Effect of Augmented Reality on Spatial Visualization Skills of Students in Understanding Chemical Bonding among Undergraduate Students of Sokoto State

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Abstract

This study investigated the effect of augmented reality on spatial visualization skills of students in understanding chemical bonding among undergraduate students of Sokoto state. The study was guided by three research objectives, three research questions and three null hypotheses on Spatial visualization of students. The study adopted quasi experimental design with pretest posttest control group structure. The study has a population of 414 100level undergraduate chemistry students out of which 200 were selected using purposive sampling technique and divided in to experimental and control group. The data was collected using spatial visualization test (SVT) and analyzed using descriptive statistics including mean, mead difference and standard deviation to answer the research questions and inferential statistics including paired sample t test and independent sample t test to test hypotheses. The findings of the research showed that AR significantly improve students' spatial visualization skill by providing them with virtual representation of abstract concepts and allowing them to interact with them in real time.

Keywords: Spatial visualization skills, Chemical Bonding, Abstract

Introduction

Chemistry is a branch of science that deals with the study of nature, properties, structure, composition and transformation of matter. It plays vital role in the life of human and generally living organisms. Chemical knowledge provides many advances in the field of agriculture, environment, energy, health, medicine, pharmacy, electronics, aerospace, biotechnology, nanotechnology, and other aspects of life (ChemE, 2023). Royal Society of Chemistry (RSC, 2022) noted that chemical substance are all over and sustaining the world ranging from water, food, drinks, cars, engines, clothes to energies we utilized.

Noting the importance of chemistry to all aspect of lives and how it tries to study various component of every single matter, it was made as compulsory subject for students intending to study all the disciplines outlined above. In view of these various researches were conducted and some are still ongoing to analyze effective strategies of teaching and learning this crucial subject. (Faruku, 2019)

However, despite the importance of chemistry, understanding the abstract concepts is very challenging for students (Cai, 2014). Therefore, the visualization of three dimensional (3D) models might play an important role in the process of comprehending this world (Aw, 2020). These models may represent chemical processes at the atomic level, which are inaccessible to sensory experience and often difficult to understand and use, as they demand high cognitive and spatial capacity, as well as abstraction skills (Frevert & Di Fuccia, 2019).

So also in understanding chemical bond which is a fundamental aspect of chemistry education, student often face difficulties in understanding the concept due to the lack of proper visualization of some chemical components. According Lynch (2023) student often struggle to understand the concept of atoms and molecules interacting in ways they cannot see directly. They tend to rely on macroscopic analogies that may not accurately reflect microscopic reality. That is why augmented reality has become a noteworthy tool for chemistry teaching, providing users with an environment of coexistence between reality and virtually (Lin, 2015). The term chemical bond refers to the force that holds atoms together in molecule and compound. Chemical bond involve abstract concepts that are not directly observable making it too difficult for students to visualize and understand chemical substances.

Consequently, educators were interested in employing contemporary and virtual technologies to assist learning environments, such as Augemted reality, vitual reality and artificial intellegnce, these technologies creatively and engagingly supports learning environments by fusing reality with digital interactions (Jesionkowska, 2020). Also, it helps in improving visualization skills of students (Yaseer, 2023). Hence, there is a propensity to combine different technologies to uphold learning goals and maximize their outcomes through the orientation of the learner centered learning strategy. AR in particular allows real and virtual objects to interact with one another, which is the only technology that connects physical reality to virtual data. It delivers a direct or indirect picture of the physical world in real time that is heightened by the addition and overlay of virtual data (Fokides & Mastrokoukou, 2018). Additionally, AR technology can be used directly or indirectly in the teaching and learning environment to assist and sustain learners in dealing with knowledge and interacting with it (visually and auditory) in an easier way to represent, store, and test knowledge (Sun, 2018).

Spatial visualization skills refers to the ability to mentally manipulate, analyze and visualize objects or shapes in three dimensions (Chiu, 2025). Spatial visualization skills are crucial for understanding complex scientific concepts such as chemical bonding, which often involve interpreting three dimensional structures and spatial relationships. Augmented Reality (AR) has shown significant promise in enhancing these skills by providing, interactive 3D visualizations that help students better understand the spatial aspects of molecules and their bonds. Studies have demonstrated that students using AR tools, such as CHEMBOND3D e modules, exhibit notable improvements in their ability to visualize and understand chemical structures compared to traditional learning methods (Kuit, & Osman, 2021). These tools allow students to manipulate virtual models, fostering a deeper comprehension of spatial relationships in chemistry (Kuit, & Osman, 2021).

Significance of the Study

This study is significant in several key ways. First, it contributes to the growing body of knowledge on the integration of Augmented Reality (AR**)** in science education, particularly in the teaching and learning of abstract chemistry concepts like chemical bonding. By comparing AR with traditional instructional methods, the study offers empirical evidence on the effectiveness of AR in enhancing students' spatial visualization skills**.** For educators, the findings will provide insight into the pedagogical benefits of AR-based instruction, potentially informing more effective and interactive teaching strategies in tertiary chemistry classrooms. Students stand to benefit directly from improved comprehension and retention of complex chemical concepts, especially those requiring mental manipulation of molecular structures.

Augmented Reality

Augmented Reality (AR) is a technology that overlays digital information onto the real world, providing an interactive and enhanced experience. AR simulations in education allow students to visualize abstract concepts and complex structures, making learning more engaging and intuitive. In chemistry education, AR can help students understand molecular structures and chemical bonds by providing three-dimensional, flexible models (Delgado-Kloos, 2018).

AR integrates virtual and real-world environments using specialized software and programming, displaying them on smart devices (Çetin and Türkan, 2022; Syawaludin, 2019). This technology allows the presentation of digital content such as images, videos, and various multimedia forms, enhancing interaction for both students and teachers and fostering deeper, more effective learning (Petrov and Atanasova, 2020; Demircioglu, 2022). AR does not require any special equipment, and since most teenagers today have smartphones with cameras, they can readily access and use augmented reality (Yaser, 2023).

Recent meta-analyses and systematic literature reviews have highlighted the increasing popularity of researching and applying AR in educational settings, as well as the educational benefits and drawbacks of this technology (Mariscal, 2020). To be considered an AR system, three characteristics are required: the mixing of real and virtual elements, real-time interaction, and three-dimensional registration (Petrov and Atanasova, 2020; Kul and Berber, 2022; Kalemkuş and Kalemkuş, 2022). Additionally, AR technology can incorporate text, video, images, audio, info graphics, and 2D/3D models (Tekedere and Göke, 2016), allowing users to interact with virtual objects within real-world scenes, thereby gaining practical experience with human-computer interaction (Ajit, 2021; Radu, 2023).

According to Pramanik (2025) AR is categorized into two types: location-based AR and vision-based AR. Location-based AR allows users to utilize GPS-enabled smart devices to track the distance between two locations. This technology combines data from the GPS, gyroscope, compass, camera, and other sensors with location data to provide information about the physical environment (Godwin-Jones, 2016; Demircioglu, 2022). Second, vision-based augmented reality focuses on image recognition techniques adopted to locate actual objects in their natural surroundings, so that virtual contexts associated with these objects can be appropriately placed. Its tracking system is classified as either marker-based or monocular (Demircioglu, 2022). Marker-based tracking requires specific labels, such as QR codes, to register the 3D images, unlike marker less tracking; hence, any part of the real environment can be utilized to trigger the virtual images. Labels, QR codes, and virtual images are examples of “triggers” or “markers,” which can be placed at any time and in any location. As the AR application controls the camera to recognize markers, the device screen can display 3D graphics or other types of actions (Godwin-Jones, 2016; Meletiou-Mavrotheris, 2019).

Spatial Visualization Skills

Spatial ability refers to a set of cognitive functions and skills essential for solving problems that involve manipulating and processing visuo-spatial information (Carlisle, Tyson, and Nieswandt, 2015). It is one of the most extensively studied areas of cognitive ability (Daniel Elford, 2022). Uttal (2024) states that there are two major spatial skills:

I. Spatial orientation. A measure of the ability to remain unconfused by changes in the orientation of visual stimuli.

II. Spatial visualization. A measure of the ability to mentally restructure or manipulate the components of the visual stimuli. It is characterized as a series of complicated multi-step manipulations of spatially presented information.

McInerney (2024) identified two essential visualization processes: manipulating and extrapolating visual imagery, and transforming abstract relationships and non-figural data into visual terms. Visual imagery is the ability to mentally represent the visual appearance of an object. Piri and Cagiltay (2024), describe a third spatial skill, spatial relation, which involves mentally rotating an object on its axes. Spatial relation is unique and distinct from other spatial abilities as it also engages brain areas associated with motor simulation (Balaban & Ullman, 2025). Spatial imagery involves mentally representing the spatial relations between parts or locations of an object to understand a problem. Spatial images retain information about an object in a form that is accessible to cognitive processes (Daniel, 2022).

Uttal and McKee (2024) report a highly significant correlation between spatial ability and tasks related to spatial reasoning in general chemistry. Further studies have consistently recognized spatial ability as a crucial factor in understanding scientific principles and academic performance (Tong, Zheng, and Zhong, 2025) If students struggle to connect observable macroscopic phenomena with submicroscopic concepts, it can hinder their full understanding of chemistry (Johnstone, 1991).

The solution lies in developing students' visual literacy. Interpreting symbols and understanding the particulate nature of spatial structures are crucial skills for solving problems in chemistry. Additionally, the chemistry education literature highlights the importance of supporting students' spatial reasoning skills through the use of molecular models (Kiernan, Manches & Seery, 2024). Consequently, a primary objective of chemistry education is to improve students' spatial abilities to construct and mentally manipulate cognitive representations of chemical phenomena. According to Cagiltay and Bichelmeyer (2024) spatial ability can be developed through three processes:

I. **Visualization processes** Perceiving spatial relations between objects and maintaining perceptual constancy.

II. **Construction processes**: Creating mental images and performing mental rotations.

III. **Reasoning processes**: Solving problems and completing exercises.

Augmented Reality (AR) provides students with the opportunity to view molecular representations from multiple perspectives when rotated. A widely recognized and frequently employed test for assessing rotation is the Purdue Spatial Visualization Test (Bartlett, 2024) which is utilized in this research. The PSVT requires students to visualize a given 3D object, perform a mental rotation of that object, and then choose the correct new view. (Daniel Elford, 2022)

Statement of Problem

Chemistry is one of the core subject of science and has received less interest from students because they found it difficult to understand. Studies revealed that students have difficulties in understanding most of the concepts in Chemistry and hold misconceptions which lead to the prevention of meaningful learning of the subject. A 21-year analysis (1999–2019) of West African senior secondary school certificate Examination (WASSCE) results showed that only 50.84% of candidates scored credit and above in Chemistry (Obafemi, 2025). This low performance of students highlights structural gaps in understanding, particularly of abstract concepts like chemical bonding. Moreover, WAEC Chief Examiner reports 2023 repeatedly cite students' inability to correctly draw bonding diagrams, balance equations, and grasp molecular structures as key reasons for poor performance in both theory and practical sections (Smith, 2020). Locally, assessments from some Sokoto State institutions show similar trends where more than 51% of students could not score more than 50% of their chemistry examination. Some concepts in chemistry that are associated with chemical structure and bonding, such as molecules, ions, hydrogen bonds and giant lattices, are abstract which create difficulties that may lead to misconceptions or difficulties in understanding chemistry. Chemical bonding is one of the foundational topics of chemistry that is abstract in nature, hence students find it very difficult to understand chemical bonding. Researchers have recommended that school curriculum most especially that of science or chemistry in particular should include representations modern technologies such as AR, VR and AI which may help many student to easily understand the concepts after viewing either static molecular visualizations or animations (Fang & Guo, 2016).

Objectives of the Study

The main aim of the study is to determine the effect of augmented reality on spatial visualization skills of students in understanding chemical bonding. Specifically, the objectives are to:

I. Determine the difference in spatial visualization skills of undergraduate students before and after learning chemical bonding through augmented reality.

II. Determine the difference in spatial visualization skills between undergraduate students who learned chemical bonding using augmented reality and those who learned chemical bonding via traditional method

III. Determine the difference in spatial visualization skills between male and female undergraduate students who learned chemical bonding via augmented reality

Research Questions

I. What is the difference in spatial visualization skills of undergraduate students before and after learning chemical bonding through augmented reality?

II. What is the difference in spatial visualization skills between undergraduate students who learned chemical bonding using augmented reality and those who learned chemical bonding via traditional method

III. What is the difference in spatial visualization skills between male and female undergraduate students who learned chemical bonding via augmented reality?

Research Hypothesis

I. There is no significant difference in spatial visualization of undergraduate students before and after learning chemical bonding through augmented reality.

II. There is no significant difference in spatial visualization skills between undergraduate students who learned chemical bonding using augmented reality and those who learned chemical bonding via traditional method

III. There is no significant difference in spatial visualization skills between male and female undergraduate students who learned chemical bonding via augmented reality.

Methodology

A quasi experimental designed was used with pretest posttest control group structure, the design was considered suitable because complete randomization may not be possible due to logistical reasons. A total of 414 100level undergraduate students from three public institutions of Sokoto inclusing Shehu Shagari University of education Sokoto, Sokoto State University and Usman Danfoyo University Sokoto, were considered as the population of the study out of which 200 were selected as the sample using purposive sampling technique. The selected sample was then grouped in to experimental and control groups where students of Usman Danfoyo Univeristy (102) students serves as the control group, students of Shehu Shagari Univeristy and Sokoto State Univeristy serves as the experimental group (98 students). The control group was taught using traditional method while the experimental was taught using AR based learning. Each group will receive a test before and after the intervention. Spatial visualization test (SVT) was used as the instrument for the data collection, The (SVT) used in this study was adapted from the Padua Visualization Test developed by Bors, Kosslyn, and Thompson (1999). To align the instrument with the context of chemical education, some of the original visualizations were modified to include chemical structures and bonding patterns relevant to undergraduate chemistry students. The instrument was validated by three experts in Science Education to ensure content relevance and appropriateness for the target population. The reliability of the instrument was determined using the test-retest method, yielding a reliability coefficient of 0.71, indicating an acceptable level of consistency. The test made up of 20 questions with multiple chemical structures. Data collected was analyzed using both descriptive and inferential statistics. Generally descriptive statistics including mean, standard deviation and mean difference was used to answer research questions, while inferential statistics including paired sample t-test and independent sample t-test was used to test hypotheses.

Data Analysis

The data was analyzed based on the research questions.

Research question one: What is the difference in spatial visualization skills of undergraduate students before and after learning chemical bonding through augmented reality?

Table 1: Difference in spatial visualization skills before and after the intervention

Test	N	Mean	Mean Dif.	Std. Dev
Pretest	200	5.53	4.80	3.520
Posttest	200	10.33		2.166

The results presented in Table 1 reveal a marked improvement in students' spatial visualization skills following the use of augmented reality (AR) in learning chemical bonding. The pretest mean score was 5.53, while the posttest mean rose significantly to 10.33, indicating a mean difference of 4.80. This suggests that the use of AR had a positive impact on enhancing students' ability to mentally manipulate and visualize molecular structures, which are core components of spatial reasoning in chemistry. However, to measure whether or not the difference is significant the data was further subjected to paired sample t test to test hypothesis one.

Table 2: Significant difference in spatial visualization skills before and after intervention

Test	Mean	df	t-value	p-value	Decision
Pretest	5.53	199	16.849	0.000	H_{01} Rejected
Posttest	10.33				

Table 2 presents the results of the paired sample t-test used to determine the difference in students' spatial visualization skills before and after the intervention. The analysis shows a pretest mean of 5.53 and a posttest mean of 10.33. With a t-value of 16.849 at 199 degrees of freedom and a p-value of 0.000, the result is statistically significant at the 0.05 level. Therefore, the null hypothesis, which stated that there is no significant difference in spatial visualization skills before and after using augmented reality, is rejected.

Research Question Two: What is the difference in spatial visualization skills between undergraduate students who learned chemical bonding using augmented reality and those who learned chemical bonding via traditional method?

Table 3: Difference in Spatial Visualization Skills of the Respondents between groups

S/N	Group	F	Average Mean	Std. Dev.	Mean Dif.
1	Control Group	102	7.99	2.548	4.78
2	Experimental Group	98	12.77	2.624	

Table 3 presents the spatial visualization skills of the respondents in both the control and experimental groups. The results show that the control group (N = 102) had an average mean score of 7.99 with a standard deviation of 2.548, while the experimental group (N = 98) had a higher average mean score of 12.77 with a standard deviation of 2.624. The mean difference between the two groups is 4.78, indicating that the experimental group, which was exposed to augmented reality learning, demonstrated better spatial visualization skills compared to the control group that used traditional methods. Moreover, to determine whether or not the difference is significant the data was subjected to independent sample t test to test hypothesis two.

Table 4: Significant Difference in Spatial visualization skills between groups

Group	Mean	Std. Dev.	df	t	p-values	Decision
Experimental	12.77	2.55	198	13.02	0.000	H_{02}
Control	7.99	2.63				Rejected

Table 4 present the result of independent samples t-test conducted to compare the spatial visualization skills of students exposed to augmented reality and those taught using traditional methods. The results show a statistically significant difference between the two groups ($t = -13.02$, $df = 198$, p-value < 0.05). The mean score for students exposed to augmented reality was 12.77 ($SD = 2.55$), indicating better performance in the spatial visualization test compared to the control group, whose mean score was 7.99 (SD = 2.63). Based on these results, Hypothesis One is rejected, confirming that augmented reality has a significant positive effect on spatial visualization skills.

Research Question Three: What is the difference in spatial visualization skills between male and female undergraduate students who learned chemical bonding via augmented reality?

Table 5: Difference in spatial visualization skills between genders

Test	N	Mean	Mean Dif.	Std. Dev.
Male	69	12.81	0.15	2.691
Female	29	12.66		2.208

Table 5 shows the difference in spatial visualization skills between male and female students who learned chemical bonding using augmented reality. The mean score for male students was 12.81, while that of female students was 12.66, resulting in a small mean difference of 0.15. The standard deviations for both groups were also relatively close. This indicates that both male and female students benefited similarly from the use of augmented reality, with only a slight and negligible difference in their spatial visualization scores. The data was further subjected to independent sample t test to test hypothesis three.

Table 6: Significant difference in spatial visualization skill between genders

Group	Mean	Std. Dev.	df	t	p-values	Decision
Male	12.81	2.691	96	0.276	0.056	H_{03}
Female	12.66	2.208				Accepted

Table 6 presents the result of the independent samples t-test conducted to determine whether there is a significant difference in spatial visualization skills between male and female students taught using augmented reality. The mean scores were 12.81 for males and 12.66 for females, with a t-value of 0.276 at 96 degrees of freedom and a p-value of 0.056. Since the p-value is greater than the 0.05 level of significance, the null hypothesis is accepted. This means that there is no statistically significant difference in spatial visualization skills between male and female students, indicating that gender did not influence the outcome of the augmented reality intervention.

Discussion

The findings from the first research question revealed that students significantly improved their spatial visualization skills after being taught chemical bonding using augmented reality (AR). This suggests that AR, by providing interactive and immersive visual experiences, allows learners to engage more deeply with abstract and complex scientific concepts such as molecular structures. Augmented reality enhances learners' ability to mentally manipulate 3D forms, which is essential in visualizing atomic interactions and bonding patterns. These results are consistent with the conclusions of Radu (2014), who emphasized that AR promotes meaningful learning by merging real-world and digital information in a way that supports spatial reasoning. Likewise, Kucuk (2016) found that students learning through AR developed stronger spatial skills due to the dynamic and visual nature of the content delivery.

For the second research question, the study found a notable difference in spatial visualization skills between students who were taught using AR and those who received instruction through traditional teaching methods. Students in the AR group outperformed their counterparts, indicating that conventional approaches may be less effective in fostering the spatial understanding required in chemistry. This aligns with the work of Akçayır and Akçayır (2017), who asserted that AR provides cognitive and perceptual support that is often missing in standard classroom instruction. Moreover, studies by Wojciechowski and Cellary (2013) show that the multisensory and interactive nature of AR not only increases student engagement but also supports deeper cognitive processing, which translates into improved academic performance in visually demanding subjects.

Regarding the third research question, findings indicated that both male and female students benefited similarly from the use of augmented reality in learning chemical bonding, with no significant gender-based differences in spatial visualization skills. This suggests that AR is an inclusive technology that supports learners across gender lines by offering equal access to interactive and visual learning experiences. These findings are supported by the work of Dunleavy et al. (2009), who noted that AR applications can minimize learning disparities by providing individualized and self-paced experiences that cater to diverse learner needs. Similarly, research by Ibáñez and Delgado-Kloos (2018) supports the view that AR technologies foster equitable participation and performance among students, regardless of gender, especially in STEM-related disciplines.

Summary of the Major findings

I. There is significant difference in spatial visualization of students between before and after learning chemical bonding using augmented reality, with high visualization skill after the intervention.

II. There is significant difference in spatial visualization skills between students learns chemical bonding using augmented reality and those learn using traditional method. With those learns using augmented reality showing higher visualization skills.

III. There is no significant difference in spatial visualization skill between male and female's students that learns chemical bonding using augmented reality.

Conclusion

This study investigated the effect of augmented reality (AR) simulations on spatial visualization skills of 100level undergraduate chemistry students in public institutions in Sokoto State. The findings revealed that students who learned chemical bonding using AR performed significantly better in spatial visualization tasks compared to those taught using traditional methods. By providing interactive and immersive learning experiences, AR helped students visualize molecular structures more effectively, thereby strengthening their spatial reasoning and conceptual understanding. The findings also support constructivist learning theories, particularly Vygotsky's Social Constructivism, which emphasizes the role of interactive and technology driven learning environments in knowledge construction.

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