

The Effect of PhET Chemistry Simulations and Learning Motivation on Senior High School Students' Chemistry Conceptual Understanding of Molecular Shape

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Abstract

This study aimed to analyze the effect of PhET Chemistry Simulations and learning motivation on senior high school students' understanding of molecular shape concepts. The study employed a quasi-experimental method with a 2×2 factorial design involving 60 tenth-grade students divided into an experimental class using PhET Chemistry Simulations and a control class receiving conventional instruction. Data were collected through a chemistry conceptual understanding test and a learning motivation questionnaire and analyzed using descriptive statistics and Two-Way ANOVA at a significance level of 0.05. The results showed that students taught using PhET Chemistry Simulations achieved higher conceptual understanding than those taught conventionally. The highest improvement was found in highly motivated students in the experimental group (58.89 points), followed by low-motivation students in the experimental group (40.33 points). Meanwhile, the conventional groups showed improvements of 52.00 points and 35.71 points, respectively. The average posttest score of the experimental class (76.80) was higher than that of the control class (68.67). Statistical analysis revealed that instructional media significantly affected students' chemistry conceptual understanding ($F = 11.091$; $p < 0.05$), and learning motivation also showed a significant effect ($F = 112.853$; $p < 0.05$). However, no significant interaction was found between instructional media and learning motivation ($F = 0.216$; $p > 0.05$). These findings indicate that PhET Chemistry Simulations effectively improve students' conceptual understanding across different motivational levels.

Keywords: Learning Motivation; Molecular Shape; PhET Chemistry Simulations; Senior High School Students; Chemistry Conceptual Understanding.

INTRODUCTION

Education significantly improves the quality of human resources by implementing effective, meaningful pedagogical practices. In the domain of science education, particularly in chemistry, it is crucial for students to not only master theoretical concepts but also to understand chemical phenomena as they manifest in their everyday experiences (Bagossi et al., 2022; Rahmawati et al., 2022). However, the chemistry curriculum at the high school level continues to face many challenges, particularly regarding the understanding of basic concepts (Risvayani et al., 2023; Pane et al., 2025; Pratomo et al., 2025). A large number of chemical concepts are inherently abstract, microscopic in nature, and require advanced visualization skills, including but not limited to atomic structure, chemical bonding, stoichiometry, chemical equilibrium, and reaction kinetics. These difficulties often result in students experiencing significant difficulty in achieving a deep understanding of the material, consequently leading to a decline in academic performance and understanding of chemical principles (Atika & Latisma, 2022; Apriani et al., 2024).

This problem is exacerbated by pedagogical frameworks that primarily emphasize teacher-centered instruction (Byusa et al., 2022; Khatimah & Chisbiyah, 2024). The prevalence of lecture-based methodologies results in reduced student engagement in autonomous knowledge

construction (Klein et al., 2023; Johnson & Coulter-Kern, 2024). As a result, students tend to absorb information rather than actively participate in conceptual exploration passively. Indeed, the study of chemistry requires engagement in activities such as observation, experimentation, and visualization to facilitate a more concrete understanding of abstract concepts. Therefore, there is a critical need for educational innovations that can foster interactive, stimulating learning experiences and encourage active student engagement (Laid & Adlaon, 2025).

One specific manifestation of educational innovation that can be implemented is the incorporation of technology-enhanced learning resources. The application of technological tools in the educational process can facilitate educators in delivering content in a more visually engaging, interactive, and contextual format (Sailer et al., 2024). Simulation-based educational resources are considered effective in helping learners understand abstract scientific principles, as they have the capacity to depict phenomena that are challenging to directly observe in a laboratory setting. A prominent simulation resource widely used in the domain of chemistry education is the PhET Chemistry Simulation, developed by the University of Colorado Boulder (Sailer et al., 2024).

The implementation of PhET Chemistry Simulations provides students with the opportunity to engage in experiential learning (learning through active participation). Interactive simulations help students visualize chemical phenomena, conduct virtual experiments independently, and correlate macroscopic, microscopic, and symbolic representations in chemistry education. This pedagogical medium helps reduce misunderstandings and promotes deeper conceptual understanding by allowing students to investigate parameters in experiments that are impractical to run directly in a laboratory setting (Meronda et al., 2025; Thuan et al., 2026). Furthermore, simulation-based pedagogy is also able to increase student engagement and dynamism throughout the educational experience. This occurs because students do not simply assume the role of passive recipients of information, but are actively engaged in interactions with the materials and results of the experiments conducted virtually, thus encouraging their participation in a more active and meaningful learning process (Rahmawati et al., 2022).

In addition to examining media factors, the construct of learning motivation emerged as a critical determinant influencing students' success in understanding chemistry concepts. Learning motivation encompasses intrinsic and extrinsic drives that foster a spirit of inquiry in students, driving them toward achieving educational goals. Students who exhibit increased levels of learning motivation tend to manifest proactive attitudes, resilience, and a deep curiosity regarding the subject matter being studied (Putra Suharnadi et al., 2024; Kong et al., 2025). Conversely, decreased learning motivation results in students exhibiting a lack of focus, passivity, and an increased tendency to encounter challenges in understanding educational content (Rahmi & S, 2022; Tang et al., 2025). Therefore, there is a significant correlation between learning motivation and students' level of understanding of chemical phenomena.

Numerous prior studies have demonstrated that the implementation of interactive educational media can improve students' learning outcomes and understanding of scientific concepts in science education (Festiyed et al., 2023; Putri et al., 2024). A clear research gap remains, particularly regarding how interactive digital simulations and students' learning motivation jointly contribute to conceptual understanding in chemistry learning. Moreover, limited empirical studies have applied a factorial experimental approach to investigate the simultaneous and comparative effects of learning media and motivation within specific abstract chemistry topics such as molecular shape at the senior high school level.

Therefore, the novelty of this study lies in integrating PhET Chemistry Simulation and learning motivation within a 2×2 factorial quasi-experimental design to examine both main effects and interaction effects on students' conceptual understanding of molecular shape. By combining technological pedagogical innovation with psychological learning factors, this study provides new empirical evidence on how digital simulation environments function across different motivational profiles of students. The findings are expected to contribute to the

development of evidence-based technology-enhanced chemistry instruction and offer practical implications for optimizing interactive learning strategies in secondary chemistry education

METHODS

This study applied a quantitative methodology using quasi-experimental techniques to investigate the impact of PhET Chemistry Simulation as a medium and the role of learning motivation on high school students' understanding of chemistry. This study used a 2×2 factorial design to analyze the main effects of learning media utilization and learning motivation, while simultaneously examining the interaction between these two variables on chemistry material understanding, particularly focusing on the subject of molecular shapes (Stiawan et al., 2022; Puja, 2024; Sequeira, 2024). The selection of a 2×2 factorial design was based on its adaptability in evaluating the individual and interactive effects of both variables, thus offering a deeper understanding of the interaction between educational technology and students' psychological factors in improving their conceptual understanding (Adamson H. & Prion, 2020; Rajagukguk et al., 2025). Many previous studies have shown that interactive simulations, such as PhET, can promote more comprehensive learning. In contrast, students' learning motivation is an important determinant in shaping their level of engagement and understanding of scientific content.

The study was conducted at SMAN 1 Pagai Selatan during the odd semester of the 2025/2026 academic year. The study population included all 10th-grade students, while the study sample was derived through a purposive sampling method, taking into account equivalence in academic proficiency and class characteristics (Ann Udeh, 2025; Sequeira, 2024). The study sample consisted of two distinct groups: an experimental cohort that was subjected to instruction using PhET Chemistry Simulation media and a control cohort that received traditional instructional methods. Quasi-experimental designs that combine purposive sampling and control groups, as evidenced in previous educational research, have demonstrated efficacy in assessing the impact of instructional interventions on student learning outcomes (Akbar et al., 2022; Triandika et al., 2023; Oh & Ahn, 2025). The factorial design of the research can be seen in the following table.

Table 1. 2×2 Factorial Design of the Research

Motivation to Learn	Learning Using PhET Chemistry Simulations (A ₁)	Conventional Learning (A ₂)
High (B ₁)	A ₁ B ₁	A ₂ B ₁
Low (B ₂)	A ₁ B ₂	A ₂ B ₂

Explanation:

A₁ = Learning using PhET Chemistry Simulations

A₂ = Conventional learning

B₁ = High learning motivation

B₂ = Low learning motivation

The independent variables identified in this study include students' utilization of educational media and their intrinsic motivation to learn. In contrast, the dependent variable is students' understanding of the molecular structure of matter in chemistry. The pedagogical approach uses PhET Chemistry Simulations through interactive exploration activities that help students visualize electron pair configurations, molecular geometry, and changes in molecular structure. In contrast, traditional teaching methods are implemented through a lecture-based approach using textbooks, supplemented by discussions and assignments. The integration of PhET educational media is demonstrated not only at the conceptual level but also empirically validated as effective in the field of chemistry education (Penn & Ramnarain, 2019; Sailema-Castro et al., 2025).

Data were collected through the use of a chemistry conceptual understanding assessment and a questionnaire related to learning motivation. The chemistry conceptual understanding

assessment was carefully designed based on indicators that measure the ability to understand the concept of molecular geometry, determine the arrangement of electron pairs, analyze molecular configurations according to VSEPR theory, and correlate molecular shape with the properties of chemical compounds. The Learning Motivation Questionnaire used a Likert scale that included indicators reflecting students' interest in learning, level of attention, persistence, curiosity, and perseverance in chemistry studies. Prior to implementation, all research instruments underwent rigorous testing for validity and reliability to ensure their efficacy (Lia et al., 2020; Setyorini et al., 2021).

The investigation began with a pretest for the experimental and control groups to assess the participants' initial competencies. Afterward, the experimental group received instruction through the use of PhET Chemistry Simulation, while the control group experienced traditional pedagogical methods (Ibrahim et al., 2025; Rizki et al., 2025). After the end of the instructional period, a posttest was administered to both groups to evaluate students' understanding of chemistry concepts after the intervention. Simultaneously, a learning motivation questionnaire was distributed to classify students into categories reflecting high and low levels of learning motivation. The research phase was conducted methodically, as illustrated in the following table.

Table 2. Stages of Research Implementation

Research Stage	Research Activities
Preparation	Preparation of learning tools, preparation of research instruments, instrument validation, and determination of research samples.
Implementation	Providing pretests, implementing learning using PhET Chemistry Simulations in the experimental class and conventional learning in the control class.
Final Stage	Administration of posttests, distribution of learning motivation questionnaires, data processing, and analysis of research results.

The research data were subjected to analysis through the application of descriptive and inferential statistical methodologies. Descriptive statistics serve to explain the mean value, standard deviation, and maximum and minimum scores related to student learning outcomes. Prior to the implementation of hypothesis testing, the data underwent an initial assessment involving normality testing and homogeneity testing to meet the prerequisites for parametric analysis. Hypothesis testing was conducted using a two-way analysis of variance (Two-Way ANOVA) at a significance threshold of 0.05, which aims to ascertain the effect of PhET Chemistry Simulation media utilization, the impact of learning motivation, and the interaction between PhET Chemistry Simulation media utilization and learning motivation on chemistry conceptual understanding among high school students.

RESULT AND DISCUSSION

Result

This section describes the findings obtained from examining the impact of PhET Chemistry Simulation and the construct of learning motivation on students' understanding of chemistry, where the investigation included two main cohorts: an experimental group engaged with PhET Chemistry Simulation and a control group following traditional pedagogical methods, with both groups stratified according to their respective levels of learning motivation. A comprehensive series of descriptive and statistical analyses, including assessment of pretest and posttest scores, normality evaluation, and homogeneity tests, are presented to provide a nuanced understanding of the differences in understanding achieved by these groups, corroborating previous research showing PhET Interactive Simulation facilitates dynamic access to different levels of conceptual representation and enhances the learning of chemical concepts, thus fostering better conceptual understanding in contrast to conventional teaching methods. PhET has been recognized as an instrument that promotes active engagement among students through interactive visualization and exploration of abstract concepts, which has been empirically linked to variations in educational outcomes in the context of pre-post-test quasi-experimental designs across various studies (Moore et al., 2014; Liswar et al., 2023).

Description of Student Learning Outcomes Statistics

The following table shows the distribution of mean pretest and posttest scores based on the learning media treatment and student learning motivation.

Table 3. Statistics of Student Learning Outcomes

Group	Instructional Media	Motivation to Learn	Pretest	Posttest	Improvement
A ₁ B ₁	PhET Chemistry Simulations	High	26,22	85,11	58,89
A ₁ B ₂	PhET Chemistry Simulations	Low	24,00	64,33	40,33
A ₂ B ₁	Conventional	High	27,25	79,25	52,00
A ₂ B ₂	Conventional	Low	20,86	56,57	35,71

The group taught using PhET Chemistry Simulations (A₁), including both high- and low-motivation students, demonstrated greater improvements in chemistry conceptual understanding compared to students receiving conventional instruction (A₂). The highest improvement was observed in the PhET group with high learning motivation (58.89), followed by the PhET group with low motivation (40.33). In comparison, students in the conventional learning groups showed lower gains, with improvements of 52.00 for highly motivated students and 35.71 for low-motivation students. These findings indicate that interactive simulation-based learning provides additional support for conceptual development across different motivational levels. The descriptive results are consistent with previous quasi-experimental studies showing that PhET simulations enhance students' conceptual understanding through interactive visualization of abstract chemical phenomena (Harahap et al., 2025; Tanzillal et al., 2026).

Comparison of Average Learning Outcomes Based on Learning Media

To see the differences in learning outcomes based on learning media, the following is a summary of the overall average.

Table 4. Posttest Average Based on Learning Media

Instructional Media	Number of Students	Posttest Average	Standard Deviation
PhET Chemistry Simulations (A ₁)	30	76,80	12,93
Conventional (A ₂)	30	68,67	13,82

The data presented in Table 4 indicate that students taught using PhET Chemistry Simulations (A₁) achieved a higher posttest average score (M = 76.80, SD = 12.93) compared to those receiving conventional instruction (A₂) (M = 68.67, SD = 13.82). The mean difference of 8.13 points suggests that simulation-based learning provided greater support for students' conceptual understanding of chemistry content. This finding indicates that interactive digital simulations can facilitate more effective learning experiences than traditional instructional approaches.

Statistical Description of Pretest and Posttest of Students' chemistry conceptual understanding

The following is descriptive data regarding the distribution of pretest and posttest scores, which provides a more detailed picture of the variation in learning outcomes in each group.

Table 5. Results of Pretest and Posttest of Students' Chemistry Conceptual Understanding

Group	Pretest Average	Posttest Average	X max	X min	SD
PhET (High Motivation)	26,22	85,11	100	72	8,09
PhET (Low Motivation)	24,00	64,33	76	56	7,52
Conventional (High Motivation)	27,25	79,25	92	68	9,47
Conventional (Low Motivation)	20,86	56,57	72	48	8,13

The results presented in Table 5 indicate an increase in students' chemistry conceptual understanding across all experimental groups from pretest to posttest. The PhET group with high learning motivation achieved the highest posttest average score (85.11), followed by the conventional group with high motivation (79.25). Students with low learning motivation also

demonstrated improvement, with posttest averages of 64.33 in the PhET group and 56.57 in the conventional group. These findings suggest that both instructional media and learning motivation contributed to improved learning outcomes, with PhET-based instruction consistently producing higher achievement across motivational levels. This pattern is consistent with previous studies reporting that interactive simulations enhance conceptual understanding through visualization of abstract chemical phenomena and promote active student engagement (Melvin C. Eleo & Ylcy B. Manguilimotan, 2024; Sakona et al., 2024).

Normality Test

To ensure that the pretest and posttest data were normally distributed, a Kolmogorov-Smirnov test was performed. The results showed that all groups were normally distributed, which supports the use of the ANOVA test for further analysis.

Tabel 6. Normality Test

Group	Pretest	Posttest
A ₁ B ₁ (High Motivation, PhET)	0,057	0,316
A ₁ B ₂ (Low Motivation, PhET)	0,125	0,104
A ₂ B ₁ (High Motivation, Conventional)	0,087	0,317
A ₂ B ₂ (Low Motivation, Conventional)	0,082	0,094

A significance value greater than 0.05 in all groups indicates that the data are normally distributed. Therefore, a two-way ANOVA test can be applied to test for differences between groups, ensuring the validity of further analysis.

Homogeneity Test

A homogeneity test was conducted to ensure that the variance between groups was uniform. Based on the results of the Levene test, a significance value greater than 0.05 indicates that the variance between groups was homogeneous.

Tabel 7. Homogeneity Test

Variable	Sig. Value	Explanation
Pretest	0,911	Homogeneous
Posttest	0,526	Homogeneous

A homogeneity test using Levene's test was conducted to examine the equality of variance across groups. As shown in Table 7, the significance values for both the pretest (Pretest = 0.911) and posttest (Posttest = 0.526) were greater than 0.05, indicating that the assumption of homogeneity of variance was satisfied. Therefore, the data met the prerequisite for further analysis using a two-way ANOVA.

Two-Way ANOVA Test Results

Hypothesis testing was conducted using two-way ANOVA to determine the effect of learning media, learning motivation, and the interaction between the two on students' understanding of chemistry.

Table 8. Two-Way ANOVA Test Results

Source of Variation	F count	Sig.	Explanation
Instructional Media	11,091	0,002	Significant
Motivation to Learn	112,853	0,000	Significant
Instructional Media x Motivation	0,216	0,644	Not Significant

The two-way ANOVA results revealed that instructional media significantly affected students' chemistry conceptual understanding. Learning motivation also showed a significant effect on students' chemistry conceptual understanding. However, the interaction between instructional media and learning motivation was not statistically significant, indicating that the effect of instructional media on chemistry conceptual understanding did not depend on students' level of learning motivation.

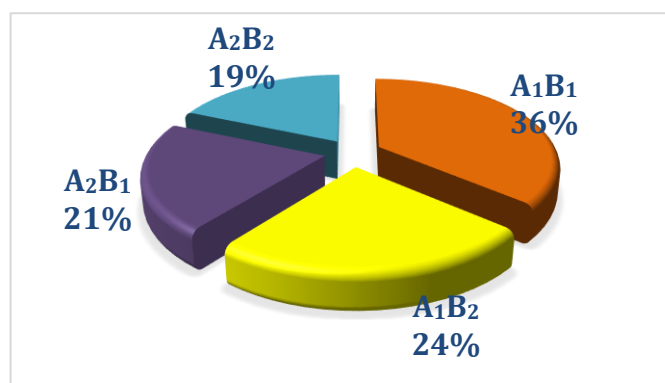


Figure 1. Percentage of Effectiveness of Learning Outcome Improvement

The figure above shows that the highest effectiveness was found in the PhET group with high motivation, which indicates that the integration of interactive media with students' intrinsic motivation provides the most optimal learning outcomes.

Discussion

The findings of the study indicate that the implementation of PhET Chemistry Simulations had a significant effect on improving students' understanding of molecular shape concepts. The group of highly motivated students using PhET achieved the highest improvement of 58.89 points, while students with low motivation showed an improvement of 40.33 points. In comparison, students taught using conventional learning showed improvements of 52.00 points for highly motivated students and 35.71 points for low-motivation students. These findings demonstrate that PhET-based learning consistently provides better conceptual gains than conventional instruction across different motivational levels (Riku, 2024; Rogie B. Escudro, 2024).

The results indicate that the interactive visualizations offered by PhET facilitate a more concrete understanding of abstract chemical concepts among students. Materials related to molecular shape require advanced spatial visualization skills because students must understand the arrangement of electron pairs, the geometric configuration of molecules, and the correlation between molecular structure and its chemical attributes (Dwiningsih et al., 2022; Pratama et al., 2025). In traditional educational paradigms, such concepts are often represented through static illustrations on the board or in textbooks, which reduces students' capacity to build mental models effectively. In contrast, PhET simulations empower students to directly manipulate molecular models, observe changes in electron configuration, and dynamically integrate symbolic representations with three-dimensional visualizations.

This phenomenon aligns with the Cognitive Theory of Multimedia Learning, which states that the synthesis of verbal and visual stimuli can enhance the development of conceptual knowledge through more effective cognitive processing (Abdinejad et al., 2021). From a statistical perspective, the two-way ANOVA results demonstrated that instructional media significantly influenced students' chemistry conceptual understanding ($F = 11.091$; $p < 0.05$). Learning motivation also showed a highly significant effect ($F = 112.853$; $p < 0.05$). However, no statistically significant interaction was found between instructional media and learning motivation ($F = 0.216$; $p > 0.05$). This indicates that the effectiveness of PhET Chemistry Simulations remained consistent regardless of students' motivational levels. These findings corroborate previous studies confirming that interactive simulations enhance conceptual understanding through virtual exploration and dynamic visualization of abstract chemical representations. Interactive simulations strengthen students' connections between macroscopic, submicroscopic, and symbolic representations, thereby reducing misconceptions and supporting deeper conceptual learning (Suryani et al. 2026).

In addition to teaching methods, the construct of learning motivation has also been shown to have a significant impact on students' understanding of chemistry ($F = 9.821$; $p < 0.05$). Students who exhibited increased levels of learning motivation achieved superior results

compared to their peers with reduced motivation in both educational intervention modalities. These findings imply that motivation serves as an intrinsic catalyst that drives students' participation in cognitive endeavors throughout the learning process. Students characterized by high levels of motivation tend to engage more thoroughly with simulation features, experiment with diverse molecular configurations, and conduct conceptual analyses of the results obtained from their virtual observations (Ikhsan et al., 2022; Lahlali et al., 2023).

These empirical observations lend credence to Self-Determination Theory, which posits that intrinsic motivation significantly enhances the quality of learning engagement through the mechanisms of curiosity, interest, and the drive for self-exploration. In the experimental cohort, students exhibiting high levels of motivation fully utilized the simulation to foster deeper conceptual understanding. They engaged not only in passive reception of information but also deeply engaged in the process of explaining concepts through the manipulation of variables and the resulting observation of the simulation. This particular scenario culminated in a clearer increase in understanding compared to the other cohorts (Jere & Mpeta, 2024; Ndagijimana et al., 2025).

However, the findings of the study also indicated that learners exhibiting low levels of motivation still achieved significant gains from utilizing PhET. The 39.67% increase in this demographic suggests that simulation media is effective in facilitating sustained engagement in the learning process, despite their relatively reduced levels of intrinsic motivation. This phenomenon may be explained by the attributes of PhET, which presents educational content in a captivating, interactive, and exploratory framework that has the potential to spark students' curiosity. Consequently, interactive digital media can serve as an external catalyst that helps increase students' attention and engagement throughout the educational experience (Ma et al., 2024).

These findings carry important pedagogical implications for chemistry education, particularly in supporting students who demonstrate lower intrinsic motivation. The results suggest that interactive simulation-based learning environments can function as inclusive instructional tools capable of reducing learning barriers associated with abstract chemistry concepts. Therefore, chemistry teachers are encouraged to integrate PhET simulations not only for academically advanced students but also for learners who require additional engagement and conceptual support during instruction.

In addition, the findings provide several recommendations for future researchers. Subsequent studies may investigate the long-term effects of PhET-based instruction on conceptual retention, critical thinking skills, and scientific reasoning across different chemistry topics. Future research could also involve larger sample sizes, diverse educational settings, and mixed-method approaches to obtain deeper insights into students' cognitive and motivational responses during simulation-based learning. Furthermore, examining additional moderating variables such as self-efficacy, digital literacy, and collaborative learning interaction may contribute to a more comprehensive understanding of how interactive simulations influence chemistry learning outcomes.

CONCLUSION

Based on the findings obtained from the analysis, the implementation of PhET Chemistry Simulation has been shown to produce significantly greater improvements in chemistry conceptual understanding compared to conventional learning. The average improvement among students in the highly motivated experimental group reached 58.89 points, while the conventional group reached 52.00 points. Similarly, among students with low motivation, the experimental group achieved an improvement of 40.33 points, compared to 35.71 points in the conventional group. Furthermore, the overall mean post-test score of students engaged with PhET (76.80) was higher than that of conventional learning (68.67), corroborated by the results of the ANOVA test, which showed significant effects of both instructional media ($F = 11.091$; $p < 0.05$) and learning motivation ($F = 112.853$; $p < 0.05$) on

students' understanding of chemistry.

Notably, the analysis also revealed no significant interaction between instructional media and learning motivation ($F = 0.216$; $p > 0.05$), indicating that the effectiveness of PhET Chemistry Simulations remained relatively stable across different motivational levels. This was evidenced by the sustained improvement among low-motivation students, which reached 40.33 points. These findings confirm that PhET functions as an adaptive instructional medium capable of promoting inclusive, exploratory, and technology-enhanced chemistry learning in 21st-century education.

REFERENCE

- Abdinejad, M., Talaie, B., Qorbani, H. S., & Dalili, S. (2021). Student Perceptions Using Augmented Reality and 3D Visualization Technologies in Chemistry Education. *Journal of Science Education and Technology*, 30(1), 87–96. <https://doi.org/10.1007/s10956-020-09880-2>
- Ajayan, P., Cao, R., & Eichler, J. F. (2025). Promoting Conceptual Learning Using Scaffolded Activities That Incorporate Interactive Simulations. *Education Sciences*, 15(5), 566. <https://doi.org/10.3390/educsci15050566>
- Akbar, S., Imamuddin, M., Rahmi, F., & Isnaniah, I. (2022). The Effectiveness of Innovative Learning on Mathematical Problem-Solving Ability: Quasi-Experimental. *International Journal of Learning and Instruction (IJLI)*, 4(2), 111. <https://doi.org/10.26418/ijli.v4i2.59784>
- Ann Udeh, C. (2025). Research methodology. In *Deep Science Publishing* (pp. 25–28). Deep Science Publishing. https://doi.org/10.70593/978-93-49307-40-7_3
- Apriani, I., Okmarisa, H., Ardiansyah, A., & Afrianis, N. (2024). Analisis Kesulitan Belajar Kimia Siswa Kelas X pada Materi Hukum Dasar Kimia di Sekolah Menengah Atas Negeri 1 Minas. *Journal of Research and Education Chemistry*, 6(2), 126. [https://doi.org/10.25299/jrec.2024.vol6\(2\).17766](https://doi.org/10.25299/jrec.2024.vol6(2).17766)
- Atika, M. D., & Latisma, L. (2022). Description of Student Chemistry Learning Difficulties in Acid Base Material Class XI IPA at SMAN 7 Padang. *Entalpi Pendidikan Kimia*, 18–26. <https://doi.org/10.24036/epk.v3i3.273>
- Bagossi, S., Swidan, O., & Arzarello, F. (2022). Timeline tool for analyzing the relationship between students-teachers-artifacts interactions and meaning-making. *Journal on Mathematics Education*, 13(2), 357–382. <https://doi.org/10.22342/jme.v13i2.pp357-382>
- Byusa, E., Kampire, E., & Mwesigye, A. R. (2022). Game-based learning approach on students' motivation and understanding of chemistry concepts: A systematic review of literature. *Heliyon*, 8(5), e09541. <https://doi.org/10.1016/j.heliyon.2022.e09541>
- Dwiningsih, K., Fajaroh, F., Parlan, P., Munzil, M., & Habiddin, H. (2022). 3D Molecular Interactive Multimedia for Building Chemistry Students' Spatial Ability. *International Journal of Emerging Technologies in Learning (ijET)*, 17(14), 253–262. <https://doi.org/10.3991/ijet.v17i14.30339>
- Festiyed, Daulay, H., & Ridhatullah, M. (2023). Influence of Interactive Multimedia Teaching Materials on Cognitive Learning Outcomes of Students in Science Lessons: A Meta-Analysis. *Jurnal Penelitian Pendidikan IPA*, 9(8), 387–396. <https://doi.org/10.29303/jppipa.v9i8.2693>
- Adamson, H. K., & Prion, S. (2020). Two-by-Two Factorial Design. *Clinical Simulation in Nursing*, 49, 90–91. <https://doi.org/10.1016/j.ecns.2020.06.004>
- Harahap, F., Susetyarini, E., Purwanti, E., Fitri, S., Rukman, N., & Pohan, H. (2025). PhET simulation in education: A bibliometric analysis of the Scopus database. *Research and Development in Education (RaDEn)*, 5, 555–570. <https://doi.org/10.22219/raden.v5i1.40504>
- Ibrahim, A., Bolaji, H. O., & Oyeyemi, W. T. (2025). PhET Simulation: A Platform to Improve Students Performance in Chemistry Content. *Journal of Chemistry Education and Integration*, 4(1), 1. <https://doi.org/10.24014/jcei.v4i1.32555>
- Ikhsan, J., Fitriyana, N., & Arif, Z. (2022). Virtual Chemistry Laboratory in Blended Online Learning Mode: The Influence on Students' Motivation and Achievement. *Pedagogika*, 144(4). <https://doi.org/10.15823/p.2021.144.9>
- Jere, S., & Mpeta, M. (2024). Enhancing Learners' Conceptual Understanding of Reaction Kinetics Using Computer Simulations – A Case Study Approach. *Research in Science Education*, 54(6), 999–1023. <https://doi.org/10.1007/s11165-024-10182-5>
- Johnson, D., & Coulter-Kern, M. (2024). Listening to students: Beliefs and attitudes about active learning and effective lecture-style courses. *Active Learning in Higher Education*, 26. <https://doi.org/10.1177/14697874241254465>

- Khatimah, M. H., & Chisbiyah, L. A. (2024). Fostering Engagement and Learning Outcomes: A Comparative Analysis of Ethnochemical and STEM-based Pedagogies for Chemistry Learning in Vocational High Schools. *Jurnal Pendidikan Sains*, 12(1), 1–6. <https://doi.org/10.17977/jps.v12i12024p001>
- Klein, K., Calabrese, J., Aguiar, A., Mathew, S., Ajani, K., Almajid, R., & Aarons, J. (2023). *Evaluating Active Lecture and Traditional Lecture in Higher Education*. <https://doi.org/10.26077/BA42-A5CC>
- Kong, S. E., Chhorn, T., & Chea, S. (2025). Self-motivation of Developing the Students' Learning Performance. *Journal of Education Innovation and Language Teaching (JEILT)*, 1(2), 47–59. <https://doi.org/10.63381/jeilt.v1i2.58>
- Lahlali, A., Chafiq, N., Radid, M., Moundy, K., & Srour, C. (2023). The Effect of Integrating Interactive Simulations on the Development of Students' Motivation, Engagement, Interaction and School Results. *International Journal of Emerging Technologies in Learning (ijET)*, 18(12), 193–207. <https://doi.org/10.3991/ijet.v18i12.39755>
- Laid, S. M. T., & Adlaon, M. S. (2025). A Systematic Review of Innovative Teaching Strategies in Science: Exploring Hands-on Learning, Technology Integration, and Student-Centered Approaches. *Acta Pedagogica Asiana*, 4(2), 101–114. <https://doi.org/10.53623/apga.v4i2.645>
- Lia, R. M., Rusilowati, A., & Isnaeni, W. (2020). NGSS-oriented chemistry test instruments: Validity and reliability analysis with the Rasch model. *REID (Research and Evaluation in Education)*, 6(1), 41–50. <https://doi.org/10.21831/reid.v6i1.30112>
- Liswar, F., Hidayati, A., Rayendra, R., & Yeni, F. (2023). Use of Phet Interactive Simulation Software in Physics Learning. *JPPIPA (Jurnal Penelitian Pendidikan IPA)*. <https://doi.org/10.29303/jppipa.v9ispecialissue.5982>
- Ma, Y., Zuo, M., Gao, R., Yan, Y., & Luo, H. (2024). Interrelationships among College Students' Perceptions of Smart Classroom Environments, Perceived Usefulness of Mobile Technology, Achievement Emotions, and Cognitive Engagement. *Behavioral Sciences*, 14(7), 565. <https://doi.org/10.3390/bs14070565>
- Melvin C. Eleo & Ylcy B. Manguilimotan. (2024). Physics Education Technology (PhET) Interactive Simulations as Teaching Aid in Enhancing Students' Performance in Physics. *EPRA International Journal of Multidisciplinary Research (IJMR)*, 60–64. <https://doi.org/10.36713/epra15991>
- Meronda, D. A., Widarti, H. R., & Yahmin, Y. (2025). Virtual Laboratories in Science Education: A Systematic Review of Effectiveness on Conceptual Understanding and Learning Outcomes. *Jurnal Pendidikan MIPA*, 26(3), 2020–2042. <https://doi.org/10.23960/jpmipa.v26i3.pp2020-2042>
- Moore, E. B., Chamberlain, J. M., Parson, R., & Perkins, K. K. (2014). PhET Interactive Simulations: Transformative Tools for Teaching Chemistry. *Journal of Chemical Education*, 91(8), 1191–1197. <https://doi.org/10.1021/ed4005084>
- Ndagijimana, J.-B., Musengimana, J., Mushimiyimana, H., Mukama, E., Habimana, O., Manirakiza, P., Dushimimana, J. C., Munyaruhengeri, J. P. A., Khan, S., & Lakin, E. (2025). Contribution of an instructional module incorporating PhET simulations to Rwandan students' knowledge of chemical reactions, acids, and bases through social interactions. *Chem. Educ. Res. Pract.*, 26(1), 289–299. <https://doi.org/10.1039/D4RP00105B>
- Oh, M., & Ahn, S. (2025). Effect of a digital sexual violence prevention education program on digital sexual violence prevention knowledge, self-protection behavior, and digital citizenship among fifth-grade children: A quasi-experimental study. *Women's Health Nursing*, 31(4), 379–391. <https://doi.org/10.4069/whn.2025.12.08.1>
- Pane, E. P., Sauduran, G. N., Simanjuntak, B., Lampola Sitorus P., & Pasaribu, S. (2025). Analisis Kesulitan Belajar Peserta Didik dalam Memahami Materi Pembelajaran Kimia Kelas XI MIA SMA. *PENDIPA Journal of Science Education*, 9(2), 458–465. <https://doi.org/10.33369/pendipa.9.2.458-465>
- Penn, M., & Ramnarain, U. (2019). South African university students' attitudes towards chemistry learning in a virtually simulated learning environment. *Chem. Educ. Res. Pract.*, 20(4), 699–709. <https://doi.org/10.1039/C9RP00014C>
- Pratama, M. S. C., Erlina*, E., Ulfah, M., Enawaty, E., & Williams, D. (2025). Augmented Reality Molecular Shape Cards: A Novel Approach to Strengthen Students' Understanding of Molecular Shape. *Jurnal Pendidikan Sains Indonesia*, 13(4), 1932–1050. <https://doi.org/10.24815/jpsi.v13i4.47653>
- Pratomo, H., Fitriyana, N., Wiyarsi, A., & Marfuatun, M. (2025). Mapping chemistry learning difficulties of secondary school students: A cross-grade study. *Journal of Education and Learning (EduLearn)*, 19(2), 909–920. <https://doi.org/10.11591/edulearn.v19i2.21826>
- Puja, I. B. P. (2024). The mediating role of online learning motivation in the influence of service quality, social media usage, and pedagogical teaching competence of teachers on student learning

- satisfaction. *Cogent Social Sciences*, 10(1), 2396934. <https://doi.org/10.1080/23311886.2024.2396934>
- Putra Suharnadi, Neviyarni S, & Herman Nirwana. (2024). The Role and Function of Learning Motivation in Improving Student Academic Achievement. *Manajia: Journal of Education and Management*, 2(1), 1–8. <https://doi.org/10.58355/manajia.v2i1.25>
- Putri, N. S., Resti Yektyastuti, & Yusuf Safari. (2024). Implementation of Physics Education Technology (Phet) Media on Student's Science Concept Understanding: A Literature Review. *Educational Researcher Journal*, 1(1), 10–18. <https://doi.org/10.71288/educationalresearcherjournal.v1i1.3>
- Rahmawati, Y., Zulhipri, Z., Hartanto, O., Falani, I., & Iriyadi, D. (2022). Students' conceptual understanding in chemistry learning using PhET interactive simulations. *Journal of Technology and Science Education*, 12(2), 303. <https://doi.org/10.3926/jotse.1597>
- Rahmi, T. S., & S, N. (2022). The role of Learning Motivation (Extrinsic and Intrinsic) and its Implications in the Learning Process. *International Journal of Educational Dynamics*, 5(1), 147–152. <https://doi.org/10.24036/ijeds.v5i1.378>
- Rajagukguk, K. P., Suyanti, R. D., Saragih, A. H., & Sinclair Taylor, P. C. (2025). Effectiveness of Project-Based Inquiry Learning in Developing HOTS-Based Scientific Literacy: Moderated by Science Process Skill. *Jurnal Pendidikan Progresif*, 15(4), 2509–2537. <https://doi.org/10.23960/jpp.v15i4.pp2509-2537>
- Riku, M. (2024). *Model Discovery Learning Berbantuan PhET Simulation untuk Meningkatkan Hasil Belajar Siswa pada Materi Bentuk Molekul*. <https://doi.org/10.61116/jiim.v1i4.275>
- Risvayani, R., Permanasari, A., & Musthafa, I. (2023). Preliminary research: Identification of Difficulty in Chemical Learning Based On Teacher and Student Perspectives. *JISAE: Journal of Indonesian Student Assessment and Evaluation*, 9(2), 171–179. <https://doi.org/10.21009/jisae.v9i2.39931>
- Rizki, I. A., Mirsa, F. R., Islamiyah, A. N., Saputri, A. D., Ramadani, R., & Habibulloh, M. (2025). Ethnoscience-enhanced physics virtual simulation and augmented reality with inquiry learning: Impact on students' creativity and motivation. *Thinking Skills and Creativity*, 57, 101846. <https://doi.org/10.1016/j.tsc.2025.101846>
- Rogie B. Escudro. (2024). Physics Education Technology (PhET) Simulation as Aid in Instruction in Learning Chemistry: An Experimental Approach. *EPRA International Journal of Multidisciplinary Research (IJMR)*, 64–68. <https://doi.org/10.36713/epra17674>
- Sailema-Castro, R. I., Licoa-Vera, G. K., Chávez, E. L. C., & Carballo, K. B. (2025). Impacto del uso de los simuladores PhET en la enseñanza de química para bachillerato: Desafíos y oportunidades docentes. *Código Científico Revista de Investigación*, 6(1), 507–534. <https://doi.org/10.55813/gaea/ccri/v6/n1/903>
- Sailer, M., Maier, R., Berger, S., Kastorff, T., & Stegmann, K. (2024). Learning activities in technology-enhanced learning: A systematic review of meta-analyses and second-order meta-analysis in higher education. *Learning and Individual Differences*, 112, 102446. <https://doi.org/10.1016/j.lindif.2024.102446>
- Sakona, A. A. R., Usman, U., & Palloan, P. (2024). The Effectiveness of Utilizing PhET in Increasing the Comprehension of Physics Concepts. *Jurnal Ilmiah Pendidikan Fisika*, 8(1), 156. <https://doi.org/10.20527/jipf.v8i1.11002>
- Sequeira, S. (2024). Chapter 53—Factorial design. In A. E. M. Eltorai, J. A. Bakal, J. M. Haglin, J. A. Abboud, & J. J. Crisco (Eds.), *Translational Orthopedics* (pp. 261–263). Academic Press. <https://doi.org/10.1016/B978-0-323-85663-8.00059-3>
- Setyorini, A. D., Yamtinah, S., Mahardiani, L., & Saputro, S. (2021). A Rasch Analysis of Item Quality of the Chemical Literacy Assessment for Investigating Student's Chemical Literacy on Chemical Rate Concepts. *European Journal of Educational Research*, volume–10–2021(volume–10–issue–4–october–2021), 1769–1779. <https://doi.org/10.12973/eu-jer.10.4.1769>
- Stiawan, E., Basuki, R., Liliarsari, L., & Rohman, I. (2022). Enhancement of Indonesian High School Student Conceptual Mastery on VSEPR Topic Using Virtual Simulation of Molecule Shapes: A Case Study of Quasi-Experimental Evidence. *Jurnal Pendidikan IPA Indonesia*, 11(4), 511–518. <https://doi.org/10.15294/jpii.v11i4.36385>
- Suryani, E., Bentri, A., Hendri, N., Rayendra, R., & Prasetya, A. (2026). Mapping Research Trends in Game-Based ICT Learning for Interactive Educational Applications: A Bibliometric Study. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, 10(2), 768–782. <https://doi.org/10.22437/jiituj.v10i2.54672>
- Tang, H., Nie, Y., & Liu, X. (2025). Investigating the Relationship Between Learning Motivation and Academic Performance: Data Analysis Based on College Students. *Journal of Teaching & Research*, <https://siducat.org/index.php/isej/>

- 1(1), 10–18. <https://doi.org/10.65170/jtr.v1i1.10>
- Tanzillal, M. I., Hertanti, E., & Suwarna, I. P. (2026). Pengaruh PhET Interactive Simultions terhadap Pemahaman Konsep Siswa pada Materi Termodinamika. *Jurnal Pendidikan Matematika dan Sains*, 14(1), 121–130. <https://doi.org/10.21831/jpms.v14i1.91208>
- Thuan, N. D., Chau, L. M. T., & Nhi, N. T. (2026). Trends and applications of ICT in physics education: A bibliometric analysis using the scopus database from 2000 to 2025. *Multidisciplinary Reviews*, 9(8), 2026383. <https://doi.org/10.31893/multirev.2026383>
- Triandika, E., Amprasto, A., & Rumanta, M. (2023). Pengaruh Model Problem Based Learning dan Motivasi Belajar Terhadap Kemampuan Berpikir Kritis Siswa Pada Mata Pelajaran IPA Kelas V Sekolah Dasar. *Nuansa Akademik: Jurnal Pembangunan Masyarakat*, 8(1), 175–188. <https://doi.org/10.47200/jnajpm.v8i1.1644>