

Students’ understanding and misconceptions of covalent bonding using ball-and-stick molecular models

Jacob Tito Ngwenya 

Department of Teacher Development, Faculty of Education, Zimbabwe Open University, Zimbabwe.
Email: ngwenyajt@gmail.com



Abstract

This study investigated the effectiveness of ball-and-stick molecular models in teaching covalent bonding to an O-Level Chemistry class in Gweru District, Zimbabwe. A convergent concurrent mixed-methods design was employed, with quantitative and qualitative data collected simultaneously and analyzed separately before integration. Quantitative data were obtained through pre- and post-tests, while qualitative data were collected using classroom observations and student questionnaires. Students’ pre- and post-test scores were compared using a paired-samples t-test. The results revealed a statistically significant improvement in students’ performance following the use of molecular models ($p < 0.0001$), indicating a positive effect on their understanding of covalent bonding. Qualitative findings showed that the models supported students in visualizing three-dimensional molecular structures and understanding the arrangement and formation of covalent bonds. However, some students developed misconceptions, including the belief that molecular models perfectly represent real molecules. Open-ended responses also revealed difficulties in understanding electron sharing and bond flexibility. The study concludes that ball-and-stick molecular models are effective instructional tools when their strengths and limitations are explicitly addressed. It recommends integrating guided discussions, formative assessment, and digital modelling with physical models to strengthen students’ conceptual understanding and connections between molecular representations, electron behavior, and chemical symbols.

Keywords: Ball-and-stick molecular models, Chemistry education, Conceptual understanding, Covalent bonding, O-Level chemistry, Students’ misconceptions.

Citation | Ngwenya, J. T. (2026). Students’ understanding and misconceptions of covalent bonding using ball-and-stick molecular models. *Asian Journal of Education and Training*, 12(4), 18–26. <https://doi.org/10.20448/edu.v12i4.9424>

History:

Received: 22 June 2026

Revised: 14 September 2026

Accepted: 21 September 2026

Published: 25 September 2026

Licensed: This work is licensed under a [Creative Commons Attribution 4.0 License](#) 

Publisher: Asian Online Journal Publishing Group

Funding: This study received no specific financial support.

Institutional Review Board Statement: The study involved minimal risk and followed ethical guidelines for social science fieldwork. Formal approval from an Institutional Review Board was not required under the policies of the Ministry of Primary and Secondary Education, Zimbabwe. Informed verbal and written consent were obtained from all participants, and all data were anonymized to protect participant confidentiality.

Transparency: The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Competing Interests: The author declares that there are no conflicts of interests regarding the publication of this paper.

Disclosure of AI Use: The researcher used AI-assisted tools, namely ChatGPT, Gemini, and Grammarly, to aid with rephrasing, refining language, and enhancing the clarity and readability of the manuscript. The ideas of the study, analysis, interpretation of findings, and conclusions, however, belong to the author. This implies that the aforementioned tools did not contribute to the generation of the research findings and the contents of the study.

Contents

1. Introduction	19
2. Background to the Study	19
3. Aim of the Research	19
4. Research Questions	19
5. Research Methodology	20
6. Population, Sample and Sampling Techniques	21
7. Data Collection Procedure	21
8. Data Presentation, Discussion and Analysis	22
9. Conclusion	24
10. Recommendations	25
References	25

Contribution of this paper to the literature

This study uniquely combines pre- and post-test evidence with classroom observations and student perceptions to examine both the effectiveness and limitations of ball-and-stick molecular models in teaching covalent bonding. It provides recent empirical evidence from a Zimbabwean O-Level classroom and identifies misconceptions that persist despite model-based instruction.

1. Introduction

Covalent bonding is one of the core topics in the Zimbabwe School Examinations Council (ZIMSEC) ordinary level syllabus, which serves as the foundation for understanding molecular structures, chemical reactions, and the properties of matter. In spite of the topic being important, students often find it challenging. The abstract nature of the concept of electron sharing between atoms, coupled with its three-dimensional nature that students cannot directly observe, makes it difficult for learners to grasp (Kuit & Osman, 2021). The result is that students develop misconceptions, such as confusing ionic and covalent bonds or misunderstanding both the molecular geometry and polarity, which can prevent them from fully understanding the chemical principles (Bergqvist, Drechsler, De Jong, & Rundgren, 2013; Tsaparlis, Pappa, & Byers, 2018).

As a way to address these challenges, teachers have resorted to using molecular models, which include ball-and-stick kits and computer-based simulations. These tools allow students to visualize molecules and assist to manipulate them, making the world of atoms and bonds visible and more tangible. The use of physical models by teachers, therefore, provides learners with a hands-on way to explore the shapes of molecules and the connections between bonds, while digital models offer interactive three-dimensional perspectives that help to dynamically illustrate bond angles, molecular geometry and the distribution of electrons (Kuit & Osman, 2021). For instance, research using the CHEMBOND3D e-module and MolView simulation tools showed that students who engaged with interactive molecular models demonstrated greater improvements in both conceptual understanding and spatial reasoning compared to students taught using conventional methods (Kuit & Osman, 2021).

The literature highlights that molecular models can support meaningful learning by assisting students with the integration of symbolic, submicroscopic and macroscopic representations of chemical phenomena. By moving beyond static textbook diagrams, learners can better connect chemical symbols and formulas with the actual three-dimensional molecular structures that they represent (Newman, Stefkovich, Clasen, Franzen, & Wright, 2018). The use of molecular models then provides a bridge between abstract concepts and concrete understanding, supporting students in creating their own mental models that are aligned with specific explanations.

However, molecular modelling is not without its limitations. Students may sometimes merely make literal interpretations of the models by confusing the representations with real molecules, thereby reinforcing misconceptions instead of resolving them (Bergqvist et al., 2013). Simple ball-and-stick models, for example, do not convey dynamic features such as electron density or the polarity of molecules, an essential feature for a comprehensive understanding of covalent bonding. Without careful guidance from teachers, students might treat molecular models the same way they treat real molecules instead of them being tools for learning.

Research also emphasizes the role of teacher expertise and instructional design on how to effectively use molecular models. Against this backdrop, educators who do not possess enough training and experience may not be able to fully utilize these tools, limiting the potential benefits for student learning (Karacop & Doymus, 2013). Moreover, while digital models can be useful in enhancing learning, the level at which students access technology and familiarize with software can vary. Studies suggest that gains are often modest unless the integration of molecular modelling is done thoughtfully into a broader instructional strategy (Roche Allred et al., 2021).

2. Background to the Study

The concept of chemical bonding underpins most of Ordinary Level chemistry. It is therefore detrimental to understand students' misconceptions, as it influences the achievement of students in advanced science topics. Chemical bonding is widely recognized as a complex topic with abstract concepts which results in many learners struggling to go beyond memorization to the level of conceptual understanding (Tsaparlis et al., 2018). Research has shown that students' misconceptions mainly stem from the failure to understand how ionic and covalent bonds form, the nature of shared electrons and the geometry of molecules. This, according to Özmen (2004), can inhibit their ability to apply chemical principles in new contexts.

These misunderstandings are not isolated but global, though they become a particular concern in contexts where poor performance in science subjects like chemistry contributes to low numbers of students taking the STEM subjects at Advanced level and universities (Gadzirayi, Bongo, Ruyimbe, Bhukuvhani, & Mucheri, 2016). In the case of Zimbabwe, where the Heritage-Based Curriculum (HBC) emphasizes relevance to local learning contexts and conceptual understanding, the examination of students' misconceptions in chemical bonding is important in aligning teaching with the needs of learners, yet few documented empirical studies have been conducted in this specific context. One investigation by Gudyanga and Madambi (2014) reported that secondary school learners develop misconceptions in chemical structure and bonding partly due to simplistic teaching approaches and inadequate instructional strategies. However, no comprehensive, recent investigations specifically targeting students' conceptual understanding of covalent bonding have been published, leaving a gap in the literature that this study seeks to address.

3. Aim of the Research

This study seeks to explore the effectiveness of ball-and-stick molecular models in supporting O-Level students' understanding of covalent bonding in secondary school chemistry. Specifically, it examines whether these tangible models can enhance students' ability to grasp abstract chemical concepts.

4. Research Questions

To address the problem of students' persistent difficulties in understanding covalent bonding, this study was

guided by the following research questions:

1. How do ball-and-stick molecular models assist students in visualizing the three-dimensional structures and bonding patterns of covalent compounds?
2. Which conceptual misunderstandings about covalent bonding remain among students, even after engaging with physical molecular models?
3. In what ways do students use the knowledge gained from ball-and-stick models when drawing chemical diagrams or explaining covalent bonding concepts?
4. How do students perceive the usefulness and limitations of ball-and-stick molecular models in their learning of covalent bonding?

5. Research Methodology

This section outlines the research methodology employed in the study to investigate the effectiveness of ball-and-stick molecular models in teaching covalent bonding. It describes the research paradigm, research approach, research design, participants, data collection methods, and data analysis procedures used to address the research questions.

5.1. Research Paradigm

A pragmatic research paradigm (pragmatism) guided the investigation, as it aligns well with the use of mixed-methods research. Pragmatism prioritizes research approaches that best address the problem under investigation, rather than commitment to a single philosophical tradition (Creswell, 2014, as cited in Ishtiaq (2019)). Within the pragmatic research paradigm, both quantitative and qualitative methods are viewed as complementary, each contributing valuable insights into complex educational contexts. Quantitative data were used to examine the achievement of students in covalent bonding, while qualitative data provided a deeper understanding of students' reasoning, misconceptions, and their experiences within the classroom. The application of the pragmatic stance allowed the researcher to integrate multiple forms of evidence, supporting a comprehensive interpretation of how ball-and-stick molecular models operate within authentic chemistry classroom settings (Johnson & Onwuegbuzie, 2004).

5.2. Research Approach

This study adopted a mixed-methods research approach which enabled the researcher to draw on the strengths of both quantitative and qualitative paradigms to provide a comprehensive understanding of how the use of molecular models in teaching influences the learning and achievement of students in covalent bonding. Mixed-methods research facilitates the integration of numerical data with rich descriptive insights, allowing researchers to explore not only what changes occur in student learning but also how and why these changes take place (Creswell & Plano Clark, 2018; Johnson & Onwuegbuzie, 2004).

The researcher collected quantitative data via pre- and post-instruction assessments which were designed to measure students' conceptual understanding and mastery of the concepts on covalent bonding. Conducting these assessments provided objective evidence of the effect that can be attributed to the instructional intervention (Tashakkori & Teddlie, 2010). By analysing changes in test scores, the degree of cognitive growth could be quantified, as well as the identification of student achievement across the sample.

However, relying on quantitative measures alone may not take into consideration other factors such as students' contextual reasoning and factors that shape their learning experiences (Mertens, 2014). To address this, the research conducted classroom observations and interviewed students to generate qualitative data, which enabled an exploration of students' thought processes, misconceptions, and how they interact with the ball-and-stick models (Maxwell, 2013). A good example is that verbal articulations of students during modelling provided the researcher with evidence of the different ways in which physical representations support meaningful visualization of molecular geometry (Southam & Costley, 2024).

By integrating these multiple strands of evidence, the mixed-methods approach allowed the study to go beyond unearthing the effect of using models on student achievement to uncovering the underlying mechanisms that shape conceptual learning (Teddlie & Tashakkori, 2009). This holistic perspective helped to highlight certain misconceptions that are persistent during students' learning as well as showing how the use of models contributes to their reasoning and visualization skills, something that may not have been evident from quantitative scores alone (Creswell & Plano Clark, 2018).

5.3. Research Design

In this study, the researcher employed the concurrent convergent case study research design to examine how the use of ball-and-stick molecular models, in the teaching of chemical bonding, affects students' learning and academic achievement. The use of this research design allowed for a deep exploration of a single Ordinary Level chemistry classroom in Gweru district, Zimbabwe in its natural teaching and learning context (Yin, 2018). Quantitative and qualitative data were simultaneously collected to allow students' learning outcomes to be examined alongside their explanations, classroom interactions, and perceptions of the molecular models. Such an approach is widely recommended in educational research for cases that require the capturing of complex classroom experiences (Creswell & Plano Clark, 2018).

5.4. Research Instruments

Multiple research instruments were used to collect data in order to capture both the students' classroom experiences and academic achievement during the teaching and learning of chemical bonding. The instruments used to collect quantitative data were the pre- and post-instruction assessments made up of 20 multiple-choice questions (MCQs). These objective test items provided the basis of measuring students' conceptual understanding of covalent bonding and also for identifying common misconceptions related to the topic. The pre-test was administered before students were introduced to the ball-and-stick molecular models to establish their prior knowledge, ideas and

misunderstandings, while the post-test was administered after the intervention to assess changes in understanding and learning gains. The researcher included distractors in the MCQs to represent common misconceptions, allowing incorrect responses to be used as indicators of conceptual difficulties (Tashakkori & Teddlie, 2010). Students' responses were then analyzed to determine overall performance trends as well as recurring errors that signalled persistent misconceptions.

To complement quantitative data obtained from pre- and post-assessment tests, the researcher conducted classroom observations during lessons in which ball-and-stick molecular models were used. These observations were meant to determine student engagement, how they interacted with models and verbal explanations of molecular structures and bonding, providing insight into learning processes that could not be captured through tests alone (Cohen, Manion, & Morrison, 2018; Yin, 2018). In addition, an open-ended student questionnaire was administered after the intervention to gather students' perceptions of the usefulness and limitations of using molecular models as a learning tool. Using open-ended questionnaires allowed the students to reflect on their learning experiences freely in their own words, contributing to a deeper understanding of how the use of molecular models can support or constrain conceptual learning (Creswell & Plano Clark, 2018).

6. Population, Sample and Sampling Techniques

6.1. Population of the Study

The study population was made up entirely of all the Ordinary Level Chemistry students in the 14 public high schools in Gweru district, Zimbabwe. The researcher purposefully selected public schools because they operate under comparable curriculum requirements, have same assessment standards and may also face similar resource constraints related to limited laboratory resources and instructional materials (Ngwenya, Makamure, & Tarusikirwa, 2025). Such contexts are particularly relevant for classroom-based chemistry research, as they reflect the learning conditions experienced by the majority of secondary school students in the country (Cohen et al., 2018).

Research studies that sought to investigate the use of low-cost teaching tools, such as ball-and-stick molecular models, within these settings therefore provide practically relevant insights into strategies that can be applied to improve the teaching and learning of chemistry under resource-constrained conditions (Gilbert, 2005).

Gweru district was also purposefully chosen because of its accessibility to the researcher, who resides and also taught in the district for nearly a decade, allowing for sustained classroom observation and close monitoring of the instructional intervention, which is important when carrying out a case study research (Yin, 2018).

6.2. Sample of the Study

From this population, the researcher chose one public co-educational boarding school (Saint Patrick's High School) and a single O-Level Chemistry class from the school. The school was deliberately selected because the researcher had taught at the institution for four years, which provided familiarity with the school culture, curriculum implementation, and classroom routines. Conducting research in a setting where the researcher is known and trusted can enhance access, reduce participant anxiety, and support more natural classroom interactions (Cohen et al., 2018; Mercer, 2007). In addition, the researcher's established professional relationship with the school administration made it easy to obtain ethical clearance and multiple-entry access throughout the study period, which is essential for classroom-based case study research (Yin, 2018).

A single O-Level chemistry class was selected to allow for an in-depth examination of students' learning outcomes and how they learn in a real classroom context. The inclusion of an entire intact class preserved the natural teaching and learning environment and also helped to minimize disruption to the normal teaching and learning process. Focusing on a single class also enabled close observation of individual learning trajectories and misconceptions, which are in alignment with the goals of case study research that gives priority to depth over breadth (Cohen et al., 2018; Stake, 1995).

7. Data Collection Procedure

In this study, the researcher used three methods to collect and gather data: Pre- and post-instruction multiple-choice assessments, classroom observations, and a student questionnaire. These methods were implemented simultaneously in line with the concurrent convergent mixed-methods design during a three-week period of teaching covalent bonding to capture both measurable learning outcomes and students' classroom experiences (Creswell & Plano Clark, 2018). Ethical clearance was obtained from the offices of the Midlands Provincial Education Director, the District Schools' Inspector and the school administration to ensure adherence to ethical standards required to conduct educational research within schools (Yin, 2018).

Before the intervention, students wrote a 20-item MCQ pre-test over a period of 40 minutes under the supervision of both the researcher and their chemistry teacher. After the pre-test, the instructional intervention using ball-and-stick molecular models was carried out over a period of three weeks. During this time, students worked both individually and in small groups to construct and explain molecular structures, while the researcher conducted non-participant observations once every week, which consisted of three double lessons, each lasting 80 minutes. To capture how students interacted with models, their level of engagement and how they verbally explained molecular structures, the researcher recorded field notes during the observed lessons (Cohen et al., 2018).

After the instructional intervention, a post-test consisting of the same 20-item MCQ test was administered. The order of the items was however, changed to minimize recall bias, and also reworded to make sure that students were responding to the concepts rather than memorized phrasing from the pre-test. The pre-test was also written over a period of 40 minutes, during the last chemistry block of the third week, which is usually designated for practical activities. Soon after the post-test, an online questionnaire was administered to all the students to gather students' reflections on the usefulness and limitations of the ball-and-stick molecular models. Included in the questionnaire were open-ended questions and a Likert scale to determine the level between 1-5 to which students agreed or disagreed with statements about their learning experiences. Administering the questionnaire online ensured that the collection of responses was timely and efficient and also made data management easier and more secure (Creswell & Plano Clark, 2018; Dillman, Smyth, & Christian, 2014; Yin, 2018).

8. Data Presentation, Discussion and Analysis

8.1. Participants Included in the Analysis

Initially, 24 students completed the pre-test. However, five students were absent on the day of writing the post-test and were therefore not included in the statistical data analysis. This implies that 19 students took part in both tests and also completed the online questionnaire. This approach of excluding the 5 students maintains consistency in measuring change over time within the same group of learners.

8.2. Quantitative Data Presentation

Table 1 presents test scores (Pre- and Post) for 19 students who completed both assessments before and after the intervention using molecular models.

Table 1. Students’ pre- and post-test scores (Out of 20).

Student Number	Pre-test Score	Post-test Score
1	12	16
2	13	17
3	12	15
4	15	18
5	12	15
6	13	16
7	14	17
8	15	19
9	16	19
10	14	18
11	13	17
12	14	18
13	15	19
14	16	20
15	12	15
16	13	17
17	14	18
18	15	19
19	16	20

8.3. Descriptive and Inferential Statistics

8.3.1. Paired-Samples t-Test

The researcher used a paired-samples t-test to make a comparison of students’ performances on the pre-test and post-test following the intervention. This statistical test was appropriately used because the same students were assessed at two different times, which allowed for a direct comparison of their scores to be possible. The paired or dependent samples t-test is widely recommended when examining mean differences within the same participants at two different times but with related conditions (Field, 2018; Pallant, 2020).

Statistical analysis was carried out using IBM SPSS Statistics version 29, which provided the researcher with both the descriptive statistics and the results of the paired-samples t-test, including the t value, degrees of freedom, and the exact p-value. The significance alpha level for the analysis was set at 0.05, which is the threshold commonly applied for educational research when determining statistical significance (Creswell & Creswell, 2018). A p-value less than 0.05 suggests that the observed difference is very low and likely occurring due to chance (Pallant, 2020). Consequently, the null hypothesis is rejected, indicating that the improvement in students’ scores from pre-test to post-test is statistically significant, and that the intervention using molecular models likely had a meaningful positive effect on their understanding of covalent bonding. The hypotheses tested in this study, including both the null and alternative, are shown below.

H₀ (Null Hypothesis): There is no statistically significant difference between students’ mean pre-test and post-test scores.

H₁ (Alternative Hypothesis): There is a statistically significant difference between students’ mean pre-test and post-test scores.

Tables 2 and 3 present the mean scores, standard deviations, and the results of the t-test analysis, showing whether the differences between pre-test and post-test scores were statistically significant.

Table 2. Descriptive statistics for pre- and post-test scores of students (N = 19).

Test	n	M	SD
Pre-test	19	14.50	1.36
Post-test	19	18.10	1.47

Table 3. Paired-samples t-test results for pre- and post-test scores of students (N = 19).

Comparison	t	df	p	Mean Difference	SD Difference
Pre-test vs. Post-test	31.57	18	< 0.0001	3.63	0.50

8.3.2. Quantitative Data Analysis and Discussion

Descriptive statistics showed that the mean score increased from the pre-test (M = 14.5, SD = 1.36) to the post-test (M = 18.1, SD = 1.47). This observed increase suggests an improvement in students’ conceptual understanding after engaging with the molecular model intervention.

The paired-samples t-test revealed a statistically significant difference between pre-test and post-test scores, t (18) = 31.57, p = 0.000, which is way less than 0.05. When a p-value is lower than the value of alpha, the significance level, the indication is that there is an extremely small probability that the difference is due to chance (Pallant, 2020).

Because the obtained p-value was far below 0.05, the null hypothesis was rejected. This means that the

improvement in students' scores is unlikely to be due to random variation and can reasonably be attributed to the instructional intervention (Field, 2018). The mean difference of 3.63 out of 20 is further testimony that students performed substantially better after the introduction of molecular models.

The findings from this study align with those obtained in previous studies, which emphasize the importance of incorporating practical and visual strategies in chemistry instruction to enhance conceptual understanding (Gilbert, 2008; Taber, 2007). The results of this study therefore contribute further empirical evidence supporting the integration of molecular models in secondary school chemistry classrooms.

While it is evident from quantitative data that the improvement in students' academic achievement was significant after the intervention, it remains important to consider that conceptual change in chemistry can be gradual and complex (Taber, 2007). Despite a notable improvement in the test scores, there is a possibility that some misconceptions may still persist, highlighting the need for continued teacher scaffolding and guided discussion when using physical models.

8.4. Qualitative Data Presentation and Analysis

8.4.1. Classroom Observations

As a way to complement quantitative findings obtained from pre- and post-tests, the researcher conducted classroom observations which focused on how students interacted with models, how they were able to construct accurate molecular representations during discussions and their common misconceptions.

Most students demonstrated curiosity and excitement about handling models during the first day of observation. They were observed working in small groups where they attempted with zeal to construct simple molecules such as water, hydrogen and methane. However, several misconceptions emerged during this initial session. Some students incorrectly created molecules of hydrogen, putting a double bond instead of a single bond. They also failed to leave space for lone pairs while creating models for water molecules. One group of students was hesitant to handle models, an indication of a lack of confidence in translating abstract textbook diagrams into three-dimensional structures.

Although there were challenges, more than half of the students were actively engaged. They asked intelligent questions, discussed strategies within their groups and continuously attempted to correct their models, albeit with some scaffolding. This aligns with previous research suggesting that hands-on activities increase engagement and promote active problem-solving and critical thinking (Gilbert, 2008; Taber, 2007).

On the second day, students were tasked with constructing more complex molecules with double and triple bonds such as carbon dioxide and nitrogen. The researcher observed that students became more confident and were able to use the concept of valence electrons in determining the number of bonds between atoms. Few errors were recorded as compared to day 1. The level of collaboration also increased, and so was the frequency of collaboration. Students became more involved in independent discussions and needed less help from the teacher.

Nevertheless, certain misconceptions persisted. Students were given a task to construct a water molecule as a follow up to day 1. Some students continued to misinterpret lone pairs of electrons, leading to inaccuracies in the spatial arrangement of molecules.

The researcher noted that group discussions appeared to scaffold learning effectively. Students who initially struggled began to verbalize the steps for constructing molecules, suggesting that peer interaction and guided exploration helped solidify their understanding. These findings are consistent with the constructivist theory, which emphasizes that collaborative learning enables students to build understanding through social interaction and hands-on experiences (Bruner, 1966).

On the third day, students engaged in applying their knowledge to novel molecules such as ethane, ethene and ethanol, where there was a mixture of single and double bonds as well as lone pairs of electrons. Students were able to merge the knowledge gained during days 1 and 2 to construct these molecules. Most misconceptions were largely resolved, but occasional errors related to the octet rule, particularly in molecules containing both single and double bonds, were observed. A few of the students miscounted electrons when placing double bonds, while some incorrectly predicted molecule shapes. Nevertheless, there was a decrease in the frequency and severity of the misconceptions compared to the previous days.

Students were actively discussing and explaining their reasoning, often using terms like "lone pairs," "bond angles," and "shared electrons" correctly. The models appeared to facilitate self-correction and provide visualization support of abstract concepts. These observations align with prior findings that practical, hands-on tools enhance conceptual understanding in science, chemistry included, by helping to close the gap between symbolic representations and real-world structures (Gilbert, 2008; Johnstone, 1991).

8.4.2. Questionnaire Data Presentation, Analysis and Discussion

The results of the questionnaire provide valuable insight into how students interpreted and experienced the use of molecular models in learning covalent bonding. The findings showed different sides of the coin: strengthened understanding and persistent misconceptions. All responses are reported using the exact number of participants ($n = 19$) as well as their corresponding percentages.

8.4.3. Likert-Scale Findings

The Likert-scale section of the questionnaire explored students' perceptions of how accurately molecular models represent real molecules, as well as any difficulties and/or misconceptions that may have arisen during their use.

The responses of students to whether models show the actual size of atoms in real molecules were evenly divided. Eight students (42.1%) did not agree with the statement, suggesting that they understood that the colored spheres in the models are only representations and not true reflections of atomic size. However, an equal proportion, 8 students (42.1%), either agreed or strongly agreed, indicating that a similar number may still interpret the model atoms as showing real atomic dimensions. The remaining 3 students (15.8%) were unsure. This division shows that students find it difficult to differentiate between a scientific model and the reality it represents (Gilbert & Justi, 2016).

When students were asked whether they think bonds in real molecules are rigid and fixed in the same way as the sticks used in molecular models, ten out of 19 responses (52.6%) were in agreement (agreed or strongly agreed) with

this statement. This implies that the majority of the class perceive chemical bonds as stiff, rod-like structures that are not flexible. In contrast, 7 students (36.8%) either disagreed or strongly disagreed, indicating correct scientific reasoning that chemical bonds are not rigid objects but rather regions of electron density. Two students (10.5%) were unsure. This misconception of viewing the physical properties of molecular models to be the same as real molecules has been frequently reported in chemistry education research (Harrison & Treagust, 2000; Taber, 2007).

When considering bond lengths of single and double bonds being similar, 9 students (47.4%) either agreed or strongly agreed, 6 students (31.6%) disagreed, while 4 (21.1%) were unsure. Nearly half of the respondents therefore appeared to associate identical stick lengths with the length of the bonds in real molecules. This assertion is consistent with findings from previous studies showing that uniform model components can unintentionally reinforce oversimplified ideas about the properties of covalent bonds (Coll & Treagust, 2003).

From the responses, students showed a more pronounced misconception about double bonds compared to single bonds. Twelve students (63.1%) either agreed or strongly agreed that a double bond in ethene means that there are two separate sticks in real molecules that connect to the same atoms. Only 6 students (31.6%) either disagreed or strongly disagreed, while 1 student (5.3%) was not sure. This suggests that many students may wrongly interpret double bonds as two physical connections instead of being areas of increased electron density between two atoms. This kind of interpretation of ball-and-stick models has been widely documented in previous studies as an area of concern, leading students to regard chemical bonding as a difficult topic (Harrison & Treagust, 2000; Taber & Watts, 2000).

In relation to bond angles, 13 students (68.4%) either agreed or strongly agreed that molecular models depict exact bond angles in molecules such as water and carbon dioxide. Five students (26.3%) disagreed, and 1 student (5.3%) wasn't sure. Although these statistics are encouraging that students do recognize the geometric arrangement of atoms, the large chunk of responses agreeing that the angles are exact is worrying, as it suggests that many may not fully appreciate that models provide approximations rather than precise representations. These findings indicate that without explicit discussion, students may assume that models depict fixed and exact structures (Gilbert & Justi, 2016).

The statement that atoms in molecules are like those in models, which are immobile and static, also revealed mixed understanding. Nine students (47.4%) agreed with this idea, 5 (26.3%) disagreed, and 5 students (26.3%) were unsure. Nearly half of the respondents appeared to view molecules as being static, which is scientifically incorrect as atoms are constantly moving due to vibrational and rotational energy (Taber, 2007).

With regard to the sharing of electrons during covalent bonding, 11 of the students (57.9%) either agreed or strongly agreed that the models clearly represent electron sharing, while 4 students (21.1%) disagreed and the other 4 students (21.1%) were unsure. Although more than half felt supported by the models in understanding covalent bonding, the other 42.1% either disagreed or were not sure. This is a reflection of the limitation that molecular models are an effective tool in illustrating structure and shape rather than submicroscopic processes such as electron distribution (Johnstone, 1991).

When considered collectively, the above percentages indicate that although molecular models are useful in assisting students to visualize three-dimensional structures better, a notable proportion of the class still held misunderstandings about what these models actually represent. These findings agree with those in existing literature, which highlight that even if instructional models are an effective way to support conceptual understanding, their efficiency is realized when their strengths and limitations are made explicit during teaching (Gilbert & Justi, 2016; Taber, 2007). Without guided explanation, students may transfer the properties of the model directly to the scientific concept, leading to alternative conceptions rather than deeper understanding.

8.4.4. Open-Ended Responses

The open-ended responses provided detailed information on how students experienced the use of molecular models during the lessons. A lot of students explained, in their own words, that “the models helped them to see the 3D shape of covalent molecules and to better understand their structure.” Such comments imply that hands-on experience made abstract concepts more concrete and easier to visualize. Being able to physically build and manipulate the molecules appeared to support students in building spatial understanding, which is a key challenge in learning chemistry. This observation is consistent with research indicating that physical manipulatives can reinforce students' spatial visualization skills and help them improve their understanding of molecular geometry (Wu & Shah, 2004).

At the same time, it is important to note that not all the feedback was positive. A large number of students expressed some confusion, particularly regarding the nature of chemical bonds and how electrons are shared between atoms. Some stated that sticks in the physical models made the bonds look like they were static, suggesting that they may have interpreted the physical properties of the model as a true reflection of molecular behavior. This mirrors the patterns observed from the Likert-scale responses, where quite a large number of students associated real chemical bonds with rigidity. The agreement between what students selected in the scaled responses and what they explained in their comments adds to the credibility of the study findings. When both qualitative and quantitative data point to similar themes, it strengthens the overall interpretation of the results of the study (Creswell & Plano Clark, 2018).

9. Conclusion

This study, through the use of pre- and post-test assessments, examined the effectiveness of using molecular models as a tool in the teaching and learning of covalent bonding. Findings from the quantitative data showed a statistically significant improvement in students' post-test scores compared to their achievement in the pre-test, leading to the rejection of the null hypothesis. This indicates that the gains were unlikely due to chance and were associated with the instructional intervention. These findings are consistent with research suggesting that concrete models can enhance understanding of abstract chemistry concepts, particularly those requiring spatial reasoning (Gilbert & Justi, 2016; Wu & Shah, 2004).

Although there was a notable improvement in the test scores, that did not reflect complete conceptual

understanding among students. Questionnaire and observational data revealed that while students remained engaged during the lessons and seemed to enjoy using the models, several continued to hold representational misconceptions. Some interpreted bonds as rigid or viewed models as exact depictions of molecular reality, a reflection of persistent misconceptions reported in prior studies (Harrison & Treagust, 2000; Taber & Watts, 2000). Molecular models proved to be valuable instructional tools, but the effectiveness of their application is dependent on explicit discussion of their limitations and integration with symbolic and submicroscopic explanations (Johnstone, 1991).

10. Recommendations

Based on the findings of this study, the researcher made several recommendations for classroom practice and for future research.

Teachers should continue to use molecular models when teaching covalent bonding, as they improve students' academic performance. However, there is a need for teachers to guide them and to explain that they do not reflect the structure of real molecules to prevent the development of alternative misconceptions.

Furthermore, instruction should connect the handling of models with electron sharing and motion to promote a deeper conceptual understanding.

Lastly, teachers should make use of formative assessments to identify misconceptions early, while classroom dialogue can help students articulate and refine their understanding. Future research could involve larger samples, use control and experimental groups and explore the use of digital and physical models to examine how different representational tools influence students' learning of chemical bonding.

References

- Bergqvist, A., Drechsler, M., De Jong, O., & Rundgren, S.-N. C. (2013). Representations of chemical bonding models in school textbooks—help or hindrance for understanding? *Chemistry Education Research and Practice*, 14(4), 589-606. <https://doi.org/10.1039/c3rp20159g>
- Bruner, J. S. (1966). *Toward a theory of instruction*. Cambridge, MA: Harvard University Press.
- Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education* (8th ed.). London: Routledge.
- Coll, R. K., & Treagust, D. F. (2003). Investigation of secondary school, undergraduate, and graduate learners' mental models of ionic bonding. *Journal of Research in Science Teaching*, 40(5), 464-486. <https://doi.org/10.1002/tea.10085>
- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Thousand Oaks, CA: SAGE Publications.
- Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). Thousand Oaks, CA: SAGE Publications.
- Dillman, D. A., Smyth, J. D., & Christian, L. M. (2014). *Internet, phone, mail, and mixed-mode surveys: The tailored design method* (4th ed.). Hoboken, NJ: John Wiley & Sons.
- Field, A. P. (2018). *Discovering statistics using IBM SPSS Statistics* (5th ed.). London, England: SAGE Publications.
- Gadzirayi, C. T., Bongo, P. P., Ruyimbe, B., Bhukuvhani, C., & Mucheri, T. (2016). *Diagnostic study on status of STEM in Zimbabwe*. Bindura University of Science Education and Higherlife Foundation.
- Gilbert, J. K. (2005). *Visualization in science education*. Dordrecht, The Netherlands: Springer.
- Gilbert, J. K., & Justi, R. (2016). *Modelling-based teaching in science education*. Cham, Switzerland: Springer International Publishing.
- Gilbert, N. (2008). *Researching social life* (3rd ed.). London, England: SAGE Publications.
- Gudyanga, E., & Madambi, T. (2014). Students' misconceptions about bonding and chemical structure in chemistry. *The Dyke*, 8(1), 24-40.
- Harrison, A. G., & Treagust, D. F. (2000). A typology of school science models. *International Journal of Science Education*, 22(9), 1011-1026. <https://doi.org/10.1080/095006900416884>
- Ishtiaq, M. (2019). Book review Creswell, J. W. (2014). *Research design: Qualitative, quantitative and mixed methods approaches* (4th ed.). Thousand Oaks, CA: Sage. *English Language Teaching*, 12(5), 40-41. <https://doi.org/10.5539/elt.v12n5p40>
- Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher*, 33(7), 14-26. <https://doi.org/10.3102/0013189X033007014>
- Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, 7(2), 75-83. <https://doi.org/10.1111/j.1365-2729.1991.tb00230.x>
- Karacop, A., & Doymus, K. (2013). Effects of jigsaw cooperative learning and animation techniques on students' understanding of chemical bonding and their conceptions of the particulate nature of matter. *Journal of Science Education and Technology*, 22(2), 186-203. <https://doi.org/10.1007/s10956-012-9385-9>
- Kuit, V. K., & Osman, K. (2021). CHEMBOND3D e-module effectiveness in enhancing students' knowledge of chemical bonding concept and visual-spatial skills. *European Journal of Science and Mathematics Education*, 9(4), 252-264. <https://doi.org/10.30935/scimath/11263>
- Maxwell, J. A. (2013). *Qualitative research design: An interactive approach* (3rd ed.). Thousand Oaks, CA: SAGE Publications.
- Mercer, J. (2007). The challenges of insider research in educational institutions: Wielding a double-edged sword and resolving delicate dilemmas. *Oxford Review of Education*, 33(1), 1-17. <https://doi.org/10.1080/03054980601094651>
- Mertens, D. M. (2014). *Research and evaluation in education and psychology: Integrating diversity with quantitative, qualitative, and mixed methods* (4th ed.). Thousand Oaks, CA: SAGE Publications.
- Newman, D. L., Stefkovich, M., Clasen, C., Franzen, M. A., & Wright, L. K. (2018). Physical models can provide superior learning opportunities beyond the benefits of active engagements. *Biochemistry and Molecular Biology Education*, 46(5), 435-444. <https://doi.org/10.1002/bmb.21159>
- Ngwenya, J. T., Makamure, C., & Tarusikirwa, M. C. (2025). Unpacking the disconnection: An exploration of barriers to practical work integration in A-Level chemistry teaching in Gweru District public schools. *Asian Journal of Education and Social Studies*, 51(7), 127-141. <https://doi.org/10.9734/ajess/2025/v51i72108>
- Özmen, H. (2004). Some student misconceptions in chemistry: A literature review of chemical bonding. *Journal of Science Education and Technology*, 13(2), 147-159. <https://doi.org/10.1023/B:JOST.0000031255.92943.6d>
- Pallant, J. (2020). *SPSS survival manual: A step by step guide to data analysis using IBM SPSS* (7th ed.). London, England: McGraw-Hill/Open University Press.
- Roche Allred, Z. D., Farias, A. J., Kararo, A. T., Parent, K. N., Matz, R. L., & Underwood, S. M. (2021). Students' use of chemistry core ideas to explain the structure and stability of DNA. *Biochemistry and Molecular Biology Education*, 49(1), 55-68. <https://doi.org/10.1002/bmb.21391>
- Southam, A., & Costley, J. (2024). The role of modelling during instruction in collaborative creativity. *Thinking Skills and Creativity*, 54, 101660. <https://doi.org/10.1016/j.tsc.2024.101660>
- Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: SAGE Publications.
- Taber, K. S. (2007). *Classroom-based research and evidence-based practice: A guide for teachers*. London, England: SAGE Publications.
- Taber, K. S., & Watts, M. (2000). Learners' explanations for chemical phenomena. *Chemistry Education: Research and Practice in Europe*, 1(3), 329-353. <https://doi.org/10.1039/B0RP90015J>
- Tashakkori, A., & Teddlie, C. (2010). *SAGE handbook of mixed methods in social & behavioral research* (2nd ed.). Thousand Oaks, CA: SAGE Publications.
- Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences*. Thousand Oaks, CA: SAGE Publications.

- Tsaparlis, G., Pappa, E. T., & Byers, B. (2018). Teaching and learning chemical bonding: Research-based evidence for misconceptions and conceptual difficulties experienced by students in upper secondary schools and the effect of an enriched text. *Chemistry Education Research and Practice*, 19(4), 1253-1269. <https://doi.org/10.1039/c8rp00035b>
- Wu, H.-K., & Shah, P. (2004). Exploring visuospatial thinking in chemistry learning. *Science Education*, 88(3), 465-492. <https://doi.org/10.1002/sce.10126>
- Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Thousand Oaks, CA: SAGE Publications.