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Rectifying misconceptions on covalent bonding using cooperative learning, concrete models, and computer simulation: A case study

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ABSTRACT

The covalent bonding concept is perceived by students as abstract to comprehend and thus leads to the development of misconceptions. The inappropriate preconception on the subject is one of the contributing factors that lead to the development of misconceptions among the students. To this end, identifying and remediating learners' misconceptions is vital for every individual teacher in order to cultivate sound scientific knowledge in their learners. This study aimed to explore two aspects: first, the misconceptions of the grade-ninth students on the covalent bonding concept. Second, the effectiveness of cooperative learning based on conceptual change instruction, the use of concrete models, and computer simulation in remediating those misconceptions. The study adopted a quantitative method. The sample comprised 20 students (n=20) studying in the ninth grade of Drukjegang Higher Secondary School in Bhutan. The misconceptions of the students were identified using two-tier diagnostic tests. The study revealed that students' common misconceptions related to covalent bonding are concentrated under five themes: the kinds of atoms that form covalent bonding, how covalent bonding is formed, the kinds of covalent bonding, the characteristics of covalent compounds, and the Lewis dot structure and the octet rule. The data collected from the pre-test and post-test were analyzed and compared to determine the effectiveness of the intervention strategies. The misconceptions of students in post-test have significantly reduced after the intervention was implemented. The study suggests the use of cooperative learning, concrete models, and computer simulation as an effective remediating means of delivering the concept of covalent bonding among the students. Implications of the findings are also discussed.

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INTRODUCTION

Covalent bonding is an integral part of chemistry education and is one of the fundamental topics in the Chemistry syllabus (Eymur & Geban, 2016). Students acquainted with sound knowledge about covalent bonding helps them to better understand other Chemistry concepts like chemical reactions, the structure of matter, change of state, and physical and chemical processes (Pabuccu & Geban, 2012). It is of utmost importance that students should have clear ideas about the covalent bond and its properties to comprehend advanced concepts containing complex molecular species (Ardiansah, 2018; Coll & Taylar, 2010). Therefore, the study of the structure and bonding in elements, and the formation of covalent compounds regarding elements and compounds are introduced from the secondary level curriculum in Bhutan (Royal Education Council [REC], 2012).

However, a study conducted by Unal et al., (2010) showed that most students have misconceptions related to covalent bonding. A study by Ozmen (2004) pointed out that misconceptions among students are one of the factors that contributed to students' low achievement in the subject. The common factor that leads to misconception amongst the students related to covalent bonding is their pre-existing beliefs which influence how they learn new scientific knowledge. A previous study asserted that students' misconceptions related to covalent bonding are concentrated around the theme such as 'the kinds of atoms that form covalent bonding,' 'how covalent bonding is formed,' 'the kinds of covalent bonding,' 'the characteristics of covalent compounds,' and 'Lewis's dot structure and the octet rule.' (Unal et al., 2010). These misconceptions appear to be resistant to attempts to change them over time, despite increased Chemistry education. A finding by Ozmen (2004) opined that students' progress in their grades without fully grasping the underlying concepts of covalent bonding.

There are multiple studies published in the public domain on the topic "misconception of covalent bonding." The authors recommended educators use strategies such as concrete models, analogical models, and computer simulations while delivering the covalent bonding concept to learners (Eymur & Geban, 2016; Pabuccu & Geban, 2012; Unal et al., 2010). However, there is no study being done on this topic in the Bhutanese context. Therefore, the study aimed to address this gap by investigating and reporting on the misconception of covalent bonding. Furthermore, the study also aimed to explore the effectiveness of intervention strategies such as cooperative learning strategy, use of concrete models, and computer simulation to overcome students' misconceptions about the covalent bonding in ninth grade. In doing so, the findings from this study will serve as a foundation landmark to understand the types of misconceptions that prevailed among Bhutanese students related to covalent bonding. Also, findings from this study will reinforce chemistry educators to adopt some of the best teaching strategies while teaching the covalent bonding concept to further enhance the teaching and learning process.

LITERATURE REVIEW

Misconceptions

Chemical bonding is one of the key concepts in the Chemistry discipline. Many of the concepts taught in Chemistry, in secondary schools are dependent upon the understanding of fundamental ideas related to chemical bonding (Nahum et al., 2013). Nevertheless, the covalent bonding concept is perceived by educators, as well as by learners as abstract for them to understand, thus leading to the development of misconceptions among the learners. One of the factors which contribute to the development of misconception among the learners is inappropriate comprehension of concepts. A study conducted by Ozmen (2004) has shown that children bring to lessons a lot of pre-existing (alternatives) conceptions about scientific phenomena that can interfere with students' learning of correct scientific principles or concepts.

Generally, students have preconceptions of chemical bonding, and they find it difficult to integrate this prior existing knowledge with the new material being covered within the class (Ardiansah, 2018; Teichert & Stacy, 2002). Therefore, this creates a vacuum between the preconception and the new concept being delivered during the lesson. However, Nicoll (2001) emphasized that understanding the concept of chemical bonding is vital for students' effective learning because it underlies most of the advancing subjects in Chemistry lessons. Students must construct the meanings of chemical bonding concepts properly to understand other Chemistry subjects such as chemical reactions, chemical reactivity, the structure of matter, change of state, and physical and chemical change. A study conducted by Unal et al. (2010) revealed that students had misconceptions associated with covalent bonding. And the most common misconceptions are related to the kinds of atoms that form covalent bonding; how covalent bonding was formed; the kinds of covalent bonding; the characteristics of giant covalent compounds; and the Lewis dot structure and the octet rule. Furthermore, the study revealed that many students had a misunderstanding that covalent bonding is formed between a metal and a non-metal atom. It had been indicated that this misconception was held by students who stated that "covalent bonding is made between a metal and a nonmetal atom". Other studies also reported that students think as if the covalent bonding was formed between a metal and a nonmetal atom (Nicoll, 2001). One possible reason for this misconception is that students lack the ability to envisage how bonding is made at the sub-microscopic level as discussed in detail in the scientific article by Chophel (2022) on the misconceptions related to the particle nature of matter.

According to Nahum et al. (2013), many of the misconceptions are results of over-simplified models used in textbooks, the use of traditional pedagogy that presents a rather limited and sometimes incorrect picture of the issues related to covalent bonding, and assessments of students' achievement that influence the way the topic is taught. Also, there are discrepancies between scientists regarding key definitions in the topic and the most appropriate models to teach it. In particular, teaching models that are intended to have transitional epistemological value in introducing abstract ideas are often understood by students as accounts of ontological reality. In the nutshell, as pointed out by Mondal and Chakraborty (2013), the sources of alternative misconceptions in Chemistry are; textbooks (inconsistent use of terminologies), school setting (teaching and learning materials), and everyday knowledge (perceptions and intuitive interpretation of phenomena).

In response to rectifying misconceptions related to covalent bonding among the students, numerous researchers have suggested various intervention strategies to be implemented while teaching covalent bonding to the students. One of the intervention strategies to get rid of misconceptions on covalent bonding is by adopting learning environments supported by the collaboration of cooperative learning and conceptual change, employed by an educator of ordinary state high school in Taiwan as an alternate instructional technique to assist the students' understanding of covalent bonding concepts (Eymur & Geban, 2016). The study comprised 72 grade-ninth students from two intact Chemistry classes taught by a teacher. The classes were randomly distributed and assigned as a control and an experimental group. The experimental group was taught by using cooperative learning supported by conceptual change approach instruction, while the control group was taught by the traditional lecture method.

To determine the effectiveness of the cooperative learning strategy, Covalent Bonding Concept Test (CBCT) was utilized as a pre-and post-test for students. After the treatment, students' interviews were conducted to gather more information. Interviews revealed that this treatment provided a platform for student-student and teacher-student interaction. Through this interaction, students had an opportunity to share their ideas and knowledge by relating their prior knowledge with new concepts. Therefore, students learned the covalent bonding concept more easily and effectively. Moreover, through this treatment, students believed that it helped them to increase their learning motivation and also develop a zeal to learn while working within the group. Also, the cooperative learning supported by conceptual change approach instruction helped students learn and increased their social skills, and rectify their misconceptions.

A similar study conducted by Unal et al. (2010), also suggested a few intervention strategies such as the use of concrete models, analogical models, and computer simulations to be used by educators to make the concept easier for the learners and remediate misconceptions related to covalent bonding. As informed by the literature mentioned above, the study adopted cooperative learning based on conceptual change instruction, the use of concrete models, and computer simulation as the intervention to remediate students' misconceptions.

OBJECTIVES

The objectives of this study are to investigate and identify the misconceptions about covalent bonding among grade-ninth students, and to investigate the impact of interventions such as the use of cooperative learning, concrete models, and computer simulation on students' understanding of the covalent bonding. Specifically, the study sought to:

1. Investigate and identify the prevalence of misconceptions on covalent bonding among grade-ninth students.
2. Investigate the effectiveness of the strategies such as cooperative learning, concrete models, and computer video simulation in addressing the misconception about covalent bonding.

Research questions

1. What are the misconceptions among grade-ninth students on covalent bonding?
2. Will strategies such as cooperative learning, concrete model, and video simulation be effective in remediating student's misconceptions related to covalent bonding?

METHODS

Design

The study adopted a quantitative method approach. The design involves one group pretest-posttest design. The statistical format of the design is *O1XO2*; the study involves one group of students who participated in the pre-test (O1), were exposed to a treatment (X), and then participated in post-test (O2) (Bhattacherjee, 2012; Cohen et al., 2007).

Population and sample of the study

The sample school has a population of 74 ninth-grade students. The sample was selected using simple random sampling. Out of the population size of 74 ninth-grade students, 20 students were taken as sample (11 males and 9 females) (Using the random online application: https://random.org) (Random.org, 2021 as cited in Chophel, 2022). All the students were assigned a number from 1 to 74, and then a random number generator was used to select the 20 participants.

Research instrument

Items for the diagnostic instrument were based on the two-tier multiple-choice format adopted by Treagust (1987). The first tier of each item consists of a content question having three choices; the second part of each item contained four possible reasons for the answer given in the first tier as evident in Figure 1.

Part B. Survey questionnaires
Two-tier multiple-choice questions

Sub-topics	Items			
Kinds of atoms which form covalent bonding	**Question 1**	***Which of the following pairs of atoms can form the covalent bond?***		
	Option	A. Mg and Cl	B. Mg and Mg	C. Cl and Cl
	Reason	1. A covalent bond is formed between a metal and non-metal		
		2. A covalent bond is formed between metal and metal		
		3. A covalent bond is formed between non-metal and non-metal		
		4. No idea about the reason.		
	Question 2	***Two nitrogen atoms combine to form a nitrogen molecule, and it constitutes of***		
	Option	A. Dative bond	B. Covalent bond	C. Ionic bond
	Reason	1. There is a sharing of electrons between nitrogen atoms		
		2. There is a transfer of electrons from one nitrogen atom to another		
		3. One nitrogen atom provides lone pair electrons to another nitrogen atom		
		4. No idea about the reason		

Figure 1. Sample questionnaires used for pre-test and post-test

The test items for this study comprised 10 multiple choice questions with four options of the reasons. The options included were the correct answer and three identified alternative reasons involving misconception. Items were categorized into five themes under the concept of the covalent bond as depicted in Table 1.

Table 1. Categorization of topics and item number

Sub-topics	Item number
Kinds of atoms that form covalent bonding	1 and 2
How covalent bonding is formed	3 and 4
Types of covalent bonding	5 and 6
Characteristics of covalent compounds	7 and 8
Lewis dot structure and stable electronic configuration	9 and 10

Validity and reliability

The two-tier diagnostic test items were reviewed and validated by a group of subject experts, and Chemistry teachers currently teaching in ninth grade. This was mainly done to determine the uncertainty of the items and level of language. For the same, the pilot testing was carried out in one of the schools in the same district. The pilot testing helped in identifying some of the repeated statements and in rectifying instructions that were not very clear while experts' feedback assisted to improve the content validity of research instruments.

Research process

All students in the sample had responded to both the pre-test and post-test. A pre-test was administered before the interventions (as evident in Figure 1) to determine the presence of misconceptions, while a post-test was conducted after the treatment to find out the impact of the interventions (as evident in Figure 2).

Intervention method

The study adhered to the following steps during interventions for the sample students:

Step 1: Twenty ninth-grade students of Drukjegang Higher Secondary School were involved in this study. They were divided into five groups to implement cooperative learning strategies.
Step 2: Students were divided into five groups as 'home groups' comprising 4 members each and numbered 1, 2, 3, and 4. Members with the same number from home groups were asked to get together known as expert groups.
Step 3: Each expert group was assigned a topic: 1) the kinds of atoms that form covalent bonding, 2) how covalent bonding is formed, 3) the kinds of covalent bonding, 4) the characteristics of the covalent compound, and 5) Lewis structure and stable electronic configuration. In the expert group, students discussed their topic by using concrete models for 20 minutes. After the discussion, they returned to their home group and share their expertise with their fellow members.
Step 4: The researcher acted as a facilitator during the discussion and provided necessary feedback and guidance.
Step 5: The researcher used a projector to teach the topic through computer simulation and video explanation as an alternative to enhance students' understanding after the activities.

a. Cooperative learning and concrete model b. Computer simulation and video strategies

Figure 2. Photo showing the implementation of intervention methods

Data analysis

The classification of students' answers or responses based on the two-tier method is shown in Table 2. Students' comprehension level of the covalent bonding was identified as a misconception, did not understand the concept well, and understood the concept well, to check students content knowledge. This description was applied to the data collection of both pre-test and post-test.

Table 2. Classification of students' answers based on the two-tier method

Answer	Reasoning	Description
Incorrect	Correct	Misconception
Correct	Incorrect	Misconception
Correct	Correct	Understood the concept well
Incorrect	Incorrect	Did not understand the concept

The data were analyzed by making a comparison between the pre-test and post-test using descriptive analysis.

RESULTS AND DISCUSSIONS

The finding from the pre-test revealed that misconceptions among the students as depicted in Table 3 are concentrated around 'types of covalent bonding,' and 'what kinds of atoms form covalent bonding.' Many students had a misunderstanding that a covalent bond is formed between a metal and a non-metal atom. In addition, 35% of participants had a misconception about 'how covalent bonding is formed.' Similarly, 35 % of the participants had misconceptions about 'the characteristics of the covalent compound,' concurring with the earlier findings. Furthermore, only two students out of twenty have sound knowledge about the stable electronic configuration (octet rule) concept.

Table 3. Students' comprehension level of covalent bonding before interventions (pre-test)

Sub-topic	Total and percentage (%) of students understanding the level of the topic					
	Misconception		Did not understand		Understood	
	No. of Students	Percentage (%)	No. of Students	Percentage (%)	No. of students	Percentage (%)
Kinds of atoms which form covalent bonding	**10**	**50**	4	20	6	30
How covalent bonding is formed	**7**	**35**	8	40	5	25
Types of covalent bonding	**14**	**70**	6	30	0	0
Characteristics of a covalent compound	**7**	**35**	10	50	3	15
Lewis dot structure and stable electronic configuration	**7**	**35**	11	55	2	10

In order to validate the impact of intervention strategies, a post-test was conducted after the intervention as evident in Figure 3.

Figure 3. Photo showing the conduct of post-test

The finding from the post-test as depicted in Table 4 revealed that misconceptions among the students significantly reduced after the intervention was implemented.

Table 4. Students' comprehension level of covalent bonding after the interventions (post-test)

Sub-topic	Total and percentage (%) of students understanding the level of the topic					
	Misconception		Did not understand		Understood	
	No. of Students	Percentage (%)	No. of Students	Percentage (%)	No. of students	Percentage (%)
Kinds of atoms which form covalent bonding	1	5	0	0	19	95
How covalent bonding is formed	1	5	0	0	19	95
Types of covalent bonding	1	5	0	0	19	95
Characteristics of a covalent compound	0	0	0	0	20	100
Lewis dot structure and stable electronic configuration	1	5	0	0	19	95

For instance, the misconceptions among the students which were concentrated around ‘types of covalent bonding,’ and ‘kinds of atoms which form covalent bonding,' have reduced to only 5%. Similarly, other thematic areas such as ‘how covalent bonding is formed,’ and ‘the stable electronic configuration of the atom,’ have been reduced to 5%. Interestingly, none of the participants had indicated that they have a misconception about 'the characteristic of covalent compound' after the treatment. The results from the pre-test and post-test were compared and analysed to draw a conclusion as depicted in Table 5. The findings revealed that the use of cooperative learning (video simulation and concrete models) in teaching the covalent bonding concept to the students was found effective in remediating students’ misconceptions.

Table 5. Summary of students’ percentage with specific misconceptions identified from the covalent bonding and correct concept for corresponding misconception

Thematic areas	Misconceptions	Percentage (%)		Correct Concept
		Pre-test	Post-test	
Kinds of atoms that form covalent bonding	A covalent bond is formed between a metal and a non-metal.	50	5	A covalent bond is formed between two non-metals that have similar electronegativities.
How covalent bonding is formed	A Water molecule is formed by transferring electrons from hydrogen atoms to an oxygen atom.	35	5	A water molecule is formed by sharing electrons between the oxygen atom and hydrogen atoms.
Types of covalent bonding	A double bond is formed by the sharing of two electrons between the oxygen atoms.	70	5	A double bond in an oxygen molecule is formed due to sharing of two pairs of electrons.
Characteristics of covalent compounds	Covalent compounds are good conductors of electricity due to the presence of free ions.	35	0	Covalent compounds are bad conductors because they cannot ionize to form free ions.

Lewis dot structure and stable electronic configuration	Fluorine molecule shares two pairs of electrons between atoms.	35	5	Fluorine molecules share only a pair of electrons to gain their stability/attain octet configuration.

As shown in Table 5, the misconceptions among the students which were concentrated around 'types of covalent bonding,' and 'kinds of atoms which form covalent bonding,' have reduced to only 5% after implementing the intervention strategies. Similarly, other thematic areas such as 'how covalent bonding is formed,' and 'the stable electronic configuration of the atom,' have been reduced to 5%. Interestingly, none of the participants had indicated that they have a misconception about 'the characteristic of covalent compound' after the intervention. Therefore, the use of cooperating learning strategies, concrete models, and computer video simulations was found to be effective in remediating students' misconceptions.

CONCLUSIONS AND RECOMMENDATIONS

The main aim of this study was to investigate the misconceptions of the grade-ninth students on the covalent bonding concept, and the effectiveness of cooperative learning based on conceptual change instruction, the use of concrete models, and computer simulation in remediating students' misconceptions. The study adopted a quantitative method approach with data collecting tools as two-tier diagnostic tests. The findings of this study revealed that most of the students have misconceptions about covalent bonding and its related features. As pointed out in the discussion section, most of the students had misconceptions related to covalent bonding in the areas such as the kinds of atoms that form covalent bonding; how covalent bonding is formed; the kinds of covalent bonding; the characteristics of covalent compounds; and Lewis dot structure and the octet rule. The reasons attributed to students' misconceptions are an inappropriate use of teaching and learning materials and pre-existing knowledge of students. Therefore, it is imperative for educators to diagnose the misconceptions of the students and accordingly implement suitable methods to rectify the misconceptions among the students.

To remediate those misconceptions from the students, multiple studies have revealed that the utilization of models such as concrete models and analogical models, cooperative learning strategy, and teaching through computer video simulations were found to be effective. Similarly, for this study, those strategies were employed and found it significantly effective in remediating students' misconceptions. The use of a cooperative learning strategy, computer video simulation, and concrete models were found to be effective in uncovering the concept of covalent bonding to the students. It was found that the students were able to comprehend the concept more realistically when they are taught by infusing cooperative learning strategy with technology. By incorporating technology in the lesson, students were able to see and visualize the microscopic structure, which otherwise students have to just restrict to their imagination. The use of technologies in the teaching and learning process provides students with a deeper understanding and meaningful learning. It also helped students in remediating their misconceptions through investigation and reflection. In addition, participants asserted that they are able to comprehend the concept better when they see structure through video animation instead of assumptions. The participant also opined that it stimulates more interest and enjoyment in learning Chemistry.

However, there were a few limitations of this study. Firstly, the sample size was small (n=20) thereby it cannot possibly be generalized as representative of the larger population. In addition, this study employed a two-tier multiple-choice test, and the drawback of this tool is, that it could not measure the confidence level of the students. Therefore, the future researcher can employ a four-tier multiple-choice test to derive authentic responses from the participants. Furthermore, this study was subjected to a quantitative research design only. Therefore, the future researcher may employ mixed methods to gather in-depth information on the misconceptions identified. The study recommends that the curriculum designers and writers of the textbook incorporate these strategies while designing and preparing future Chemistry curricula. In addition, Chemistry teachers are recommended to use teaching strategies such as cooperative learning, video simulation, and concrete models to teach the covalent bonding concept. Furthermore, teachers may explore new teaching strategies such as concept mapping, and metacognition strategies to uplift students' critical and analytical thinking skills.

REFERENCES

Ardiansah. (2018). Colleges students' misconception about the type of bonding. *MATEC Web of Conferences*, *150*, 1-7. https://doi.org/10.1051/matecconf/201815005079

Bhattacherjee, A. (2012). *Social Science Research: Principles, Methods, and Practices*. University of South Florida. http://scholarcommons.usf.edu/oa_textbooks/3

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

Chophel, Y. (2022). Remediating misconceptions related to particulate nature of matter using video animation: An action research. *International Research Journal of Science, Technology, Education, and Management*, 2(1), 65-77. https://doi.org/10.5281/zenodo.649677

Cohen, L., Manion, L. & Morrison, K. (2007). Research Methods in Education (6th ed.). Routledge

Coll, R.K., & Taylor, N. (2010). *Research in Science & Technological Education Alternative Conceptions of Chemical Bonding Held by Upper Secondary and Tertiary Students*. *August 2014*, 37-41. https://doi.org/10.1080/02635140120057713

Eymur, G. & Geban, O. (2016). The collaboration of cooperative learning and conceptual change: Enhancing the students' understanding of chemical bonding concepts. *Ministry of Science and Technology, Taiwan*. https://doi.org/10.1007/s10763-016-9716-z

Fadillah, A. & Salirawati, D. (2018). Analysis of misconceptions of chemical bonding among tenth-grade senior high school students using a two-tier test. *AIP Conference Proceedings*, 2021(October 2018). https://doi.org/10.1063/1.5062821

Nahum, T.L., Naaman, R.M., Hofstein, A., & Taber, K.S. (2010). *Studies in Science education teaching and learning the concept of chemical bonding*. *April 2013*, 37-41. https://doi.org/10.1080/03057267.2010.504548

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

Ozmen, H. (2004). Some student misconceptions in Chemistry: *Journal of Science Education and Technology*, 13(2).

Pabuccu, A. & Geban, O. (2012). Students ' conceptual level of understanding of chemical bonding. *International Online Journal of Educational Sciences*, *4*(3), 563-580.

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

Peterson, R., Treagust, D.F, & Garnett, P. (1986). Identification of secondary students' misconceptions of covalent bonding and structure concepts using a diagnostic instrument. *Research in Science Education*, 16(1), 40-48. https://doi.org/10.1007/BF02356816

Prodjosantoso, A.K., Hertina, A.M., & Irwanto. (2019). The misconception diagnosis of ionic and covalent bonds concepts with three tiers diagnostic test. *International Journal of Instruction*, 12(1), 1477-1488. https://doi.org/10.29333/iji.2019.12194

Random. Org. (2021). True random number generator. https://www.random.org/

Royal Education Council. (2012). Science Curriculum Framework: Classes PP - XII. Royal Government of Bhutan.

Teichert, M.A., & Stacy, A.M. (2002). Promoting the understanding of chemical bonding and spontaneity through student explanation and integration of ideas. *Journal of Research in Science Teaching*, 39(6), 464-496. https://doi.org/10.1002/tea.10033

Unal, S., Costu, B., & Ayas, A. (2010). Secondary school students' misconceptions of covalent bonding. *Journal of Turkish Science Education*, 7(2). http://www.tused.org