode through the salt bridge and finally back to the anode.	56.7
5.2. If the cathode is made of Y, then Y+ ions in the solution get electrons from the cathode and become atoms that accumulate on the cathode although the solution contains H+ ions and not Y+ ions.	48.4
5.3. The path described in point 5.1 is important to complete the circuit in the electrochemical cell.	35.2
5.4. The function of the salt bridge is to help transfer electrons from one solution to another.	30.9
5.5. In electrochemical cells, oxidation occurs at the cathode.	26.2
5.6. Hydrogen gas forms although the solution does not contain H+ ions.	21.5
5.7. The function of salt bridge is to replace any deficiency in electrons which are consumed in both solutions in the electrochemical cell.	21.4
5.8. The cathode rod dissociates into the solution, although it gains electrons.	20.7
5.9. The anode releases electrons to the solution.	20.0

Most students do not pay attention to the types of ions present in the solutions of an electrochemical cell. Almost one half of the sample predicts that Y atoms at the cathode (made of Y metal) will form from the gain of electrons by Y^+ ions, although the solution does not contain these ions. Another example is misconception 5.6 which shows that some participants predict the formation of hydrogen gas in a solution which does not have H^+ ions.

The function of the salt bridge is not clear to many students. In the current study, some participants think that its function is to help transfer electrons from one solution to another. Also, some participants think that the salt bridge compensates any deficiency in electrons by supplying them to the solutions. Similar misconceptions regarding the function of the salt bridge are reported in the previous research (Acar & Tarhan, 2007; Dindar et al., 2010; Lin et al., 2002; Özkaya et al., 2003)

Some students lack a basic understanding of the electrochemical cell. They confuse anode with cathode and vice versa. For instance, some participants believe that oxidation occurs at the cathode, some participants believe that the cathode could dissociate into the solution and some participants believe that the anode releases electrons to the solution. This confusion in the functions of the anode and the cathode is also reported by Özkaya et al. (2003).

Combustion

Interestingly, participants' misconceptions in the combustion topic were the highest percentage compared to other misconceptions that resulted from the current study. As shown in Table 7, about two thirds of the samples believed that the mass of magnesium strip was greater than the mass of magnesium oxide. It seemed that students ignored the conservation of matter when thinking about chemical reactions. Previous research reported similar misconceptions with regards to the combustion of different substances (Barke et al., 2009; Chang et al., 2010; Ozmen & Ayas, 2003). The majority of the sample reasoned that the magnesium strip lost part of its mass as energy through combustion and that made the mass of the resulting magnesium oxide less than the mass of the magnesium strip. This justification, which was based on the effect that the release of energy had on the mass of substances, was also reported by Barke and his colleagues (2009).

Table 7. Common misconceptions related to combustion

Misconception	Percentage
6.1. The mass of magnesium strip is greater than the mass of magnesium oxide that forms after burning the magnesium strip.	62.2
6.2. Magnesium strip loses part of its mass as energy through combustion and that makes the mass of resulting magnesium oxide less than the mass of the magnesium strip.	61.4

Oxidation and Reduction

Although Omani twelfth grade students study oxidation and reduction reactions in the first semester for approximately two months, they could not identify whether the given situation, or phenomenon involves a redox reaction. Table 8 illustrates some examples. For instance, some participants justify the brownish colour on iron nails when immersed in a blue copper sulphate solution by stating that they rust. Others think that the brownish colour is because of the magnetic attraction between iron nails and copper atoms in the copper sulphate solution. Less than half of the sample anticipates that electrons transfer to copper ions and consequently they turn into atoms which precipitate on the iron nails. Similar findings are reported by Barke and colleagues (2009). Surprisingly, this experiment is an exploratory activity of redox reactions in the twelfth grade chemistry textbook in the chapter on oxidation and reduction. The chapter discusses explicitly half reactions and related chemical equations and electron transfers. This is part of the teaching at the very beginning of the second semester; the CMDT test was administered at the end.

Most students do not pay attention to the types of ions present in the solutions of an electrochemical cell. Almost one half of the sample predicts that Y atoms at the cathode (made of Y metal) will form from the gain of electrons by Y^+ ions, although the solution does not contain these ions. Another example is misconception 5.6 which shows that some participants predict the formation of hydrogen gas in a solution which does not have H^+ ions.

The function of the salt bridge is not clear to many students. In the current study, some participants think that its function is to help transfer electrons from one solution to another.

Also, some participants think that the salt bridge compensates any deficiency in electrons by supplying them to the solutions. Similar misconceptions regarding the function of the salt bridge are reported in the previous research (Acar & Tarhan, 2007; Dindar et al., 2010; Lin et al., 2002; Özkaya et al., 2003)

Table 8. Common misconceptions related to oxidation and reduction

Misconception	Percentage
7.1. When iron nails are immersed into copper sulphate solution (blue solution), they become brownish in colour because they rust.	30.6
7.2. When iron nails are immersed into copper sulphate solution (blue solution), they become brownish in colour because the magnetic ability of iron nails attract copper atoms.	29.5
7.3. When a copper plate is folded like an envelope and heated in a hot flame, copper becomes black on the outside while it stays red on the inside. The black colour results from the deposition of ash on the outer side.	29.5
7.4. Combustion causes the deposition of black ash in point 7.3.	25.1
7.5. The high temperature in point 7.3 changes the copper atoms to black.	20.1
7.6. The reason that the formation of rust in coastal regions in Oman is faster than in interior regions is that iron atoms are destroyed by the heat from the sun and the drizzle of sea water. Therefore, they become brownish in colour.	20.1

Some students lack a basic understanding of the electrochemical cell. They confuse anode with cathode and vice versa. For instance, some participants believe that oxidation occurs at the cathode, some participants believe that the cathode could dissociate into the solution and some participants believe that the anode releases electrons to the solution. This confusion in the functions of the anode and the cathode is also reported by Özkaya et al. (2003).

Another CMDT item explores participants' ability to identify whether heating a thin plate of copper on a hot flame involves a redox reaction. The percentage of participants who can correctly identify whether this is a redox reaction is 55.7%. This percentage in the study of Barke and his colleagues (2009), who used a similar item, was 59%. In the current study, some participants think that the resulting black colour is because of the deposition of ash for which some participants justified this as a result of a combustion reaction. Others think that the high temperature turns the colour of the copper atoms to black; a very naïve justification which is not expected from twelfth graders. This percentage is much lower (only 4%) in the study reported by Barke and his colleagues (2009).

In a third CMDT item justifying the formation of rust in the coastal regions in Oman, some participants believe that heat of the sun and sea drizzle destroy the iron atoms and therefore they become brownish. However, 65% of participants could identify this as a redox reaction.

Conclusions and Recommendations

The purpose of the current study was to diagnose twelfth grade students' common misconceptions in chemistry. With its two tiers, the CMDT was able to diagnose several misconceptions. Although the current study confirms several misconceptions which have been identified in previous studies, some misconceptions reached higher percentages compared with findings from several previous studies. These results are serious alerts to the teaching of chemistry at the secondary education level in Oman. Science teachers and textbooks writers need to pay more attention to students' misconceptions. An effort needs to be made to diagnose and treat students' misconceptions on a frequent basis. The current study contributes to this effort. However, a systematic and continuous diagnosis of students' misconceptions needs to be put in place. Consequently, textbooks need to be written in ways that take these misconceptions into considerations by providing classroom activities and laboratory experiences which help students avoid misconceptions. Examples can be found in the literature (e.g. Barke et al., 2009).

The nature of misconceptions identified in the current study and the high percentages that some of them receive point to the need to modify and improve the way some chemical concepts are presented and discussed. The cumulative studies on misconceptions in chemistry need to guide science textbooks writers and science teachers to adopt the recommendations of these studies and improve the way chemistry concepts are presented. For instance, misconceptions that are diagnosed in the current study regarding the structure of compounds may be prevented if the following *principles* are discussed in student textbooks or/and science classrooms:

1. Ionic compounds are formed from metals (on the left in the periodic table) and non-metal (on the right in the periodic table) to form lattices (misconception 2.2).
2. Ionic compounds do not exist as molecules (misconceptions 2.1 & 2.3).
3. Change of state does not affect the bonds within molecules (misconceptions 2.4).
4. The subscripts in the chemical equations represent the number of atoms in the molecule and the coefficients represent the number of molecules (misconceptions 2.5 & 2.6).

Other principles should be formulized regarding other chemical misconceptions diagnosed in this study or previous studies. These principles should be explicitly stated in student chemistry textbooks. They also should be accompanied with sub-microscopic representations such as two-dimensional sketches, three-dimensional models and/or computerized simulations. Research has shown that helping students construct mental associations among the macroscopic, sub-microscopic and symbolic levels of representations led to successful learning of chemistry (Bucat & Mocerino, 2009; Cheng & Gilbert, 2009; Chiu & Wu, 2009; Johnstone, 2006; Tan et al., 2009; Treagust & Chandrasegaran, 2009; Wu et al., 2001).

Identifying the sources of students' misconceptions goes beyond the scope of the current study. However, based on the national chemistry curriculum used in Omani public schools and its related textbooks for grades 10-12, some misconceptions may be traced back to the way chemistry concepts are presented to students in these textbooks. For instance, the over-emphasis of the solar system model for the atom and its frequent appearance in science and chemistry textbooks may be a possible source for the high percentage recorded for misconception 1.1. Besides, of the electron cloud model is neglected in student textbooks; it appears on one occasion only when the tenth grade science textbook illustrates different models for the atom.

Omani chemistry textbooks also neglect the integration of the sub-microscopic representations to two levels of chemistry, namely the macroscopic and the symbolic. For instance, not a single sub-microscopic representation appears in three subsequent units (out of six units) of the 12^{th} grade chemistry textbook. These units are: oxidation-reduction reactions, electrochemical cells and electrolysis and energy changes plus rate of reactions. Ignoring the sub-microscopic level to this extent may be a possible source for some participants' failure to correctly solve the CDMT items which involve sub-microscopic representations (eight items). Going beyond mere arithmetic calculations and symbolic manipulations to the visualization at the sub-microscopic level gives meaning to these calculations and symbols and helps students visualize the unobservable processes. Tan and his colleagues (2009) argue that understanding the sub-microscopic and symbolic level notations and explanations of the macroscopic experience is essential for students' understanding of the observations and results which they obtain from the experiments and reactions they carry out.

Additionally, the literature stresses the importance of laboratory experiments in teaching for conceptual change in chemistry. In fact, most of the ideas given by Barke and his colleagues (2009) in their misconceptions book are laboratory-based. Omani chemistry textbooks provide less opportunity for students to experience the chemical changes at the macroscopic level in the laboratory. Eight experiments are the only experiments specified for twelfth grade chemistry. Taking into account that the sub-microscopic representations are ignored in student textbook, narrative descriptions are the dominant approach to present and discuss chemical topics in student textbook. Thus, Omani textbooks writers should design laboratory experiments that target the identified misconceptions by the current study and integrate them into twelfth grade textbook. A research project to explore this possibility would be of much benefit to teachers and students.

Other possible sources are prescribed by Lin and Chiu (2007) which include, beside textbooks: teachers' instruction, language and words, the daily life experience, social environment, causal effect and intuition. A follow-up study could be an exploration of the sources for students' misconceptions, especially those which received high percentages in the current study, using alternative research methods such as interview, think-aloud procedures and classroom observations of classroom interactions and discourse.

Furthermore, students' misconceptions should be discussed in the classroom using a conceptual change procedure such the one proposed by Khourey-Bowers (2011). This procedure encompasses the following steps: First, students' prior knowledge is revealed. Then, a bridging lesson is delivered. Next, the "experts" perspective on the concept is provided. Then, an opportunity is given to students to apply the concept to test its fruitfulness and plausibility. Finally students are asked to reflect on their new understanding. An alternative procedure called a discussion template by Chin and Teou (2009) could be adapted to facilitate the process of conceptual change. In this procedure, two opposing ideas regarding the concept under study are presented to students; one of them is the scientific idea and the other is a misconception. Chin and Teou use what they call concept cartoons with two different characters to illustrate these two opposing ideas. Alternatively, science teachers might use other forms such as stories or role plays to present the opposing ideas by two different characters. Then, students in their groups need to decide with whom they agree (and why) and with whom they disagree (and why). At the same time, they need to jot down their opinions and related justifications on the discussion template. Next, each group defends its opinion in front of the class. A whole class discussion, guided by the teacher, follows to finally reach the scientific understanding of the concept. A follow-up experimental study to test the effectiveness of these pedagogical ideas on treating 12^{th} graders' misconceptions in chemistry is needed. The identified misconceptions in the current study should be taken into account.

One limitation of the current study is that it focuses on 12^{th} graders. Although studying this grade level gives summative understanding of students' misconceptions regarding different scientific concepts, it does not show how these misconceptions develop since related concepts are first introduced in previous grades. Therefore, a longitudinal study which traces the development of misconceptions can add to our understanding of this issue, especially for basic concepts such as atomic, molecular and compound structures; acids and bases and chemical bonding. Another limitation of the current study is that it focuses on public schools. In Oman, private schools use different international curricula. Comparing students' misconceptions in public and private schools can clarify the differences, if any, between the two types of schooling systems. It may also uncover some pitfalls in the curricula used in both types of schooling.

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Appendix 1

Examples of the CMDT items

Item 2: In all types of covalent bonds, there is an equal attraction of shared electrons from atoms participating in the bond:

a. Yes
b. No

Reason/justification:

a. Each atom shares the same number of electrons.
b. There is a difference in electronegativity for atoms that participate in the covalent bond.
c. Both atoms have the same number of valence electrons.
d. Each atom attracts its own electron(s) more than other electron(s) from the other atom.

Item 16: Ammonia gas forms from the reaction of hydrogen gas and nitrogen gas:

$$N_2(g) + 3H_2(g) \leftrightarrows 2NH_3(g)$$

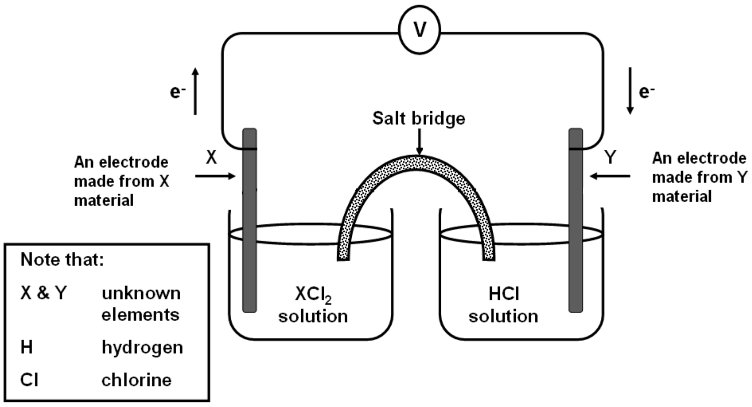
Before equilibrium:

a. The rate of ammonia formation is greater than the rate of hydrogen formation.
b. The rate of hydrogen formation is greater than the rate of ammonia formation.
c. The rate of ammonia formation equals to the rate of hydrogen formation.

Reason/justification: Before equilibrium:

a. The rate of the reverse reaction is greater than the rate of the front reaction.
b. The rate of the front reaction is greater than the rate of the reverse reaction.
c. The rate of the reverse reaction equals to the rate of the front reaction.

Item 21: Review the following electrochemical cell:



The oxidation takes place in:

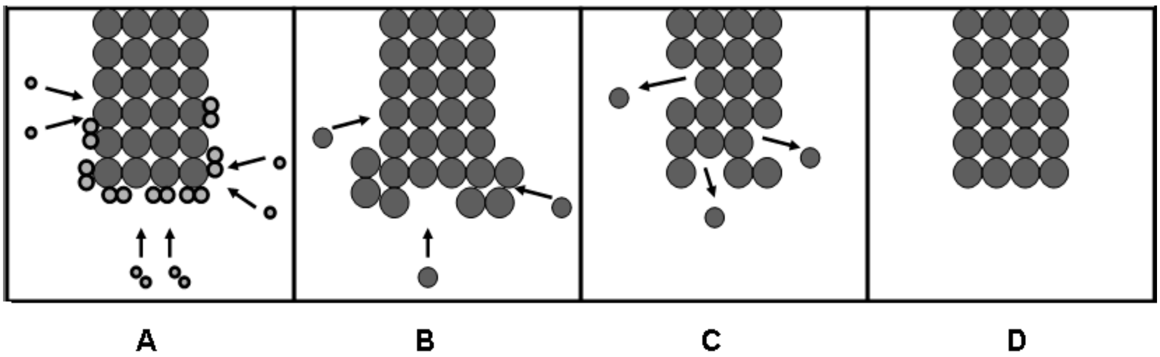
a. X
b. Y

Reason/justification:

a. X releases electrons to the XCl_2 solution.
b. X releases electrons that move to Y through the wire.
c. X reacts with oxygen to form OX_2.
d. Y loses electrons which are gained by H^+ to form hydrogen gas.

Item 24: use the electrochemical cell in Item 21 to solve this item:

The precise diagram that represents what happens at Y electrode is:



Reason/justification:

a. H+ ions gain electrons to form hydrogen gas.
b. Y+ ions gain electrons to form Y atoms which deposit on the Y bar.
c. The Y electrode starts to dissociate in the solution because Y atoms lose electrons to form Y ions.
d. The reaction takes place in the solution and not on the electrode.