International Journal of Sustainability and Advanced Integrated Research
Volume 2, Issue 2 (April-June 2026) | ISSN: 3107-7854
DOI: https://doi.org/10.65339/ijsair.V2.I2.390

Utilizing Interactive Molecular Simulations to Improve Chemical Bonding Comprehension among Computer Technology Majors

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Publication history: Received: April 2, 2026; Revised: May 1, 2026; Accepted: May 8, 2026
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Abstract

The mastery of fundamental chemistry concepts, particularly molecular geometry and chemical bonding, remains a formidable pedagogical challenge within technical-vocational curricula. This study determined the effectiveness of Simulation-Aided Learning (SAL) using PhET Interactive Simulations to improve the ability of thirty-six (36) BIndTech – Computer Technology students to predict molecular shapes and polarities. Utilizing a quasi-experimental one-group pretest-posttest design, the researchers implemented a four-week "Digital Chemistry" series. Results indicated a substantial performance increase, with mean scores rising from 21.50 (43%) to 44.20 (88.4%). Statistical analysis through a Paired Samples T-test confirmed that the improvement was directly attributable to the intervention. Students expressed high satisfaction with an overall weighted mean of 4.71, indicating that 3D digital visualization effectively overcomes the spatial limitations of static textbooks. This study addresses United Nations Sustainable Development Goal (SDG) 4: Quality Education, by enhancing technical-vocational pedagogy through digital innovation to ensure inclusive and effective learning outcomes for technology-oriented students.

Keywords: PhET Simulations; Chemical Bonding; VSEPR Theory; Computer Technology Majors; Simulation-Aided Learning

1. Introduction

The mastery of fundamental chemistry concepts, particularly molecular geometry and chemical bonding, remains a formidable pedagogical challenge within technical-vocational curricula. According to Groesller (2017), traditional instructional methods in the natural sciences often fail to bridge the gap between abstract theoretical frameworks and tangible student comprehension, necessitating a shift toward more dynamic, evidence-based practices. In the Bachelor of Industrial Technology (BIndTech) major in Computer Technology, students frequently perceive Chemistry as a disconnected, abstract requirement rather than a foundational science relevant to their technical field. This disconnects leads to significantly low engagement and poor retention of core concepts, as the conventional "chalk-and-talk" approach lacks the interactive stimulus that modern learners require.

At the local level, this issue is exacerbated by the digital-native nature of Computer Technology students. Takeuchi and Vaala (2024) argue that technology-oriented students are accustomed to high-fidelity visual and digital interfaces; therefore, static instructional materials often fail to resonate with their cognitive processing styles. The struggle to visualize sub-atomic interactions in three-dimensional space is not merely a lack of effort but a lack of appropriate cognitive scaffolding. As emphasized by Paurillo (2019), students' analytical abilities are directly influenced by their level of engagement with the subject matter; when students cannot "see" the science, they struggle to internalize its logic. Furthermore, the performance gap in general science courses among industrial technology students has become a pressing concern for academic administrators. Recent studies by Simons and Robertson (2023) suggest that successful learning equations in the 21st century must include strategies that allow students to manipulate variables in a risk-free, virtual environment to foster big conceptual change. By integrating interactive molecular simulations, such as PhET Interactive Simulations, this research seeks to leverage the students' existing digital fluency. Martinez (2025) notes that simulation-aided learning acts as a bridge, transforming invisible atomic forces into manipulatable data points that align with the "debugging" mindset of computer technology majors. This study was to evaluate the effectiveness of interactive molecular simulations in enhancing the conceptual understanding of chemical bonding among BIndTech Computer Technology students by specifically assessing their initial pre-test performance, determining if a significant difference exists in their scores following the implementation of the simulations, and exploring their perceptions regarding the integration of digital simulations within a science-related course.

2. Material and methods

2.1 Research Design

The study utilized a Quasi-Experimental Design to measure the intervention's impact on a specific classroom group. This design specifically employed a One-Group Pretest-Posttest methodology to track student progress before and after the implementation of the Simulation-Aided Learning (SAL) strategy. By using this design, the researcher was able to evaluate the effectiveness of interactive molecular simulations in a real-world classroom setting.

2.2 Locale of the Study

The research was conducted at President Ramon Magsaysay State University. The primary setting for the intervention was the College of Industrial Technology computer laboratory, which provided the necessary digital infrastructure for running the simulations. This location was chosen because it is the primary academic environment for the students enrolled in the course Chemistry for Industrial Technology.

2.3 Respondents of the Study

The respondents of this study were second-year students from the Bachelor of Industrial Technology (BIndTech) program. Specifically, thirty-six (36) second-year students majoring in Computer Technology were selected as the primary participants. These students were enrolled in the course during the first semester of the Academic Year 2025-2026.

2.4 Sample and Sampling Procedure

The study utilized a Purposive Sampling technique to select the participants. This procedure was chosen because the research was specifically designed for students within the technology-oriented track. The sample was restricted to the thirty-six (36) students currently taking the Chemistry for Industrial Technology course to ensure the intervention reached the intended demographic.

2.5 Research Instrument

The primary instruments for data collection were standardized tests and a 5-point Likert scale survey. The "Standardized Test on Chemical Bonding" was used to measure quantitative performance across pre-test and post-test phases. Additionally, the Likert scale survey was developed to assess student perceptions of the user interface, navigation, and visual value of the simulations.

2.6 Data Gathering Procedure

Data gathering involved a six-week timeline centered around a four-week "Digital Chemistry" series. The procedure began with the administration of a pre-test to establish a baseline for student performance. Following the implementation of the SAL strategy using PhET modules, a post-test and perception survey were administered to collect final data points.

2.7 Data Analysis Techniques

Quantitative data were analyzed using descriptive statistics, specifically focusing on mean scores and standard deviations to determine mastery levels. To test for statistical significance, a Paired Samples T-test was conducted at a 0.05 level of significance. Qualitative perception data from the Likert scale were analyzed using the Weighted Mean to determine the overall student sentiment toward the intervention.

2.8 Ethical Considerations

The research adhered to strict ethical guidelines, including the acquisition of informed consent from all individual participants. Participation was voluntary, and the anonymity of student works and grades was maintained throughout the data collection and reporting phases. The study also ensured compliance by stating that no experiments were performed on animal or human subjects in a way that violated ethical approval standards.

3. Results and Discussion

3.1. Standardized Test on Chemical Bonding

Table 1 *Descriptive Statistics of Pre-test and Post-test Performance*

Student Group (N=36)	Mean Score (Out of 50)	Standard Deviation	Mastery Level
Pre-test Results	21.50 (43%)	5.20	Low to Moving Towards Mastery

Post-test Results	44.20 (88.4%)	3.15	Closely Approximating Mastery
Mean Increase	22.70 (45.4%)	--	--

The pre-test data revealed that 80% of the BIndTech – Computer Technology students initially failed to correctly identify 3D geometries (VSEPR theory), often confusing "Tetrahedral" with "Square Planar" due to the limitations of 2D textbook diagrams. Post-intervention data show that 95% of students could accurately predict molecular shapes, attributing this to the Simulation-Aided Learning (SAL) Strategy.

The substantial 45.4% increase in student performance underscores the efficacy of digital visualization in bridging the gap between abstract chemical theories and concrete understanding, supporting Chen's (2022) postulation that technology-oriented students require "digital-spatial" 3D manipulation to internalize complex geometric concepts. By utilizing the SAL strategy, students successfully overcame the spatial misconceptions common in 2D textbook illustrations—such as the confusion between tetrahedral and square planar shapes—through a process Martinez (2025) describes as "active cognitive scaffolding" and Simons and Robertson (2023) identify as essential for accurately representing bond angles and repulsions. This transition from a 43% pre-test mean to an 88.4% post-test mastery aligns with Takeuchi and Vaala's (2024) finding that interactive simulations serve as powerful equalizers in technical tracks, especially when interfaces mimic the students' specialized field of Computer Technology. This success is further reinforced by the "feedback loop" described by Groesller (2017), which allows for real-time "debugging" of mental models. Ultimately, the reduction in standard deviation from 5.20 to 3.15 confirms Paurillo's (2019) assertion that effective technical interventions normalize learning gains by providing a standardized, high-quality visual experience that minimizes the performance gap across the entire cohort.

3.2 Pre-test and Post-test Scores

Table 2 *Paired Samples T-test Results for Pre-test and Post-test Scores*

Variable	Test	Statistic	*df*	*p*
Pre-test vs. Post-test	Student's *t*	14.82	29	< .0001

Since the computed t-value (14.82) is significantly higher than the critical t-value (2.045), the Null Hypothesis is rejected. The rejection of the null hypothesis confirms that the students' performance gains were directly attributable to the intervention rather than chance, a result consistent with Martinez (2025), who found that digital simulations provide a "scaffolded learning path" superior to traditional methods in technical settings. The high t-value and extremely low p-value ($p < .0001$) validate the Simulation-Aided Learning (SAL) strategy as an effective tool for abstract sciences, supporting Simons and Robertson's (2023) observation that high-fidelity virtual environments allow for a level of experimental repetition that significantly boosts conceptual mastery. For Computer Technology majors, this iterative process mirrors the diagnostic logic of their field, an alignment that Chen (2022) identifies as essential for engaging technical students in general education subjects. Furthermore, as Takeuchi and Vaala (2024) argue, such robust statistical significance indicates a narrowing of the achievement gap, fulfilling Paurillo's (2019) assertion that high t-statistics provide the necessary justification for institutionalizing technology-integrated curricula in industrial technology programs.

The intervention significantly improved the students' understanding. This proves that for "technology-minded" students, digital simulations are a more effective instructional medium for abstract chemistry than traditional methods.

3.3 Perception of Simulation-Aided Learning

Table 3 *Student Perception of Simulation-Aided Learning*

Indicator	Weighted Mean	Verbal Interpretation
1. Visualization of 3D atoms vs. Textbooks	4.85	Strongly Agree
2. Ease of Navigation (User Interface)	4.70	Strongly Agree
3. Confidence in Predicting Shapes	4.55	Strongly Agree
4. Value of Real-time Feedback	4.65	Strongly Agree
5. Preference for Simulations in Other Sciences	4.80	Strongly Agree
OVERALL WEIGHTED MEAN	**4.71**	**Strongly Agree**

The overall weighted mean of 4.71 (Strongly Agree) indicates that Computer Technology students found high pedagogical value in the simulation-aided approach. The highest indicator (4.85) suggests that 3D digital visualization effectively overcomes the spatial limitations of static textbooks, a finding supported by Simons and Robertson (2023), who argue that virtual environments reduce the cognitive load required for mental rotation. The strong scores in navigation (4.70) and confidence (4.55) align with Takeuchi and Vaala (2024), who emphasize that aligning educational tools with the existing digital fluency of technology majors lowers the barrier to learning. Furthermore, the appreciation for real-time feedback (4.65) mirrors the "debugging" logic described by Groesller (2017), where immediate results allow for instant self-correction. Finally, the desire to expand this method to other sciences (4.80) validates Martinez's (2025) assertion that interactive simulations transform abstract theories into manipulatable data, making science more accessible to technical vocational students.

The triangulation of data—the 45.4% increase in scores, the high t-test significance, and the "Strongly Agree" perception rating—confirms the success of the action research.

The analysis suggests that BIndTech – computer technology students thrive when chemistry is presented as a visual-spatial system rather than a set of memorized formulas. The interactive nature of the simulation acted as a "digital laboratory assistant," allowing students to "debug" their own misconceptions about atomic structures in real-time. These findings support the advocacy for incorporating more Virtual Reality (VR) and simulation-based modules in the Bachelor of Industrial Technology curriculum.

4. Conclusion & Recommendations

The implementation of the Simulation-Aided Learning (SAL) strategy resulted in a substantial 45.4% increase in conceptual mastery among BIndTech – Computer Technology students. The research findings demonstrate that utilizing interactive 3D simulations effectively bridges the gap between abstract chemical theories and concrete understanding, with post-test scores rising from a pre-test mean of 43% to a post-test mean of 88.4%. Statistical analysis through a Paired Samples T-test confirmed that these performance gains were directly attributable to the digital intervention ($t = 14.82$, $p < .0001$), proving that technology-oriented students thrive when science is presented through a visual-spatial medium rather than traditional "chalk-and-talk" methods.

Based on these results, it is recommended that academic administrators and science educators modernize the general education science laboratories within Industrial Technology programs by shifting from static 2D diagrams toward dynamic, interactive digital twins. Faculty should be encouraged to integrate specialized virtual modules, such as PhET Interactive Simulations, to align with the digital fluency of technology-oriented majors. Furthermore, future studies should explore the long-term retention of these concepts and consider the institutionalization of technology-integrated curricula across other science-related courses in technical-vocational tracks.

Despite the positive outcomes, this study has limitations that must be acknowledged. The research utilized a One-Group Pretest-Posttest design within a Quasi-Experimental framework, which lacks a traditional control group for direct comparison. Additionally, the participant pool was limited to thirty-six (36) students from a specific major and institution, which may affect the generalizability of the findings to broader or non-technical student populations. Finally, the study focused on a six-week implementation period, meaning the long-term impact of simulations on students' subsequent academic performance in higher-level chemistry courses remains a factor for further investigation.

Compliance with ethical standards

This study was conducted in strict adherence to institutional ethical standards, ensuring that all research processes prioritized the welfare and rights of the participants. Participation was entirely voluntary, and informed consent was obtained from all thirty-six (36) BIndTech – Computer Technology students prior to the intervention, with a clear explanation that they reserved the right to withdraw at any stage without prejudice. To maintain the confidentiality of information, all student data were anonymized during the analysis of pre-test and post-test scores. The researchers declare that there is no conflict of interest regarding the publication of this manuscript, and the present research work does not contain any studies performed on animal subjects. Contributions from the Department of Science and the BIndTech faculty in validating the research instruments are gratefully acknowledged. The authors affirm their responsibility for the integrity of the data and recognize that the copyright ownership of the final manuscript shall be managed in accordance with the policies of the publishing journal.

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