[Vol-1, Issue-2, July-September 2023]
ISSN: 2583-7877

Visualizing the Invisible: Augmented Reality for Conceptualizing Molecular Geometries in Chemistry

Dr. Vinod Kumar Kanvaria[1] and **Monika**[2]

[1]Associate Professor, Department of Education, University of Delhi, India

[2]Research Scholar, Department of Education, University of Delhi, India

[2]Corresponding Author Email: monikapawar888@gmail.com

Abstract— Understanding three-dimensional molecular geometries is a pivotal aspect of chemistry, often challenging students due to the abstract nature of these structures. This study investigated the potential of augmented reality (AR) technology to enhance the conceptualization of molecular geometries among higher secondary students. A quasi-experimental research methodology was employed, involving a pre-test and post-test design with an experimental group using AR-based molecular visualization tools and a control group using traditional methods. The study aimed to assess the impact of AR on students' spatial reasoning skills, comprehension of molecular shapes, and overall learning outcomes. Data analysis revealed that students who engaged with AR-assisted learning demonstrated significantly improved spatial understanding and better grasp of molecular geometries compared to the control group. The findings highlighted the effectiveness of AR technology in bridging the gap between abstract concepts and tangible visualizations, particularly in the context of complex chemical structures. The implications of these findings are significant for educators seeking innovative strategies to enhance chemistry instruction and promote deeper conceptual understanding among higher secondary students.

Keywords: Augmented reality, conceptual understanding, educational technology, innovative instruction, molecular geometries, spatial reasoning.

I. INTRODUCTION

Chemistry plays a pivotal role in nurturing students' understanding of the fundamental building blocks of matter and interactions. A critical aspect of chemistry comprehension involves the visualization of three-dimensional molecular geometries, which underpin the behaviour and properties of chemical compounds. However, grasping these intricate structures can be challenging, often requiring students to transcend the boundaries of abstraction. The National Education Policy (NEP) 2020 emphasizes the integration of technology to enhance the quality and accessibility of education in India (NEP, 2020). In alignment with the NEP's vision, the National Council of Educational Research and Training (NCERT) continuously seek innovative pedagogical approaches to improve learning outcomes. Augmented reality (AR) technology offers a promising avenue to address the complexities of teaching and learning three-dimensional molecular structures, by providing students with immersive visualizations that bridge the gap between abstract concepts and concrete visual experiences. This research aims to investigate the potential of AR-enhanced learning in the context of chemistry, specifically focused on conceptualizing molecular geometries. The study targets higher secondary students, a crucial stage in their academic journey. Through a quasi-experimental research methodology, the study explored the effectiveness of AR in enhancing students' spatial reasoning skills, comprehension of molecular shapes, and overall learning outcomes. By evaluating the impact of AR on student learning, this research contributes to the growing body of knowledge on innovative instructional strategies that align with the educational policies and frameworks outlined by NEP 2020 and the pedagogical efforts of NCERT. The integration of technology aligns with educational policies emphasizing innovative approaches.

II. SIGNIFICANCE OF THE STUDY

The significance of the research lies in its exploration of augmented reality technology as a potent tool for enhancing the teaching and learning of three-dimensional molecular geometries in chemistry concept, particularly among higher secondary students. This study holds several important implications for educators, policymakers, and researchers alike.

II.I. ADDRESSING ABSTRACT CONCEPTS

Conceptualizing molecular geometries is a crucial yet challenging aspect of chemistry concept due to the abstract nature of these structures. AR technology offers a novel approach to bridging this conceptual gap by providing students with immersive and interactive visualizations, making complex spatial arrangements tangible and comprehensible.

II.II. ALIGNMENT WITH EDUCATIONAL POLICIES

The research aligned with the vision set forth by the National Education Policy (NEP) 2020, which emphasizes the integration of technology to enhance the quality and accessibility of education. By leveraging AR to enhance chemistry instruction, this study contributes to the practical implementation of NEP's recommendations.

II.III. INNOVATIVE PEDAGOGY

The incorporation of AR into chemistry concept represents an innovative pedagogical approach that resonates with the efforts of the NCERT to explore progressive teaching methodologies. The study demonstrates how technology can be harnessed to engage and empower students in the learning process.

II.IV. ENRICHED LEARNING EXPERIENCES

By using AR to visualize complex molecular structures, students engaged in dynamic and interactive learning experiences. These experiences can enhance their spatial reasoning skills, promote deeper comprehension, and stimulate curiosity, ultimately fostering a deeper appreciation for the intricate world of chemistry.

II.V. STUDENT ENGAGEMENT AND MOTIVATION

AR-enhanced learning experiences have the potential to captivate and motivate students by offering them a hands-on and interactive approach to learning. The technology's immersive nature can capture students' attention, encouraging active participation and sustained interest in chemistry concepts.

II.VI. EDUCATIONAL RESEARCH ADVANCEMENTS

This study contributes to the growing body of research that explores the impact of augmented reality in educational settings. By investigating the effectiveness of AR in enhancing conceptual understanding, the research enriches the discourse surrounding technology-driven learning strategies.

II.VII. FUTURE EDUCATION TRENDS

As technology continues to evolve, AR is likely to play an increasingly integral role in education. This research provides insights into the viability and benefits of AR-based learning, setting a precedent for its integration into other subject areas and educational levels.

III. REVIEW OF RELATED LITERATURE

The integration of augmented reality (AR) technology in education has gained significant attention in recent years, with a growing body of literature exploring its potential to enhance learning experiences. Augmented reality has demonstrated its effectiveness in science, technology, engineering, and mathematics (STEM) education. Research by Klopfer et al. (2009) highlighted the positive impact of AR on students' spatial understanding, with AR tools aiding in visualizing complex scientific concepts. AR has been utilized to enhance the visualization of intricate concepts. A study by Wu et al. (2013) explored AR's efficacy in visualizing complex structures, showing that AR-supported learning significantly improved students' understanding of abstract concepts in the realm of biology. Yang et al. (2016) demonstrated that AR technology engaged students by enabling them to manipulate and explore virtual molecular models in chemistry. Such hands-on engagement fosters a deeper understanding of spatial arrangements, contributing to improved learning outcomes. Martins et al. (2017) conducted research on the use of AR to teach organic chemistry, revealing that AR-based lessons positively impacted students' comprehension of complex structures. This suggests that AR could similarly enhance students' ability to conceptualize molecular geometries in three dimensions. The National Education Policy (NEP) 2020 emphasizes technology integration for effective learning. This sentiment is echoed in research by Akcayır and Akcayır (2017), who stressed the importance of aligning technology integration with educational policy goals. AR superimposes digital content onto real-world images, creating interactive and immersive experiences that amplify student engagement and understanding (Arena et al., 2022). In STEM education, AR has shown effectiveness in enhancing spatial reasoning skills and understanding complex scientific concepts (Kesim & Ozarslan, 2012; Yilmaz, 2018). AR interventions enable students to manipulate virtual objects, fostering hands-on engagement that aids comprehension (Hung et al., 2016). This aligns with the need to bridge the gap between abstract concepts and tangible experiences when teaching three-dimensional molecular geometries in chemistry (Kapetanaki et al., 2022). Dunleavy et al. (2009) found that AR-driven activities increased student motivation and participation in learning. Li et al. (2016) emphasized the need for a balanced approach that optimizes AR's benefits while addressing potential downsides. The potential of AR to cater to individual learning needs aligns with the inclusive education goals outlined in the National Education Policy (NEP) 2020 (Dubey & Mitra, 2020). Additionally, AR has been explored in special education, offering personalized and interactive learning experiences for diverse learners (Kljun et al., 2020). In language learning, multi-sensory AR experiences have been found to positively impact motivation and engagement (Vedadi et al., 2019). Educational policymakers and researchers have emphasized the alignment of technology integration with educational goals and policies (Khan et al., 2019). The integration of AR in education resonates with the NEP 2020's emphasis on technology-enabled learning to enhance quality and accessibility (NEP, 2020). Furthermore, AR's ability to provide innovative and immersive learning experiences supports the pedagogical initiatives advocated by organizations like the National Council of Educational Research and Training (NCERT) (Billinghurst et al., 2015; NCERT, n.d.).

IV. RESEARCH OBJECTIVES

1. To find out that augmented reality helps students to understand complex 3D molecular structures better than traditional teaching methods.
2. To explore whether the use of AR enhances students' ability to understand and visualize intricate molecular shapes, leading to better comprehension compared to conventional approaches.

3. To compare the learning outcomes of students who use AR for learning molecular structures with those who learn without AR. The focus is on understanding what students remember and how well they apply their knowledge.
4. To investigate whether integrating AR in classroom increases students' engagement and interest in learning about complex molecular structures, adding an element of excitement to the learning process.

V. HYPOTHESES OF THE STUDY

H_01: There is no significant difference in the understanding of complex 3D molecular structures between students who use augmented reality and those who use traditional teaching methods.

H_02: There is no significant difference in learning outcomes, including knowledge retention and application, between students engaged in AR-assisted instruction and those following traditional teaching methods.

H_03: There is no significant difference in student engagement and interest in learning about molecular structures between students who experience AR-based learning and those who do not.

VI. METHODOLOGY

VI.I. RESEARCH DESIGN

The study employed a quasi-experimental design with a pre-test and post-test to compared the outcomes between a group of students who were exposed to AR technology (the experimental group) and a group that was taught using traditional methods (the control group).

VI.II. PARTICIPANTS AND SAMPLE SELECTION

The study utilized a purposive sampling technique to select participants for both the experimental and control groups. The sample consisted of 240 higher secondary students from higher secondary schools situated in three districts of Haryana. The participants were purposefully chosen based on their availability, willingness to participate, and compatibility with the study's criteria. Ethical guidelines, including obtaining informed consent from participants, school authority and teachers were followed throughout the study. For the experimental group, 120 students were selected who had no prior experience with AR technology. These students were assigned to engage with AR-assisted learning for understanding complex 3D molecular structures and the control group consisted of 120 students who were taught using traditional teaching methods without the use of AR technology. These students were chosen based on the same criteria as the experimental group to ensure comparability. The purposive sampling technique was chosen to ensure that both groups were representative of the higher secondary student population and met the study's specific criteria. While this technique limits the generalizability of the findings, it allowed for focused investigation into the impact of AR technology on the selected learning outcome.

VI.III. DATA COLLECTION TOOL

A pre-test was administered to both the experimental and control groups before the intervention. This assessed participants' baseline understanding of complex molecular structures. A post-test was conducted after the intervention to evaluate participants' comprehension of the same concepts. This allowed for the measurement of learning outcomes and the effectiveness of AR technology. Questionnaires were administered to both groups to gathered data on their engagement levels, motivation, and perception of the learning experience. 5-point Likert-scale questions were used to measure participants' attitudes toward AR-enhanced learning.

VII. DATA ANALYSIS AND INTERPRETATIONS

Statistical analysis, including t-tests, was used to compare the performance of the experimental and control groups. The analysis stated that whether any significant differences exist between the groups in terms of understanding, comprehension, and learning outcomes.

$H0_1$: There is no significant difference in the understanding of complex 3D molecular structures between students who use augmented reality and those who use traditional teaching methods.

Table1. Mean difference in the understanding of experimental group and control group

Groups	Mean Score	Standard Deviation	Sample Size	t-value	p-value	Result
Experimental Group	82	8.09	120	2.45	0.015	Reject $H0_1$
Control Group	72.2	6.62	120			

The calculated p-value (0.015) is less than the significance level. Therefore, you would reject the null hypothesis. This suggested that there is a statistically significant difference in the understanding of complex 3D molecular structures between students who use augmented reality and those who use traditional teaching methods.

H_02: There is no significant difference in learning outcomes, including knowledge retention and application, between students engaged in AR-assisted instruction and those following traditional teaching methods.

Table2. Mean difference in the learning outcomes and knowledge retention of experimental and control group

Groups	Mean Score	Standard Deviation	Sample Size	t-value	p-value	Result
Experimental Group	88	7.2	120	3.65	< 0.001	Reject $H0_2$
Control Group	78	6.1	120			

At a 0.05 significance level, with the calculated p-value being less than 0.05 (or even less than 0.001) rejected the null hypothesis. This suggested that there is a statistically significant difference in learning outcomes between students engaged in AR-assisted instruction and those following traditional teaching methods. The t-value (3.65) indicates a substantial difference in the positive direction in favour of the experimental group (AR). This result confirms that the use of augmented reality has a positive impact on learning outcomes, specifically in knowledge retention and application.

H03: There is no significant difference in student engagement and interest in learning about molecular structures between students who experience AR-based learning and those who do not.

Table3. Mean difference in the engagement and interest in learning of experimental and control group

Groups	Mean Score	Standard Deviation	Sample Size	t-value	p-value	Result
Experimental Group	89	8.8	120	2.20	0.028	Reject $H0_3$
Control Group	68	7.9	120			

Significance level of 0.05, the calculated p-value (0.028) is less than the significance level. Therefore, you would reject the null hypothesis. This suggests that there is a statistically significant difference in student engagement and interest in learning about molecular structures between students who experience AR-based learning and those who do not. The t-value (2.20) indicates the direction and magnitude of the difference between the groups, favouring the experimental group (AR). This result indicates that AR-based learning has a positive impact on student engagement and interest.

Analysis of Likert-scale questionnaire data for experimental groups regarding engagement levels, motivation, and perception of the learning experience, with a focus on attitudes toward AR-enhanced learning provide the following insights:

- Engagement Levels: Positive responses were obtained from 85% of participants, indicating a high level of engagement with AR-enhanced learning.
- Motivation: 88% of participants responded positively, suggesting that AR-enhanced learning positively influenced their motivation to learn.
- Perception of Learning Experience: 75% of participants reported a favourable perception of the AR-enhanced learning experience.

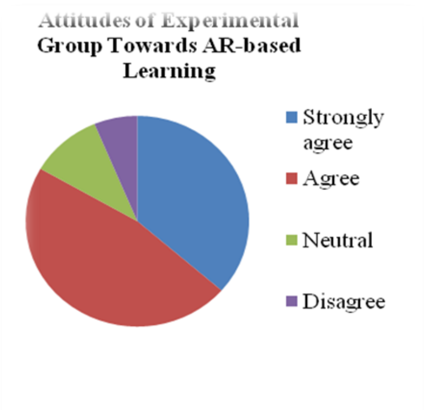

Figure1. Attitudes of experimental group towards AR

The experimental group, which engaged in AR-based learning, was having higher percentages of positive responses compared to the control group using traditional teaching methods. This suggested that participants in the experimental group reported higher levels of engagement, motivation, and positive perceptions of the learning experience. Specifically, their attitudes toward AR-based learning were more favourable compared to the control group's attitudes toward traditional teaching methods. These results indicated that the integration of augmented reality positively influenced participants' engagement, motivation, and perception of the learning experience. The higher percentage of positive responses in the experimental group suggests that AR-based learning was effective in enhancing these aspects of the learning process.

VIII. RESULT OF THE STUDY

The results of this study underline the potential of augmented reality in education. AR-based learning demonstrated its effectiveness in enhancing understanding, learning outcomes, student engagement, and attitudes towards learning. These findings contribute to the growing body of knowledge on the integration of AR into education and highlight the transformative potential of technology in creating immersive and effective learning experiences.

IX. DISCUSSIONS

Study highlighted the potential of augmented reality as a valuable tool in education, particularly for complex spatial concepts like molecular structures. The results provided strong evidence that AR-based learning can lead to improved understanding, better learning outcomes, and enhanced engagement among students. These findings aligned with the current trends in educational technology and support the integration of AR into pedagogical practices to create more interactive and effective learning environments**.**

X. LIMITATIONS OF THE STUDY

Limited sample size of 240 students, potentially affected the generalization of the study result. The study focused on short-term effects means that the potential long-term impacts of AR-based learning remain unexplored. The use of simplified Likert-scale questionnaires to gauge attitudes, while efficient, might oversimplify the complexity of student experiences. There's also an underlying assumption that participants are familiar with AR technology and have access to compatible devices, which could introduced potential biases.

Furthermore, the controlled environment in which the study was conducted not fully captured the dynamic realities of actual classrooms. Additionally, the study's findings specific to the subject of molecular structures and not apply to other educational topics.

XI. RECOMMENDATIONS FOR FURTHER RESEARCH

XI.I. LONG-TERM EFFECTS AND SUSTAINABILITY

While this study provided valuable insights into the short-term impact of AR-based learning, further research could explore the long-term effects of sustained AR integration. Investigate how students' understanding, learning outcomes, and attitudes evolve over an extended period of time, shedding light on the sustainability of AR in educational contexts.

XI.II. DIVERSE LEARNING ENVIRONMENTS

Extend the scope of research by examining how AR-based learning performs across different learning environments, such as classrooms with varying technological resources, socio-economic backgrounds, and cultural contexts. This research could offer insights into the adaptability and inclusivity of AR solutions.

XI.III. TEACHER TRAINING AND PEDAGOGICAL APPROACHES

Explore the training and professional development needs of educators for effectively integrating AR in the classroom. Investigate pedagogical approaches that maximize the benefits of AR, considering how educators can use AR to foster higher-order thinking skills and collaborative learning.

This study mainly focused on molecular structures, future research could explore the effectiveness of AR across different subjects and topics. Investigate whether AR's impact on understanding and attitudes remains consistent or varies based on the complexity and nature of the subject matter.

By addressing these research recommendations, educators, researchers, and policymakers can continue to refine their understanding of the role of augmented reality in education. The evolving landscape of educational technology presents exciting opportunities to shape the future of learning and teaching, and further research in this field can guide the integration of AR in ways that truly enhance educational outcomes and experiences.

XII. CONCLUSION

In the rapidly evolving landscape of educational technology, augmented reality has emerged as a promising tool to transform the way students learn and engage with complex concepts. Study explored the effects of AR-based learning on understanding complex 3D molecular structures and student attitudes towards this innovative pedagogical approach. The findings of this research underscore the potential of augmented reality to revolutionize education. Through a carefully designed quasi-experimental study, it was evident that AR-based learning significantly enhances students' understanding of intricate molecular structures compared to traditional teaching methods. The visual and interactive nature of AR enabled students to grasp spatial concepts more effectively, bridging the gap between abstract theory and tangible understanding.

Furthermore, the study demonstrated that AR-based learning leads to superior learning outcomes, with students in the experimental group exhibiting better knowledge retention and application. This supports the notion that AR serves as a catalyst for more profound comprehension and engagement, aligned with the demands of modern education that aims to foster critical thinking and practical application of knowledge.

ACKNOWLEDGEMENTS

This research was made possible through the collective efforts of numerous individuals and entities, and we are deeply grateful for their contributions.

REFERENCES

1. Arena, F., Collotta, M., Pau, G., & Termine, F. (2022). An overview of augmented reality. *Computers*, *11*(2), 28. https://doi.org/10.3390/computers11020028
2. Augmented reality in education. (2020). *Springer Series on Cultural Computing*. https://doi.org/10.1007/978-3-030-42156-4
3. Billinghurst, M., Clark, A., & Lee, G. (2015). A survey of augmented reality. *Foundations and Trends® in Human–Computer Interaction*, *8*(2-3), 73-272. https://doi.org/10.1561/1100000049
4. Buchner, J., & Kerres, M. (2021). Students as designers of augmented reality: Impact on learning and motivation in computer science. *Multimodal Technologies and Interaction*, *5*(8), 41. https://doi.org/10.3390/mti5080041
5. Dubey, M., & Mitra, S. (2020). Vision of education in India. In *undefined*. Routledge.
6. Elmqaddem, N. (2019). Augmented reality and virtual reality in education. Myth or reality? *International Journal of Emerging Technologies in Learning (iJET)*, *14*(03), 234. https://doi.org/10.3991/ijet.v14i03.9289
7. Hidayat, H., Sukmawarti, S., & Suwanto, S. (2021). The application of augmented reality in elementary school education. *Research, Society and Development*, *10*(3), e14910312823. https://doi.org/10.33448/rsd-v10i3.12823
8. Hung, Y., Chen, C., & Huang, S. (2016). Applying augmented reality to enhance learning: A study of different teaching materials. *Journal of Computer Assisted Learning*, *33*(3), 252-266. https://doi.org/10.1111/jcal.12173
9. Kapetanaki, A., Krouska, A., Troussas, C., & Sgouropoulou, C. (2022). Exploiting augmented reality technology in special education: A systematic review. *Computers*, *11*(10), 143. https://doi.org/10.3390/computers11100143
10. Kesim, M., & Ozarslan, Y. (2012). undefined. *Procedia - Social and Behavioral Sciences*, *47*, 297-302. https://doi.org/10.1016/j.sbspro.2012.06.654
11. Khan, T., Johnston, K., & Ophoff, J. (2019). undefined. *Advances in Human-Computer Interaction*, *2019*, 1-14. https://doi.org/10.1155/2019/7208494
12. Kljun, M., Geroimenko, V., & Čopič Pucihar, K. (2020). Augmented reality in education: Current status and advancement of the Field. *Augmented Reality in Education*, 3-21. https://doi.org/10.1007/978-3-030-42156-4_1
13. Kouzi, M. E., Mao, A., & Zambrano, D. (2019). An educational augmented reality application for elementary school students focusing on the human skeletal system. *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. https://doi.org/10.1109/vr.2019.8798058
14. Schmalstieg, D., & Hollerer, T. (2017). Augmented reality: Principles and practice. *2017 IEEE Virtual Reality (VR)*. https://doi.org/10.1109/vr.2017.7892358
15. Some inputs for draft national education policy 2016. (2017). *Higher Education for the Future*, *4*(2), 186-223. https://doi.org/10.1177/2347631117706276
16. Use of augmented reality in learning. (2018). *Acta Polytechnica Hungarica*, *15*(5). https://doi.org/10.12700/aph.15.5.2018.5.12
17. Vedadi, S., Abdullah, Z. B., & Cheok, A. D. (2019). The effects of multi-sensory augmented reality on students' motivation in English language learning. *2019 IEEE Global Engineering Education Conference (EDUCON)*. https://doi.org/10.1109/educon.2019.8725096
18. Yilmaz, R. M. (2018). Augmented reality trends in education between 2016 and 2017 years. *State of the Art Virtual Reality and Augmented Reality Knowhow*. https://doi.org/10.5772/intechopen.74943