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Effects of Chemical Bonding Animation-Based Instruction on Secondary School Students' Academic Achievements: A Quasi-Experimental Study

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ABSTRACT

Understanding chemical bonding presents a persistent challenge for secondary school students due to the abstract and subatomic nature of the concepts involved. This study examined the effectiveness of an animation-based instructional package in improving students' understanding of chemical bonding. A quasi-experimental pretest–posttest design was employed involving 160 Senior Secondary School II students drawn from eight public secondary schools in Nigeria. Students were assigned to either an experimental group that received animation-supported instruction or a control group that received conventional instruction. Data were collected using a researcher-developed multiple-choice achievement test and analyzed using independent-samples t-tests and one-way analysis of variance. The results indicated that students exposed to animation-based instruction achieved significantly higher posttest scores than those taught using conventional methods across all schools. In addition, no significant differences were found among the experimental groups across schools, suggesting that the instructional effect of the animation package was consistent across different educational contexts. These findings provide empirical evidence that animation-based instruction can effectively support students' understanding of abstract chemistry concepts and highlight its potential as a pedagogical tool for improving secondary school chemistry education.

Keywords: *animation-based instruction, chemical bonding, science education, multimedia learning, quasi-experimental research, secondary education.*

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INTRODUCTION

Understanding chemical bonding remains a persistent challenge for secondary school students, mainly because the concepts involved are abstract and submicroscopic.[1] Processes such as electron transfer and electron sharing cannot be directly observed, requiring learners to construct mental models that integrate symbolic, verbal, and spatial information.[2] Research in chemistry education has consistently shown that these representational demands often lead to cognitive overload, misconceptions, and reduced engagement, particularly when instruction relies primarily on verbal explanation and static textbook illustrations.[3]

Advances in educational technology have created opportunities to address these challenges through dynamic visualizations, including animation-based instructional resources. From the perspective of the Cognitive Theory of Multimedia Learning, learning is enhanced when verbal and visual information are presented in a coordinated manner that supports dual-channel processing and reduces extraneous cognitive load.[4] Well-designed animations can make invisible molecular processes visible, illustrate temporal sequences, and support learners in forming coherent mental representations of chemical phenomena.[5] Empirical studies have reported that animation and computer-based visualizations can improve students' conceptual understanding and retention in science, particularly for topics involving change over time and complex interactions.[6]

Despite growing interest in animation-supported instruction, several gaps remain in the literature. Many existing studies examine animation in isolated classroom contexts, with limited sample sizes or narrow instructional scopes.[7] Furthermore, empirical evidence from

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[1] Jarkko Joki and Maija Aksela, "The Challenges of Learning and Teaching Chemical Bonding at Different School Levels Using Electrostatic Interactions Instead of the Octet Rule as a Teaching Model," *Chemistry Education Research and Practice* 19, no. 3 (2018): 932–53, https://doi.org/10.1039/C8RP00110C; Abdelouahed Lahlali et al., "Students' Alternative Conceptions and Teachers' Views on the Implementation of Pedagogical Strategies to Improve the Teaching of Chemical Bonding Concepts," *International Journal of Engineering Pedagogy (IJEP)* 13, no. 6 (September 20, 2023): 90–107, https://doi.org/10.3991/ijep.v13i6.41391.

[2] Kerstin Danckwardt-Lillieström, Maria Andrée, and Margareta Enghag, "The Drama of Chemistry – Supporting Student Explorations of Electronegativity and Chemical Bonding through Creative Drama in Upper Secondary School," *International Journal of Science Education* 42, no. 11 (July 23, 2020): 1862–94, https://doi.org/10.1080/09500693.2020.1792578.

[3] Georgios Tsaparlis, Eleni T. Pappa, and Bill Byers, "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, no. 4 (2018): 1253–69, https://doi.org/10.1039/C8RP00035B.

[4] Richard E. Mayer, "The Past, Present, and Future of the Cognitive Theory of Multimedia Learning," *Educational Psychology Review* 36, no. 1 (March 17, 2024): 8, https://doi.org/10.1007/s10648-023-09842-1.

[5] Chia-Yin Lin and Hsin-Kai Wu, "Effects of Different Ways of Using Visualizations on High School Students' Electrochemistry Conceptual Understanding and Motivation towards Chemistry Learning," *Chemistry Education Research and Practice* 22, no. 3 (2021): 786–801, https://doi.org/10.1039/D0RP00308E.

[6] Emelie Patron et al., "An Exploration of How Multimodally Designed Teaching and the Creation of Digital Animations Can Contribute to Six-Year-Olds' Meaning Making in Chemistry," *Education Sciences* 14, no. 1 (January 10, 2024): 79, https://doi.org/10.3390/educsci14010079; Hsin-Kai Wu, Joseph S. Krajcik, and Elliot Soloway, "Promoting Understanding of Chemical Representations: Students' Use of a Visualization Tool in the Classroom," *Journal of Research in Science Teaching* 38, no. 7 (September 30, 2001): 821–42, https://doi.org/10.1002/tea.1033; Astrid Berg et al., "Representational Challenges in Animated Chemistry: Self-Generated Animations as a Means to Encourage Students' Reflections on Sub-Micro Processes in Laboratory Exercises," *Chemistry Education Research and Practice* 20, no. 4 (2019): 710–37, https://doi.org/10.1039/C8RP00288F.

[7] Mohammadreza Farrokhnia, Ralph F. G. Meulenbroeks, and Wouter R. van Joolingen, "Student-Generated Stop-Motion Animation in Science Classes: A Systematic Literature Review," *Journal of Science Education and Technology* 29, no. 6 (December 10, 2020): 797–812, https://doi.org/10.1007/s10956-020-09857-1; Alexandros Kleftodimos, "Computer-Animated Videos in Education: A Comprehensive Review and Teacher Experiences from Animation Creation," *Digital* 4, no.

secondary school settings in developing contexts, including Nigeria, remains relatively scarce. This is noteworthy given ongoing concerns about students' performance and engagement in senior secondary school science subjects, especially chemistry. In addition, few studies have systematically examined whether animation-based instruction produces consistent learning gains across multiple school environments, an issue critical to evaluating the broader applicability of these instructional approaches.[8]

The present study addresses these gaps by examining the effectiveness of an animation-based instructional package designed to support students' understanding of chemical bonding. Using a quasi-experimental pretest–posttest design across eight secondary schools, the study compares the achievement of students taught with animation-supported instruction with that of students taught using conventional teaching methods. In addition, the study investigates whether the effectiveness of the animation intervention varies across different school contexts.

By providing multi-school empirical evidence on the role of animation in chemistry instruction, this study contributes to the growing body of research on multimedia learning in science education. The findings offer insights into how animation-based instructional resources can support students' understanding of abstract chemical concepts and inform instructional practices to improve science learning outcomes in secondary education.

METHOD

This study adopted a quasi-experimental pretest–posttest design to examine the effect of an animation-based instructional package on secondary school students’ understanding of chemical bonding.[9] A quasi-experimental approach was deemed appropriate because random assignment of students to groups was not feasible within the existing school structure.[10] The design enabled comparison of learning outcomes between students exposed to animation-supported instruction and those taught using conventional instructional methods under authentic classroom conditions.

The participants comprised 160 Senior Secondary School II (SSS II) students drawn from eight public secondary schools in Bauchi Local Government Area, Nigeria. The schools were purposively selected based on their inclusion of chemical bonding in the chemistry curriculum during the study period and their willingness to participate. Within each school, students

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3 (July 12, 2024): 613–47, https://doi.org/10.3390/digital4030031; Peter Knapp, Ella Evans, and Thirimon Moe-Byrne, “How Effective Are Video Animations in Practitioner Education? A Systematic Review of Trials,” *Patient Education and Counseling* 109 (April 2023): 19, https://doi.org/10.1016/j.pec.2022.10.052.

[8] Rachel Atomatofa et al., “Effect of Integrating Animation Videos into Science Instruction in Under-Resourced Rural Nigerian Schools,” *Journal of Curriculum and Teaching* 14, no. 4 (October 17, 2025): 87, https://doi.org/10.5430/jct.v14n4p87; Azeez Arisekola SALMAN, “Effect of Instructional Animation on Pupils’ Academic Performance in Literacy,” *Journal of Education Technology* 9, no. 3 (August 25, 2025): 566–76, https://doi.org/10.23887/jet.v9i3.98340; Abhishek Bhattacharjee, “Harnessing Animation for E-Content in Education: A Comprehensive Analysis,” *Green Lifestyle and International Market* 2, no. 1 (June 27, 2025): 52–62, https://doi.org/10.34256/glim25.0201052.

[9] Donald T. Campbell and Julian C. Stanley, *Experimental and Quasi-Experimental Designs for Research* (Boston, MA: Houghton Mifflin Company, 1963); T D Cook and D T Campbell, *Quasi-Experimentation: Design & Analysis Issues for Field Settings* (Houghton Mifflin, 1979), https://books.google.co.id/books?id=BFNqAAAAMAAJ.

[10] Samuel J. Stratton, “Quasi-Experimental Design (Pre-Test and Post-Test Studies) in Prehospital and Disaster Research,” *Prehospital and Disaster Medicine* 34, no. 6 (December 26, 2019): 573–74, https://doi.org/10.1017/S1049023X19005053.

were assigned to either an experimental group or a control group, with 10 students in each group. Participants were typically between 14 and 19 years of age and followed the duplicate curriculum content in chemistry during the term in which the study was conducted.

Purposive sampling was employed to ensure that participants had characteristics relevant to the study's objectives, particularly enrollment in SSS II chemistry classes where chemical bonding was actively taught. This approach allowed the researchers to focus on contexts in which the instructional intervention could be meaningfully implemented and evaluated.

Students' understanding of chemical bonding was assessed using a researcher-developed 10-item multiple-choice achievement test. The instrument focused on key concepts related to ionic and covalent bonding, including electron transfer, electron sharing, and molecular formation, as prescribed in the senior secondary school chemistry curriculum. Content and face validity were established through expert review by experienced chemistry educators, who evaluated the clarity, relevance, and alignment of test items with instructional objectives. The instrument was pilot-tested to assess readability and item functionality. Reliability analysis using Cronbach's alpha yielded a coefficient of 0.81, indicating satisfactory internal consistency.

Prior to instruction, all participants completed a pretest to establish a baseline of knowledge about chemical bonding. The experimental groups were then taught using an animation-based instructional package developed to illustrate key bonding processes through dynamic visual representations. The animations depicted molecular interactions such as electron transfer in ionic bonding and electron sharing in covalent bonding. They were presented during regular classroom sessions with teacher guidance to ensure consistent instructional delivery.

The control groups received conventional instruction covering the duplicate content, primarily through verbal explanation, chalkboard illustrations, and standard instructional materials. Both groups received equivalent instructional time. At the conclusion of the instructional period, all participants completed a posttest using the same achievement test to measure learning gains.

Data were analyzed using IBM SPSS.[11] Descriptive statistics were computed to summarize participants' test scores. Independent-samples t-tests were conducted to compare posttest performance between experimental and control groups within each school. In addition, a one-way analysis of variance (ANOVA) was conducted to determine whether posttest scores across schools differed significantly among the experimental groups. All statistical tests were evaluated at the $\alpha = .05$ significance level. Prior to analysis, assumptions of normality and homogeneity of variance were examined.

Permission to conduct the study was obtained from the relevant school authorities. Participants were informed of the study's purpose, and participation was voluntary. Students'

[11] Zuzana Čaplová and Petra Švábová, "IBM SPSS Statistics," in *Statistics and Probability in Forensic Anthropology* (Elsevier, 2020), 343–52, https://doi.org/10.1016/B978-0-12-815764-0.00027-7.

anonymity and confidentiality were assured, and all data were used exclusively for research purposes.

RESULTS AND DISCUSSION

Results

Descriptive statistics were computed to summarize students' pretest and posttest performance across the control and experimental groups. The results indicate that both groups demonstrated comparable levels of prior knowledge before the instructional intervention. Following the instruction, however, the experimental group achieved higher mean posttest scores than the control group, suggesting an overall improvement associated with the animation-based instructional package.

Table 1. Descriptive Statistics of Pretest and Posttest Scores

Group	Test Type	N	Mean (M)	Standard Deviation (SD)
Control Group	Pretest	80	5.06	0.98
Control Group	Posttest	80	5.06	1.05
Experimental Group	Pretest	80	5.04	1.01
Experimental Group	Posttest	80	5.89	1.12

As shown in Table 1, pretest mean scores for the control and experimental groups were closely aligned, indicating initial equivalence between groups prior to treatment. In contrast, posttest results reveal a higher mean score for the experimental group compared to the control group, providing preliminary descriptive evidence of the positive impact of animation-based instruction. These patterns were further examined using inferential statistical analyses, as reported in the subsequent sections.

Effect of Animation-Based Instruction

Independent-samples t-tests were conducted to examine differences in posttest achievement between the experimental and control groups. Across all eight participating schools, students who received animation-based instruction achieved significantly higher posttest scores than those taught using conventional instructional methods ($p < .05$ in all cases). Although the magnitude of the score differences varied slightly across schools, the direction of the effect was consistent: the experimental groups outperformed the control groups in every comparison.

Figure 1 provides a visual summary of these findings by comparing the aggregated mean posttest scores of the control and experimental groups. As illustrated in the figure, the experimental group demonstrated a higher overall mean score than the control group. This visual pattern reinforces the statistical evidence obtained from the t-test analyses, clearly indicating that animation-based instruction was associated with improved learning outcomes in chemical bonding.

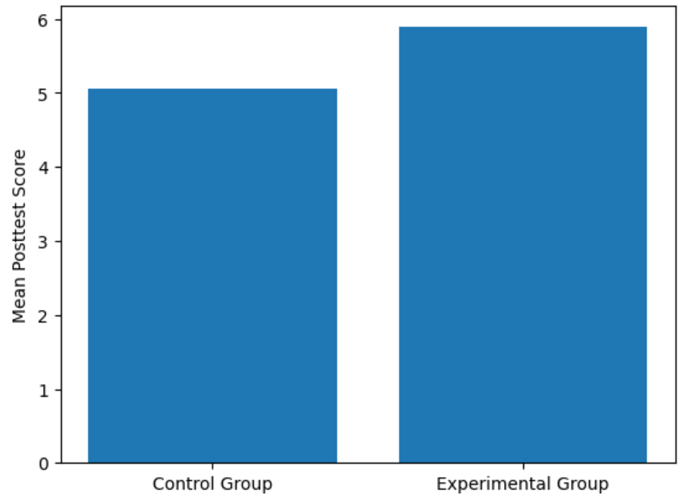

Figure 1. Comparison of Posttest Achievement between Control and Experimental Groups

The statistical and graphical results demonstrate that the animation-based instructional package had a positive, consistent effect on students' academic achievement compared with conventional teaching methods.

Comparison of Experimental Group Performance across Schools

A one-way analysis of variance (ANOVA) was conducted to examine whether posttest achievement among students in the experimental groups differed significantly across the eight participating schools. The analysis revealed no statistically significant difference in mean posttest scores across schools, $F(7, 72) = 0.572$, $p = 0.776$, indicating that the effectiveness of the animation-based instructional package was consistent across school contexts.

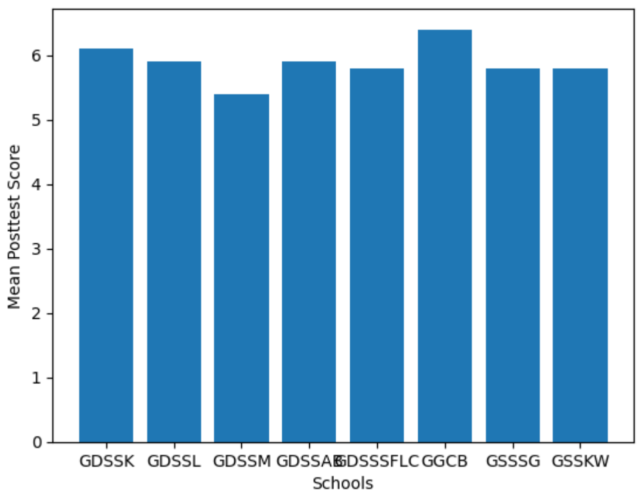

Figure 2. Mean posttest scores of experimental groups across participating schools.

Figure 2 presents a visual comparison of the mean posttest scores across the eight schools for the experimental groups. As shown in the figure, the mean scores across schools display only minor variations, with all experimental groups achieving comparable levels of performance. The absence of pronounced differences among the bars visually supports the ANOVA result, confirming that no single school demonstrated a substantially stronger or weaker outcome than the others. The statistical and graphical evidence indicate that the animation-based instructional package produced uniform learning gains across diverse school environments, suggesting that its effectiveness was not dependent on specific school-level factors.

Discussion

The present study examined the effectiveness of an animation-based instructional package in improving secondary school students' understanding of chemical bonding. The findings demonstrated that students exposed to animation-supported instruction consistently achieved higher posttest scores than those taught using conventional methods. In addition, the absence of statistically significant differences among experimental groups across schools indicates that the instructional effect of the animation package was stable across diverse educational contexts.

These findings can be explained through the Cognitive Theory of Multimedia Learning, which posits that learning is enhanced when information is presented through coordinated verbal and visual channels that support dual-channel processing and reduce extraneous cognitive load.[12] Chemical bonding concepts require learners to integrate symbolic representations, verbal explanations, and submicroscopic processes that cannot be directly observed. Animation-based instruction supports this integration by dynamically representing molecular interactions over time, thereby facilitating mental model construction and improving conceptual understanding.[13]

The results of this study are consistent with previous research demonstrating that animated and computer-based visualizations enhance students' understanding of abstract chemistry concepts. Özmen, Demircioğlu, and Demircioğlu found that students who learned chemical bonding through computer animations combined with instructional scaffolding achieved significantly higher conceptual understanding and showed fewer misconceptions than those taught through traditional methods.[14] Similarly, Höffler and Leutner reported that dynamic visualizations are particularly effective for learning processes involving change and transformation, provided that the animations are designed to align with cognitive principles.[15] These findings reinforce the argument that animation is most effective when it serves a pedagogical purpose rather than merely being decorative.

Beyond supporting conceptual understanding, animation-based instruction may also mitigate the cognitive difficulties associated with abstract chemical representations. Empirical work using eye-tracking and cognitive processing measures has shown that dynamic

[12] Richard E. Mayer, *Multimedia Learning* (Cambridge University Press, 2009), https://doi.org/10.1017/CBO9780511811678.
[13] Richard E. Mayer and Valerie K. Sims, "For Whom Is a Picture Worth a Thousand Words? Extensions of a Dual-Coding Theory of Multimedia Learning.," *Journal of Educational Psychology* 86, no. 3 (September 1994): 389–401, https://doi.org/10.1037/0022-0663.86.3.389.
[14] Haluk Özmen, Hülya Demircioğlu, and Gökhan Demircioğlu, "The Effects of Conceptual Change Texts Accompanied with Animations on Overcoming 11th Grade Students' Alternative Conceptions of Chemical Bonding," *Computers & Education* 52, no. 3 (April 2009): 681–95, https://doi.org/10.1016/j.compedu.2008.11.017.
[15] Tim N. Höffler and Detlev Leutner, "Instructional Animation versus Static Pictures: A Meta-Analysis," *Learning and Instruction* 17, no. 6 (December 2007): 722–38, https://doi.org/10.1016/j.learninstruc.2007.09.013.

visualizations help learners allocate attention more effectively and integrate multiple representational levels in chemistry learning.[16] By externalizing invisible processes such as electron transfer and electron sharing, animations reduce the mental effort required to infer these processes from static diagrams or verbal descriptions alone.

An important contribution of the present study is its demonstration of consistent instructional effects across multiple school settings. While prior studies have often been conducted in single classrooms or controlled laboratory environments, the current findings suggest that well-designed animation-based instruction can function as a robust pedagogical tool across varied institutional contexts. This is particularly relevant for secondary education systems where instructional quality and resources may differ substantially across schools. The consistency observed across schools indicates that animation-supported instruction may help standardize access to high-quality conceptual representations in chemistry learning.

Despite these contributions, several limitations warrant consideration. The use of purposive sampling and relatively small group sizes within each school may limit the generalizability of the findings. In addition, the study focused on short-term learning outcomes measured immediately after instruction; therefore, conclusions regarding long-term retention or sustained conceptual change cannot be drawn. Future research should employ longitudinal designs, larger samples, and mixed-methods approaches to examine how students internalize animated representations over time and how these representations influence misconceptions and transfer of learning.

The findings provide empirical support for integrating animation-based instructional resources into secondary school chemistry education. When grounded in cognitive theory and aligned with instructional objectives, animations can serve as an effective means of supporting students' understanding of abstract scientific concepts, thereby enhancing learning outcomes in chemistry.

CONCLUSION

This study examined the effectiveness of an animation-based instructional package in enhancing secondary school students' understanding of chemical bonding. Using a quasi-experimental design across eight secondary schools, the findings demonstrated that students who received animation-supported instruction consistently achieved higher posttest scores than those taught using conventional teaching methods. In addition, the absence of significant performance differences among experimental groups across schools indicates that the instructional benefits of the animation package were stable across varied educational contexts.

The findings contribute to the growing body of research on multimedia learning in science education by providing multi-school empirical evidence that animation-based instruction can effectively support students' comprehension of abstract chemical concepts.

[16] Sheng-Chang Chen, Mi-Shan Hsiao, and Hsiao-Ching She, "The Effects of Static versus Dynamic 3D Representations on 10th Grade Students' Atomic Orbital Mental Model Construction: Evidence from Eye Movement Behaviors," *Computers in Human Behavior* 53 (December 2015): 169–80, https://doi.org/10.1016/j.chb.2015.07.003.

By visually representing submicroscopic processes such as electron transfer and electron sharing, the animation package helped reduce cognitive barriers associated with chemical bonding. It supported the construction of coherent mental models. These results reinforce theoretical perspectives from multimedia learning research that emphasize the importance of integrating verbal explanations with dynamic visual representations.

From a practical standpoint, the study suggests that animation-based instructional resources can serve as a valuable pedagogical tool in secondary school chemistry instruction, particularly for topics involving complex, invisible processes. When thoughtfully designed and implemented with teacher guidance, animations can improve learning outcomes and provide more equitable access to high-quality conceptual explanations across schools with varying instructional conditions.

Despite its contributions, the study has limitations that should be acknowledged. The use of purposive sampling and relatively small group sizes within each school may limit the generalizability of the findings. Moreover, the study focused on short-term learning outcomes and therefore does not address long-term knowledge retention or the persistence of conceptual change. Future research should explore longitudinal effects, examine additional chemistry topics, and investigate how specific animation design features influence students' learning processes and conceptual understanding. The findings underscore the pedagogical value of animation-based instruction for supporting secondary school students' understanding of abstract scientific concepts. Integrating cognitively informed animations into chemistry instruction holds promise for improving learning outcomes and advancing the quality of science education.

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