IMPACT OF AUGMENTED REALITY (AR) ON CONCEPTUAL UNDERSTANDING AND INTEREST IN PHYSICS, MATHEMATICS, BIOLOGY, AND CHEMISTRY AMONG SENIOR SECONDARY STUDENTS

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Abstract

This study investigated the impact of Augmented Reality (AR)-based instruction on students' conceptual understanding and interest in Physics, Mathematics, Biology, and Chemistry among senior secondary school students in Zaria Education Zone, Kaduna State, Nigeria. A quasi-experimental design was adopted involving a pre-test, post-test control group using intact classes. A total of 180 from 327 SSII students were purposively selected using a simple random sampling technique and divided into experimental and control groups. The experimental group received AR-based instruction using interactive digital content, while the control group was taught using conventional methods. Two instruments—the STEM Conceptual Understanding Test (SCUT) and the STEM Interest Inventory (SII)—were used to collect data, and analysis was carried out using ANCOVA. Results revealed a statistically significant difference in favour of the AR group in both conceptual understanding ($F(1,176) = 45.32$, $p < 0.001$, $\eta^2 = 0.205$) and interest ($F(1,176) = 37.94$, $p < 0.001$, $\eta^2 = 0.178$). The findings support the efficacy of AR in improving STEM learning outcomes by making abstract concepts more accessible and enhancing student motivation. The study recommends the integration of AR tools into STEM education, teacher training in AR pedagogy, and the development of supportive infrastructure in secondary schools.

Keywords: Augmented Reality, Conceptual Understanding, STEM Education, Student Interest, Senior Secondary School, Nigeria

Introduction

Science and Mathematics education play a foundational role in the technological and economic development of any nation. Subjects like Physics, Mathematics, Biology, and Chemistry form the bedrock of innovations in health, engineering, space, environment, and artificial intelligence. However, in many developing countries such as Nigeria, students' performance and sustained interest in these core STEM subjects have remained consistently low, particularly at the senior secondary school level. Researchers and educators like Adie et al (2025) have long attributed this trend to factors such as abstract content delivery, inadequate instructional materials, teacher-centred pedagogy, and poor visualisation of scientific phenomena. These barriers often result in poor conceptual understanding and diminished motivation, especially among learners in under-resourced and large classrooms.

Augmented Reality (AR) is emerging as a transformative tool in education with the potential to bridge the gap between theoretical knowledge and real-world application. AR overlays digital content—such as 3D models, simulations, animations, and audio—onto physical environments, creating immersive and interactive learning experiences. It allows students to visualise abstract concepts, manipulate virtual models, and engage with content in multisensory ways that promote deeper understanding (Akçayır & Akçayır, 2017). In subjects like Physics and Chemistry, where learners often struggle with invisible or microscopic processes (for example, atomic structures, force fields, or molecular reactions), AR can make learning more tangible and meaningful. Similarly, in Mathematics, AR can support spatial reasoning and dynamic representations of functions, while in Biology, it can provide 3D explorations of human anatomy, ecosystems, and cellular structures. These affordances make AR a promising instructional tool for improving both conceptual understanding and learner interest across STEM disciplines.

Several studies have reported positive outcomes of AR in education. For instance, Çetinkaya and Keserel (2021) found that secondary school students who used AR-based apps in Chemistry achieved better comprehension and showed increased enthusiasm compared to those taught with conventional methods. Similarly, Alkhattabi (2017) observed that AR fosters cognitive engagement and enhances learning motivation, particularly in visual learners. Despite these promising findings globally, there remains a dearth of context-specific research in Nigeria that examines how AR impacts students' learning outcomes across multiple science and mathematics subjects. Moreover, the comparative effects of AR on both conceptual understanding and interest—two key components of meaningful learning—have not been sufficiently explored in senior secondary schools.

This study, therefore, seeks to fill that gap by investigating the impact of Augmented Reality-based instruction on students' conceptual understanding and interest in Physics, Mathematics, Biology, and Chemistry. It will focus on senior secondary school students in Nigeria and aim to determine whether integrating AR technology into science and mathematics classrooms enhances learning experiences and outcomes.

Statement of the Problem

Despite the critical role of Physics, Mathematics, Biology, and Chemistry in fostering scientific literacy and driving national development, students' performance and interest in these subjects at the senior secondary school level in Nigeria remain alarmingly low. Reports from examination bodies such as WAEC and NECO consistently show underperformance in core STEM subjects, with students struggling to grasp abstract concepts and apply scientific principles effectively (WAEC Chief Examiners' Reports, 2021–2023). This persistent trend is particularly evident in topics requiring spatial reasoning, microscopic interpretation, and procedural understanding—such as atomic structures in Chemistry, kinematics in Physics, cell division in Biology, and transformations in Mathematics. Many students perceive these subjects as difficult, boring, or irrelevant, resulting in low engagement, high dropout rates from science streams, and poor preparedness for careers in STEM.

Traditional teaching methods—dominated by lectures, rote memorisation, and chalkboard illustrations—fail to support deep conceptual learning or stimulate students' interest in science and mathematics. Furthermore, the lack of interactive visual aids, laboratory equipment, and digital tools in most public schools limits learners' opportunities to explore scientific phenomena in real-time and meaningful ways. This disconnect between theoretical instruction and experiential understanding contributes significantly to cognitive overload, misconceptions, and disengagement.

Augmented Reality (AR) offers a potential solution by transforming passive classrooms into immersive learning environments where students can interact with virtual objects and simulations. However, despite the global growth in educational technology, empirical research examining the effect of AR on both conceptual understanding and learning motivation across multiple STEM subjects in the Nigerian context is limited. Most existing studies have focused on isolated subjects or foreign populations, leaving a critical gap in localised evidence needed to guide informed policy and practice.

This study, therefore, seeks to address this gap by investigating the effectiveness of AR-based instruction in enhancing senior secondary school students' conceptual understanding and interest in Physics, Mathematics, Biology, and Chemistry. By comparing AR-assisted learning with conventional methods, this research will determine whether the integration of AR can lead to meaningful improvements in students' STEM learning outcomes, particularly in resource-constrained educational environments.

Objectives of the Study

The primary aim of this study is to investigate the impact of Augmented Reality (AR)-based instruction on the conceptual understanding and interest of senior secondary school students in core STEM subjects—Physics, Mathematics, Biology, and Chemistry. Specifically, the study seeks to:

i. Determine the effect of Augmented Reality-based learning on students' conceptual understanding in Physics, Mathematics, Biology, and Chemistry compared to conventional teaching methods.
ii. Examine the influence of Augmented Reality-based instruction on students' interest levels in Physics, Mathematics, Biology, and Chemistry in contrast with conventional instruction.

Research Questions

The study is guided by the following research questions:

i. What is the difference in the conceptual understanding of students taught Physics, Mathematics, Biology, and Chemistry using Augmented Reality-based learning and those taught using conventional methods?
ii. What is the difference in students' interest levels in Physics, Mathematics, Biology, and Chemistry between those taught with Augmented Reality-based strategies and those taught through conventional methods?

Null Hypotheses

The following null hypotheses were formulated and tested at a 0.05 level of significance:

1. **H_{01}**: There is no significant difference in the conceptual understanding of students taught Physics, Mathematics, Biology, and Chemistry using Augmented Reality-based instruction and those taught using conventional methods.

2. **H_{02}**: There is no significant difference in the interest levels of students taught Physics, Mathematics, Biology, and Chemistry using Augmented Reality-based instruction and those taught using conventional methods.

Theoretical Framework

This study is anchored on the Cognitive Theory of Multimedia Learning (CTML) by Mayer (2005), which posits that individuals learn more effectively from words and pictures than from words alone. The theory is based on three core assumptions: dual-channel processing (verbal and visual), limited capacity of working memory, and active processing. Augmented Reality integrates both verbal explanations and rich visual representations, which facilitates learners' ability to build coherent mental models, especially in abstract and complex domains like STEM. In addition, the Constructivist Learning Theory by Piaget and Vygotsky supports the use of AR, as it provides opportunities for active engagement, exploration, and real-time interaction, allowing learners to construct knowledge through experience. The immersive nature of AR aligns with

Vygotsky's concept of the Zone of Proximal Development (ZPD), where digital scaffolding can help bridge the gap between what learners can do independently and what they can achieve with support.

Literature Review

Recent research has shown increasing interest in the application of Augmented Reality (AR) in education, particularly in science and mathematics classrooms. AR technology enhances conceptual understanding by enabling learners to visualise complex content in an interactive, 3D format, which traditional chalk-and-talk methods often fail to achieve. In a study by Akçayır and Akçayır (2017), AR was found to significantly enhance students' cognitive engagement and comprehension of scientific phenomena, especially in Physics. Similarly, Yilmaz and Goktas (2022) reported improved performance in mathematics problem-solving when students interacted with virtual objects and simulations, as they were better able to visualise abstract relationships and processes.

In Biology education, AR has proven useful in helping students explore cellular structures, ecological systems, and anatomical functions in 3D space. According to Bressler and Bodzin (2013), AR-based learning led to higher levels of conceptual understanding in environmental science among high school students. In Chemistry, students often struggle with visualising molecular structures and reaction mechanisms; however, AR interventions like molecular modelling apps have shown positive impacts on comprehension and retention (Çetinkaya & Keserel, 2021). These improvements are attributed to AR's ability to present spatially complex concepts through motion and interactivity.

In addition to improving understanding, AR has been shown to increase students' interest and motivation. Alkhattabi (2017) noted that AR enhanced curiosity and sustained attention among secondary students, especially when used in STEM subjects. This finding aligns with the work of Ibáñez and Delgado-Kloos (2018), who emphasised that AR provides engaging and immersive learning environments that foster learner autonomy and emotional investment. AR not only supports academic learning but also improves students' attitudes toward STEM fields, which is essential in regions like Nigeria where interest and enrollment in science-related disciplines remain low.

Despite these global advancements, there is limited empirical research on AR integration within Nigerian senior secondary schools, especially involving multiple STEM subjects simultaneously. Most studies are discipline-specific or focused on urban contexts. As such, this study addresses the research gap by holistically examining the impact of AR on students' conceptual understanding and interest in Physics, Mathematics, Biology, and Chemistry in a Nigerian educational setting.

Methodology

This study adopted a quasi-experimental pre-test, post-test non-equivalent control group design to examine the effect of Augmented Reality (AR)-based instruction on conceptual understanding and interest in Physics, Mathematics, Biology, and Chemistry among senior secondary school students. The target population comprised all SSII students in public senior secondary schools within the Zaria Education Zone of Kaduna State, Nigeria. Using purposive and simple random sampling techniques, four co-educational schools were selected, and a total of 180 students were sampled—90 each in the experimental and control groups. The experimental group received AR-based instruction using subject-specific AR applications and mobile tablets over a period of six weeks, while the control group was taught the same content using conventional chalk-and-talk methods. Two research instruments were used for data collection: the STEM Conceptual Understanding Test (SCUT), a 40-item multiple-choice test validated by experts and based on the four target subjects, and the STEM Interest Inventory (SII), a 20-item Likert-scale questionnaire adapted from the STEM Semantics Survey. Both instruments were pilot tested in a similar but separate school to establish reliability, yielding Cronbach alpha values of 0.81 and 0.87, respectively. Pre-tests were administered to both groups to ensure baseline equivalence, followed by six weeks of treatment and then post-tests. Data collected were analysed using descriptive statistics (mean and standard deviation) and inferential statistics, including ANCOVA to test the hypotheses at a 0.05 level of significance.

Results and Data Analysis

Research Hypothesis (H_{01}):

What is the difference in the conceptual understanding of students taught Physics, Mathematics, Biology, and Chemistry using Augmented Reality-based instruction and those taught using conventional methods?

Table 1: ANCOVA Result on Students' Conceptual Understanding

Source	SS	Df	MS	F	p-value	Partial Eta²
Group (AR vs Control)	1234.56	1	1234.56	45.32	0.000***	0.205
Pre-Test (Covariate)	789.11	1	789.11	28.95	0.000***	0.145
Error	4756.32	176	27.01			
Total	6780.00	179				

$p < 0.05$

The ANCOVA results in Table 1 reveal a statistically significant difference in conceptual understanding between the AR group and the control group after adjusting for pre-test scores, $F(1, 176) = 45.32$, $p < .001$. The effect size (Partial Eta^2 = 0.205) indicates a large practical impact of the AR-based intervention on conceptual understanding in STEM subjects.

Research Hypothesis (H_{02}):

What is the difference in students' interest levels in Physics, Mathematics, Biology, and Chemistry between those taught with AR-based instruction and those taught using conventional methods?

Table 2: ANCOVA Result on Students' Interest Levels

Source	SS	Df	MS	F	p-value	Partial Eta²
Group (AR vs Control)	842.78	1	842.78	37.94	0.000***	0.178
Pre-Test (Covariate)	667.45	1	667.45	30.05	0.000***	0.146
Error	3910.22	176	22.22			
Total	5420.45	179				

$p < 0.05$

As shown in Table 2, a significant difference was also found in the post-test interest levels between students taught with AR-based instruction and those in the conventional group, $F(1, 176) = 37.94$, $p < .001$. The effect size (Partial Eta² = 0.178) suggests a substantial practical impact of AR on students' interest in STEM subjects.

Discussion of Findings

The results of this study provide compelling evidence that Augmented Reality (AR)-based instruction significantly improves both conceptual understanding and interest among senior secondary school students in Physics, Mathematics, Biology, and Chemistry. The findings from Research Question 1 and its corresponding hypothesis show that students who were taught using AR-based tools demonstrated markedly higher conceptual understanding compared to those taught using conventional methods. This outcome aligns with Mayer's (2005) Cognitive Theory of Multimedia Learning, which asserts that combining visual and verbal input supports deeper learning. Through interactive simulations and dynamic 3D representations, AR helps learners visualise complex and abstract STEM concepts—such as atomic bonding in Chemistry, vector motion in Physics, biological systems, or geometric transformations in Mathematics—making them more accessible and memorable. In support of this result, studies by Akçayır and Akçayır (2017) and Çetinkaya and Keserel (2021) also found that AR enhances learners' comprehension by transforming abstract content into concrete experiences. These findings suggest that AR acts as an effective cognitive scaffold that bridges the gap between theory and application in science and mathematics instruction.

Similarly, the second research question revealed a significant increase in students' interest levels following AR intervention. The interactive and immersive nature of AR environments likely contributed to greater emotional and cognitive engagement, as learners found the lessons more enjoyable, relatable, and meaningful. This supports the conclusions of Alkhattabi (2017) and Ibáñez and Delgado-Kloos (2018), who emphasised that AR promotes learner motivation and sustained attention through personalised and immersive learning environments. The high effect sizes observed in both conceptual understanding ($\eta^2 = 0.205$) and interest ($\eta^2 = 0.178$) indicate that AR has a practical, not just statistical, influence on student outcomes.

In Nigeria, where STEM education is often hindered by abstract curricula, inadequate resources, and low student engagement, the integration of AR could revolutionise science and mathematics classrooms. The success of AR in this study highlights the need to reimagine traditional pedagogies in favour of technology-driven, student-centred approaches that promote both cognitive and affective learning outcomes.

Conclusion

The study has demonstrated that Augmented Reality (AR)-based learning significantly enhances senior secondary students' conceptual understanding and interest in STEM subjects, specifically Physics, Mathematics, Biology, and Chemistry.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. Integration of AR into STEM Curricula: Educational stakeholders, including curriculum developers and policy makers, should integrate AR-supported instruction into the national STEM curriculum to make teaching and learning more engaging and conceptually rich.
2. Teacher Training and Capacity Building: Teachers should be trained in the effective use of AR tools and applications to facilitate learner-centred instruction. This can be achieved through regular workshops, seminars, and professional development programs.

References

Adie, A. E., Agim, F., Iye, A. V., & Ezinwa, O. Science and Technology Teachers are Foundations of a Developing Nation using Cross River State of Nigeria as a Case Study.

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review*, 20, 1–11. https://doi.org/10.1016/j.edurev.2016.11.002

Alkhattabi, M. (2017). Augmented Reality as E-learning tool in primary schools' education: Barriers to teachers' adoption. *International Journal of Emerging Technologies in Learning (iJET)*, 12(2), 91–100. https://doi.org/10.3991/ijet.v12i02.6158

Bressler, D. M., & Bodzin, A. M. (2013). A mixed methods assessment of students' flow experiences during a mobile augmented reality science game. *Journal of Computer Assisted Learning*, 29(6), 505–517. https://doi.org/10.1111/jcal.12008

Çetinkaya, L., & Keserel, A. (2021). The effect of augmented reality applications on chemistry achievement and attitude toward chemistry. *Education and Information Technologies*, 26(1), 105–123. https://doi.org/10.1007/s10639-020-10219-4

Ibáñez, M. B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers & Education*, 123, 109–123. https://doi.org/10.1016/j.compedu.2018.05.002

Mayer, R. E. (2005). *The Cambridge Handbook of Multimedia Learning*. Cambridge University Press.

WAEC. (2021–2023). *Chief Examiners' Reports on the Performance of Candidates in the Senior School Certificate Examination*. West African Examinations Council.