Grade-12 Students' Misconceptions of Covalent Bonding and Structure

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Studies on student misconceptions in science and in particular chemistry have been of interest to science educators and teachers at all levels of education. In chemistry, research on student understanding and misconceptions have been conducted in the conceptual areas of oxidation, chemical reactions, chemical equilibrium, the mole concept, solubility, transformation of matter, conservation in chemical reactions, thermodynamics, chemical and physical change, and stoichiometry (*1*).

The most common approaches for obtaining information in misconceptions research are through interviews with students and/or open-ended responses to questions on specific science topics (*2*). Although interviewing has been found to be a successful method for misconceptions research, classroom teachers do not necessarily have the available time or facilities to interview students. Further, not only is interviewing students time consuming, it requires substantial training to be an effective interviewer. A more complex approach to interviewing students is the analysis of students' conceptual difficulties in completing complex scientific problem-solving tasks and on the simple tasks of which the complex tasks are composed (*3*).

An alternative approach for identifying misconceptions, which may be of more use in classroom teaching, is to use items based on a multiple choice format. While most multiple choice tests only have tested content, some (*4, 5*) have recommended the use of student reasoning including known misconceptions to formulate test items. This paper describes a multiple-choice pencil-and-paper diagnostic instrument used to measure student understanding of covalent bonding and structure concepts. Following the administration of the diagnostic instrument to 84 grade-12 students, analysis of the results provided evidence of seven commonly held misconceptions.

The Instrument and Its Administration

The diagnostic instrument was composed of 15 two-tier multiple-choice items (*6*). The first tier of each item consists of a content question having two, three, or four choices; the second part of each item contained four possible reasons for the answers given in the first tier, which included the correct answer and three alternative reasons involving misconceptions. The alternative reasons and misconceptions were identified from unstructured interviews and student-written responses to open-ended versions of the test instrument. The *Covalent Bonding and Structure Diagnostic Instrument* specifically examines the conceptual areas of bond polarity (three items), molecular shape (five items), polarity of molecules (three items), lattices (two items), intermolecular forces (two items), and the octet rule (two items). Most items were problem centered (two examined more than one conceptual area) and were based on known areas of conceptual difficulty identified from experiences in teaching students at this level of schooling. Content validity for the test instrument was ensured by basing the test's construction on a previously validated list of propositions that represented the chemistry syllabus taught and through successive pilot studies and reviews by two experienced chemistry teachers and a tertiary chemistry educator.

Table 1. The Percentages of Grade-12 Chemistry Students (*n* = 84) Selecting Each Response Combination for an Item Testing Bond Polarity

Choice to first part	Reason A	Reason B	Reason C	Reason D	Total
1	0.0	3.7	61.4[a]	2.4	67.5
2	2.4	22.9	7.2	0.0	32.5

[a] Correct response combination.

The instrument was administered to a total of 84 grade-12 students from three different coeducational high schools and six different chemistry classes. All students completed the test in less than 40 min. A student's answer to an item was considered correct if the student selected both the correct content choice and the correct reason. Items of the instrument were evaluated for both correct responses and incorrect response combinations selected by the students. Particular attention was paid to those response combinations involving more than 20% of the students. Analysis of incorrect response combinations provided data on student misconceptions of concepts and the propositional knowledge related to that item. An example of an item testing student understanding of bond polarity is shown below:

Which of the following best represents the position of the shared electron pair in the HF molecule?

(1) H :F (2) H : F

Reason

(A) Nonbonding electrons influence the position of the bonding or shared electron pair.

(B) As hydrogen and fluorine form a covalent bond the electron pair must be centrally located.

(C) Fluorine has a stronger attraction for the shared electron pair.

(D) Fluorine is the larger of the two atoms and hence exerts greater control over the shared electron pair.

The responses combinations selected by the student sample for the above question are given in Table 1. As indicated in the table, only 61% of the grade-12 students could correctly ascertain the position of the shared electron pair in the H–F bond and give the correct reason for their choice. Twenty-three percent of this student sample believed that in a covalent bond such as the H–F bond, the electron pair must be centrally located.

Results and Discussion

Eight major misconceptions were identified through analysis of incorrect response combinations of the items (Table 2). These misconceptions are discussed under the categories of bond polarity, shape of molecules, polarity of molecules, intermolecular forces, and the octet rule.

Table 2. The Most Common Misconceptions of Covalent Bonding and Structure Held by Grade-12 Students ($n = 84$)

Misconception	Percentage of Students with Misconception
Bond Polarity	
Equal sharing of the electron pair occurs in all covalent bonds.	23%
Shape of Molecules	
The shape of molecules is due only to the repulsion between the bonding electron pairs.	25%
The shape of molecules is due only to the repulsion between the nonbonding electron pairs.	22%
Bond polarity determines the shape of a molecule.	27%
Polarity of Molecules	
Nonpolar molecules form when the atoms in the molecule have similar electronegativities	34%
Intermolecular Forces	
Intermolecular forces are the forces within a molecule.	23%
Strong intermolecular forces exist in a continuous covalent (network) solid.	33%
Octet Rule	
Nitrogen atoms can share five electron pairs in bonding.	20%

Bond Polarity

As indicated by students' responses to the question given above, 23% of students appeared to have correctly related electron sharing to covalent bonds, but had not considered the influence of electronegativity and the resultant unequal sharing of the electron pair on bond polarity. Sixty-one percent of this sample had considered the effect of unequal sharing of the electron pair on bond polarity.

Shape of Molecules

While 78% of students were able to demonstrate an understanding of the principles of the valence shell electron pair repulsion theory on one test item, subsequent test items revealed how weak their understanding really was since its application to problem situations led to the identification of three common misconceptions. Twenty-five percent of students justified a linear structure of SCl_2 as a result of "repulsion between bonds." Students with this view did not consider the influence nonbonding electron pairs have on the shape of a molecule. A second misconception, considered by 22% of the students, was that only the repulsion between the nonbonding electron pairs determined the V shape of the SCl_2 molecule. A third misconception was where students considered the polarity of the bonds in the molecule when accounting for molecular shape. For example, 27% of students, when accounting for the shape of the NBr_3 molecule, considered that the polarity of the N–Br bonds determined the shape of the molecule. In another item, concerning the shape of $COCl_2$, the polarity of the C=O bond was considered to be a significant factor in ascertaining the shape.

Polarity of Molecules

More than 40% of students indicated that they understood concepts related to polarity of molecules as measured by three items. However, when determining the polarity of a molecule, 34% of students considered the polarity to be only dependent on the electronegativity difference between the atoms forming each bond in the molecule. The shape of the molecule was not identified by these students to contribute to the overall polarity of the molecule.

Intermolecular Forces

Two misconceptions highlighted student confusion on the nature of intermolecular forces. In particular, intermolecular forces were incorrectly identified by 23% of students as the forces within a molecule and by 33% of students as the forces present within a continuous covalent solid. The grade-12 students in this sample were aware of the relationship between the strength of the intermolecular forces and the melting point and boiling point of a substance. However, it was evident that students were equating intermolecular forces with covalent bonds and were not aware of the variations in strength of covalent bonds compared with intermolecular forces.

Octet Rule

Seventy-four percent of students had an understanding of the octet rule principle; however, a common misconception relating to applying this principle was that the number of covalent bonds formed by a nonmetal atom equals the number of electrons in the valence shell. Twenty percent of students considered that nitrogen atoms in N_2Cl_4 could share five electron pairs in bonding. These students have not considered the principles of electron sharing and the restrictions on period two elements in particular when forming covalent bonds.

Conclusions and Implications for Teaching

The two-tier diagnostic instrument on *covalent bonding and structure* does appear to provide a feasible approach for evaluating students' understanding and for identifying commonly held misconceptions. This instrument can be a useful teaching aid since it enables teachers to evaluate student conceptual understanding through a diagnostic instrument that is relatively easy to administer and score. Teachers who become more familiar with these student misconceptions have the opportunity to develop instructional approaches that will minimize the likelihood of these misconceptions occurring. However, this research was not designed to identify teaching strategies to induce conceptual change (*7*), and no teaching approaches were used to address the observed misconceptions. Further, much work is necessary to develop appropriate teaching/learning approaches that will assist teachers and students to overcome any misconceptions already acquired. Indeed, this may be a difficult task since reported research often fails to relate conceptual changes to new teaching and learning experiences (*7*), and it is well documented that students frequently retain their existing views even following further instruction (*8*).

One drawback of this multiple-choice instrument is that, on the basis of student scores, a teacher cannot differentiate between students who guess the answer and those who hold genuine misconceptions. However, based on the development of the instrument from student verbal and written responses and on the results reported here, the relationship between content and reason responses was consistent across students (*6*).

This study has demonstrated the extent of weaknesses in student comprehension of chemistry concepts in covalent bonding and structure. These findings are consistent with research (*9*) that shows that science teachers, often through demands of an overburdened curriculum, are more concerned with the completion of academic work than with students' understanding of the concepts. The *covalent bonding and structure* diagnostic instrument provides chemistry teachers with a teaching aid that assesses student knowledge of facts and their understanding of those facts.

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