AQUADEMIA
2026, 10(2), ep26006
ISSN 2542-4874 (Online)
https://www.aquademia-journal.com/

Research Article

OPEN ACCESS

Effect of Augmented Reality-Enhanced Hands-on Chemistry Activities (AREHCA) on students' academic performance in hybridisation and molecular shape

Daniel Morrison [1*], Charity Esenam Anor [1], Godfred Safo-Adu [1], Nelly Adjoa Sakyi-Hagan [1]

[1] University of Education, Winneba, GHANA
*Corresponding Author: danielmorinomorrison@gmail.com

Citation: Morrison, D., Anor, C. E., Safo-Adu, G., & Sakyi-Hagan, N. A. (2026). Effect of Augmented Reality-Enhanced Hands-on Chemistry Activities (AREHCA) on students' academic performance in hybridisation and molecular shape. *Aquademia, 10*(2), ep26006. https://doi.org/10.29333/aquademia/19283

ARTICLE INFO

Received: 02 Dec. 2025
Accepted: 04 Jul. 2026

ABSTRACT

Technology in science education enhances teaching and learning by helping students visualise abstract concepts. Augmented Reality-Enhanced Hands-on Chemistry Activities (AREHCA) integrate digital tools with practical tasks, supporting a deeper understanding of hybridisation and molecular shapes. This study investigated the effect of AREHCA on a purposively selected group of senior high school students in Ghana. The study employed an action research design with a sample of 65 students. Pre-tests, post-tests, and a delayed post-test were used to measure performance and retention, while gender effects were examined using t-tests, frequencies, and correlation analysis. The results showed a statistically significant improvement in students’ performance after the intervention, with the delayed post-test confirming sustained knowledge retention. A very weak negative correlation between male and female scores indicated that AREHCA benefited both genders equally. The study therefore recommends the integration of AREHCA into the teaching of hybridisation and molecular shapes to further improve students’ academic performance.

Keywords: augmented reality-enhanced hands-on chemistry activities, academic performance, hybridisation, molecular shapes, chemistry education

INTRODUCTION

Educational institutions, especially the senior high schools, are embracing cutting-edge technology with the hope of enriching the teaching and learning processes, of which Ghana is no exception (Mensah et al., 2022; Serdyukov, 2017). This technological evolution is paving the way for the creation of learning environments that are not just realistic and engaging but also enjoyable, promoting curiosity in learners (Tang et al., 2022). The focus of this study is the realm of Augmented reality-enhanced hands-on chemistry activities (AREHCA) in education, a domain with the potential to revolutionise how humans engage with the use of traditional hands-on activities blended with the use of computers and digital learning in chemistry education (Ekwueme et al., 2015; Mahr et al., 2023). AREHCA stands at the intersection of traditional hands-on learning and augmented reality technology, promising to transform the landscape of chemistry education. Beem (2020) and Bougsiaa (2016) opine that this technique serves as a bridge between the real world and the realm of virtual reality, with a particular emphasis on its educational potential. With AREHCA, digital information integrates with the physical environment, superimposing computer-generated images onto the real world, and creating a harmonious blend where users can interact with real and virtual objects in the chemistry classroom (Graham et al., 2022).

Both Augmented reality (AR) and hands-on activities have been shown to have impacted learning positively (Astuti et al., 2019; Shana & Abulibdeh, 2020). The use of AR in education has the potential to enhance problem-solving skills (Astuti et al., 2019), reduce cognitive load on learners, increase motivation in the realm of chemistry, and improve academic performance (Kao & Ruan, 2022). Additionally, studies suggest that hands-on activities can improve students’ confidence in their academic abilities and promote engagement in the learning process (Zhang et al., 2016). According to the Ministry of Education of Ghana (2010), the Ghanaian chemistry syllabus requires that the hybridisation and shapes of molecules be treated in such a way that the particular the hybridisation states and shapes of molecules, be it sp, sp^2, sp^3, linear, bent, trigonal planar, trigonal bipyramidal, tetrahedral, and octahedral be illustrated for students to comprehend. To achieve this, students should be able to make connections of the three fundamental levels of chemical representations, which are the macroscopic, sub-microscopic, and symbolic dimensions (Luviani et al., 2021).

These students are often challenged with comprehending the connection among these fundamental levels, which affects their academic performance (Luviani et al., 2021). The challenge requires a teaching strategy that would enable students experience learning through visualisation and practice with real objects. However, there remains a research gap in the school where the study was carried out, with regard to the use of augmented reality tools , such as AREHCA, in helping students construct knowledge of the concept of hybridisation and molecular shapes, and the level of chemical representations. The integration of augmented reality applications, such as the MEL Science app, into hands-on chemistry activities has the potential to empower students with experimental concepts, ultimately enhancing their academic performance and skills acquisition (Jokiranta, 2014; Resnyansky et al., 2018). This exploration is therefore paramount as it holds significant implications for educational practices aimed at promoting deeper understanding and mastery of the chemistry concepts among students (Ogbeba & Ajayi, 2018; Ziden et al., 2022).

Recognising the need for innovative approaches to address these issues, a blend of augmented reality and hands-on activities would create an interactive and immersive learning environment for chemistry learners (Jiménez, 2019). In light of this perspective, this study aimed to determine the effect of augmented reality-enhanced hands-on chemistry activities (AREHCA) on the selected students' academic performance in hybridisation and molecular shapes. The following research questions were addressed in the study:

RQ1. What is the effect of AREHCA on students' academic performance in hybridisation and molecular shapes?

RQ2. What is the differential effect of AREHCA on the academic performance of male and female students in hybridisation and molecular shapes?

LITERATURE REVIEW

Theoretical Framework of the Study

Constructivism is a learning methodology that stresses learners' active participation in creating their own understanding and awareness of the world. It allows individuals to build concepts of reality in their minds by what they do, how they interact with others, and by thinking about what they have done (Piaget, 1950). In an education setup, constructivism therefore argues beyond the idea of information getting passed from the teacher to the student, but instead it becomes a means through which learners make meaning out of their experiences (Vygotsky, 1978). Under its lenses, learners are active contributors rather than mere passive receivers of knowledge (Holmes, 2019). Their prior beliefs, earlier knowledge, and experiences influence their interpretation of new information, thereby shaping their understanding of the world. The cognitive activities involved in this process include classification, comparison, sampling inferencing as well as reflecting upon the ideas (Bruner, 1961).

Scaffolding, a key element of constructivism, refers to the provision of guidance and support for learners to add onto what they already know (Misra & Vaishali, 2019). This can be in the form of prompts, hints, modelling, and feedback, which should gradually decrease with increased independence. Constructivist learning environments are designed in such a way that they involve students in active inquiry, exploration, and problem-solving (Mogashoa, 2014). Typically, these include hands-on activities, class discussions on various topics as well as working together on projects with practical applications. Through the manipulation of materials by learners, misunderstandings can be rectified while more accurate mental models about what is being learned are developed. In addition to this, constructivism places great emphasis on the fact that the learning process is social, hence interaction and collaboration are paramount (Vygotsky, 1978). It sees learning as a socially situated process facilitated through dialogues amongst peers and teachers within the classroom space (Hurst et al., 2013). Interaction with classmates or teachers may help one see things differently, thereby helping someone to make sense of the topic better by raising questions or offering suggestions.

In augmented reality enhanced hands-on chemistry activities (AREHCA), constructivism is the guiding force behind creating and implementing learning experiences that allow students to actively understand hybridisation and molecular shapes (Erbas & Demirer, 2019). Also, AREHCA provides a platform which students can manipulate virtual molecular models, conduct experiments through a game or activity, and explore molecular structures on their own while immersed in the virtual reality. Thus, through the use of augmented reality-based chemistry activities, students can form mental models of these molecular shapes by observing, interacting with the materials used, and then reflecting on them. Also, as students have access to mediated support and peer guidance, they can progress in their understanding of hybridisation and molecular shape (Boonmoh & Jumpakate, 2019). Moreover, cooperation among peers and teachers results in interactions among them so that they all respond according to what happens, stimulating personal reflection on key concepts about chemistry, especially for hybridisation and molecular shapes. As such, the constructivist approach underlies the design of AREHCA as it aims at making learning environments dynamic, interactive, and student-centred using technology as an integral part of it; hence, fostering active participation during classroom instruction.

Augmented Reality (AR) in Teaching and Learning

Augmented reality in teaching and learning is the use of technology in merging virtual elements, like videos, graphics, and animations, seamlessly with real-world environments in real-time in the chemistry classroom (Smuseva & Rolich, 2018). Its potential in education has garnered significant attention, evidenced by various meta-analyses citing its effectiveness (Garzón & Acevedo, 2019). In chemistry, augmented reality (AR) has been explored, particularly in visualising complex microstructures of substances. For instance, Zheng and Waller (2017) pioneered "ChemPreview", an innovative AR application facilitating the manipulation of biomolecular structures at the atomic level. Notably, this tool enables intuitive interactions with proteins, utilising natural hand gestures to enhance user engagement and comprehension. Similarly, Lee and Tucker-Kellogg (2020) unveiled 'Palantir', an innovative open-source AR tool tailored for visualising protein molecular structures. Palantir empowers users to manipulate 3D models through intuitive gestures like zooming and rotating on mobile device screens. Moreover, Lee and Tucker-Kellogg extended its utility by developing two application prototypes designed for university courses.

Furthermore, some researches have included uses of augmented reality (AR) into real-world educational settings. For example, Chen and Liu (2020) looked at how AR combined with a variety of teaching strategies affected students' learning. Their results showed that the hands-on AR group fared much better on an interest questionnaire and a chemical reaction concept exam than the demonstration AR group. Furthermore, studies have demonstrated that implementing AR in chemistry classes can improve students' retention of knowledge over time. For example, Cai et al. (2014) developed an inquiry-based augmented reality learning tool centered on "the composition of substances," showcasing its ability to improve students' cognitive abilities and cultivate good attitudes toward learning. According to Vázquez-Cano et al. (2020), these studies collectively provide evidence in favour of the sustainability of augmented reality in chemistry instruction. The main idea behind this is that AR makes it easier to see concepts in the microscopic world by superimposing virtual elements onto the actual world (Wu et al., 2013). According to Akçayir and Akçayir (2017), it also provides an interactive operating experience at the micro-level, allowing users to interact with virtual objects intuitively and get an instant response.

The use of augmented reality in educational settings, particularly in chemistry classrooms, has some restrictions, according to some academics. According to Squire and Jan (2007), AR may prove difficult for students to use effectively if it is not supported by a well-designed interface and sufficient guidance. Furthermore, problems like sluggish touch features, erroneous recognition, and location-based augmented reality apps may require more lecture time, which would complicate the learning process. Given these challenges, evaluating user acceptance is crucial when introducing new technology into a specific domain. Considering the benefits and the challenges, AREHCA would likely offer a new avenue for facilitating interactive learning experiences by enhancing the real world with virtual elements while at the same time allowing students to manipulate objects through hands-on activities if implemented effectively. Unlike virtual reality (VR), AREHCA focuses on enhancing virtual objects within real imagery, thereby ensuring users remain connected to the physical world (Batdı & Talan, 2019). Indeed, AREHCA represents a modern technology that overlays encoded multimedia content, such as video, graphics, animation, text, or sound of chemical contents onto real-world objects captured by a camera, which serves as a tool for human-machine interaction (Yılmaz & Batdı, 2016).

Hands-on Activities and Their Effect on Students' Learning in the Chemistry Classroom

Hands-on activities in the chemistry classroom involve learners using their hands to engage in concrete tasks that enhance their learning experiences (Selco, 2020). These tasks include weighing, measuring, demonstrating, conducting tests or experiments, and other actions contributing to students' achievement and retention in the chemistry classroom. According to Dayal and Ali-Chand (2022), hands-on activities in the chemistry classroom are instructional methods where students actively participate, both mentally and physically, to enhance efficient learning experiences in the chemistry classroom. AREHCA therefore, presents students with the opportunity to manipulate physical materials during their learning process. This approach, centered on the concept of learning by doing, which implies that organised activities are undertaken by teachers and students for a common educational goal result in more effective and lasting learning (Bates, 2015).

Additionally, a variety of interactive assignments known as hands-on activities are intended to pique students' attention and encourage their participation in the learning process (Kibga et al., 2021). Therefore, rather than being passive learners in the chemistry classroom, these activities enable the students to actively participate in creating their own knowledge. Students' excitement and increased interest in chemical activities are fostered by hands-on activities, which result in meaningful learning in the classroom (Ajayi, 2017). Students' experiences are improved, and their academic achievement is much raised by this active participation. Research has shown that using hands-on teaching methods improves student performance. These include a study by Shah and Rahat (2014) that found that when a hands-on educational strategy was utilised, the experimental group's performance differed significantly from that of the control group in terms of knowledge, comprehension, and application abilities. Luecke et al. (2023), who found that students in hands-on programs outperformed comparison groups by 20 percentile units, lend support to this. Students' ingenuity in addressing problems, independence, and ability to overcome early disabilities could all be enhanced by the hands-on approach to education (Anwer, 2019). This implies that allowing students to manipulate objects during the teaching and learning process could result in significant improvement for even below-average students. According to Puranik (2020), students benefit greatly from the hands-on approach to teaching and learning. He maintained that the practical exercises encourage students to participate in class and provide attention to their needs, which helps them become more imaginative, critical thinkers, and innovators.

A study was conducted by Kırılmazkaya and Dal (2022) on the effect of the hands-on method on students' academic achievement and scientific attitude. The authors observed a significant difference in favour of the experimental group when comparing the scientific attitude scale results between the control group, taught using traditional methods, and the experimental group. Another study by Ekwueme et al. (2015) on the effectiveness of hands-on activities on the academic performance of students in science and mathematics. This study aimed to examine the influence of a hands-on approach on students' academic achievements and their perspectives on this hands-on method-based teaching method. The findings indicated an improvement in both student performance and engagement in mathematics and basic science activities.

Additionally, 155 senior high school students participated in a study by Iyamuremye et al. (2023) on the value of practical, hands-on activities in teaching and learning chemistry. According to the results, students were actively participating and had favourable opinions about the application of chemistry in practical practice. The study also revealed a very statistically significant difference between the outcomes of the pre- and post-tests.

The impact of the hands-on activity learning method (HALS) on Delta State students' performance and interest in chemistry was evaluated in the Nweke et al. (2022) study. The findings showed that students who were taught using the Hands-on Activity Learning Strategy (HALS) and those who were taught using the lecture method (LM) had significantly different mean accomplishment and interest scores, with HALS being the more successful approach. The mean achievement and interest scores in chemistry for male and female students taught with HALS did not differ significantly, according to the study.

Moreover, a study was conducted by Osuntuyi (2021) on the impact of hands-on activities on students' academic achievement in science and technical education. The study concluded that hands-on activities significantly impact classroom concentration among science and technical education students. Additionally, these activities were found to enhance knowledge retention, foster creativity, and improve problem-solving skills in these students. Therefore, AREHCA is an innovative teaching approach that allows students to both interact physically with learning materials and engage virtually with complex chemical concepts. The blend of these two teaching strategies would help deepen students' understanding, enhancing motivation, and fostering critical thinking skills.

METHODOLOGY

Research Design

This study utilised an action research design, focusing exclusively on quantitative methods for data analysis. The quantitative approach involved evaluating students' academic performance both before and after the intervention, as well as comparing the performance of male and female students post-intervention scores.

Sample and Sampling Technique

An intact science class of 65 students formed the study sample. These students were purposely selected based on the chemistry concepts chosen and the class being available to the researchers.

Research Instruments

The research instrument used to measure students' performance was a test. A pre-intervention test assessed students' understanding of hybridisation and molecular shapes before the implementation of augmented reality-enhanced hands-on chemistry activities (AREHCA). This test featured 10 multiple-choice questions, two essay questions on the relevant concepts, and was administered within a 20-minute timeframe. Post-tests were conducted following each week of AREHCA implementation, but the final post-test, also called the delayed post-test, was carried out on the second week after the final AREHCA implementation. The delayed post-test was conducted in order to help determine students' retention of hybridisation and molecular shapes after the intervention. This resulted in a total of four post-tests over the study period. These post-tests comprised a total of eight essay questions and 40 multiple-choice items on hybridisation and molecular shapes, with each test also timed at 20 minutes. This implies that a particular post-test has 10 multiple-choice items, and two essay questions, just as the pre-tests. The post-tests aimed to evaluate the impact of AREHCA on students' academic performance and to compare the performance of male and female students following the intervention. To ensure effective learning had taken place, a delayed post-test, which was the final post-test, was conducted and compared to the means of the formative post-test data collected at the end of the first three weeks of the intervention. Each test (pre-test and post-tests) was scored over a total of 10 marks. The scoring was divided equally between the multiple-choice and essay sections. The multiple-choice section consisted of 10 items, with each question carrying 0.5 mark, giving a total of 5 marks. Students received full marks for correct answers and zero for incorrect or unanswered items. The essay section contained two questions, each allocated 2.5 marks, making a total of 5 marks. A marking scheme was used to award marks based on accuracy of content, correct scientific explanations, appropriate use of terms, clarity of diagrams, and completeness of responses. Partial marks were given where students showed some correct understanding.

Data Collection Procedure

The data collection procedures of this study took three stages: pre-intervention, intervention, and post-intervention activities. The pre-intervention activities took place within the first week of the research implementation. The researchers conducted a test on hybridisation and molecular shapes. This was to reaffirm the perceived conceptual difficulties that students had in hybridisation and molecular shapes. The pre-test consisted of 10 multiple-choice test items and two essay-type questions. With the multiple-choice items, the students were to select the most appropriate response from a set of four response options.

The intervention activities were carried out after the pre-intervention activities, and these activities were to address the difficulties students face in learning about hybridisation and molecular shapes. The intervention activities were clearly spelled out in the lesson note used by the researchers during the study. The activities were carried out within four weeks, and they are as follows;

Week 1: Introduction to hybridisation and molecular shapes

Objective: The student will be able to explain the concept of hybridisation and molecular shapes.

Duration: 1 hour 30 minutes

Activities:

- The lesson began with a lecture complemented by a video explaining atomic orbitals, valence bond theory, and the concept of hybridisation
- The hybridisation states (sp, sp^2, sp^3) were introduced, and how they relate to molecular shapes.

- The basic shapes of molecules (linear, trigonal planar, tetrahedral, trigonal bipyramidal, octahedral) were explained using video demonstrations.
- Students were engaged in a discussion about the importance of hybridisation and molecular shapes in chemical properties and reactions.
- Students were given an overview of how augmented reality, using the MEL Science app and molecular kits, will be used in the coming weeks to explore hybridisation and molecular shapes.
- A simple AR simulation was demonstrated to show the hybridisation state and shape of a molecule (HCl)
- A molecular kit was used to build molecular models (HCl) and to determine its hybridisation states.
- A post-test comprising 10 multiple choice question and two essay types was conducted to assess students' understanding.

Week 2: Describing hybridisation states of molecules

Objective: A student will be able to determine the hybridisation states of molecules.

Duration: 1 hour 30 minutes

Activities:

- Molecular kits were used to build models of some molecules (CH_3COOH, NH_3, I_2) to determine the hybridisation states of the built models of the molecules.
- The MEL Science App was used to show the shapes of these molecules (CH_3COOH, NH_3, I_2) to visualise their hybridisation states. The app allowed students to manipulate these virtual molecules from different angles to view their hybridisation states.
- Students were encouraged to compare their hands-on models with the AR visualisations and manipulations.
- There was a discussion by students on the characteristics of the various hybridisation states (sp, $sp^{2,}$ and sp^3)
- Students were encouraged to ask questions and clarify any doubts about hybridisation states.
- A post-test comprising 10 multiple choice question and two essay types was conducted to assess students' understanding.

Week 3: Illustrating shapes and bond angles of specific molecules (CH_3COOH, NH_3, I_2)

Objective: The student should be able to determine the shapes of molecules (CH_3COOH, NH_3, I_2).

Duration: 1 hour 30 minutes

Activities:

- Students were provided with a brief overview of each molecule's structure
- Molecular kits were used to build models of CH_3COOH, $NH_{3,}$ and I_2.
- The models of these molecules using the molecular kits helped students to determine the actual shapes of these molecules.
- The shapes of the CH_3COOH, NH_3 and I_2 were displayed in the virtual environment. Students had the opportunity to use the MEL Science app to manipulate these molecules in the virtual environment, which helped them to determine the actual shape of these molecules.
- The use of augmented reality and hands-on approach helped students to determine the bond angles in each molecule as well.
- The AR molecular models and the hands-on models were compared to appreciate both the virtual and physical manipulation of the molecules and their effects on students' conceptual understanding.
- Students were grouped and allowed to manipulate both the physical and the virtual models. They were also encouraged to discuss with one another how it helped them get a concrete understanding of the concepts.
- Students were encouraged to ask questions and clarify any doubts on the molecular shapes of CH_3COOH, $NH_{3,}$ and $I_{2.}$
- A post-test comprising 10 multiple choice question and two essay types was conducted to assess students' understanding.

Week 4: Illustrating shapes of specific molecules ($C_3H_8O_3$, H_2O_2, H_2O)

Objective: The student will be able to determine the shapes of $C_3H_8O_3$, HCl, $H_2O_{2,}$ and H_2O.

Duration: 1 hour 30 minutes

Activities:

- Students were provided with a brief overview of each molecule's structure
- The students used molecular kits to build models of $C_3H_8O_3$, $H_2O_{2,}$ and H_2O. They were also guided to determine the actual shapes and their bond angles in the virtual environment.
- The AR molecular models and the hands-on models were compared to appreciate both the virtual and physical manipulation of the molecules and their effects on students' conceptual understanding.
- For emphasis, students were grouped and allowed to manipulate both the physical and the virtual models. They were also encouraged to discuss or interact with one another to promote shared acquired knowledge.
- Students were encouraged to ask questions and clarify any doubts on the molecular shapes of $C_3H_8O_3$, HCl, H_2O_2, and H_2O.
- A post-test comprising 10 multiple choice question and two essay types was conducted to assess students' understanding.

Post-Intervention Activities

The post intervention activities comprised all the assessments carried out during and after the four-week intervention period. Besides the post-test after following every intervention, a delayed post-intervention test was carried out during the sixth week of the study to assess the impact of

Table 1. Frequency distribution of students' pre-test scores

Score	Pre-test Frequency (%)	Post-test 1 Frequency (%)	Post-test 2 Frequency (%)	Post-test 3 Frequency (%)	Delayed Post-test Frequency (%)
0-5	49 (75.38)	27 (43.55)	2 (3.08)	0 (0.0)	2 (3.08)
6-10	16 (24.62)	35 (56.45)	63 (96.92)	65 (100)	63 (96.92)
Mean	**3.92**	**5.78**	**7.35**	**8.28**	**9.29**

Table 2. Means and standard deviations of pre-intervention test and delayed post-test scores of students

Group	Test	N	Mean	SD	Mean Difference
Intact Class	Pre-Intervention test	65	3.92	1.86	5.37
	Post-Intervention test	65	9.29	0.71	

N=Number of Students, SD= Standard Deviation

AREHCA on students' academic performance and knowledge retention. The delayed post-test comprised two essay-type and 10 multiple-choice questions focusing on the concepts taught, just as the individual post-test. All questions were adapted from the West African Secondary School Certificate Examination past questions.

Validity and Reliability

Though the questions were adapted, the content and face validity were checked by experts in the content area to ensure that the items measured what they were supposed to measure. Reliability of the test items was determined using a test-retest method. In this method, the test was given to 20 students who were not part of the experimental group on two separate occasions. A Pearson's correlation coefficient value was therefore calculated to be 0.70.

Data Analysis

The pre-test, post-test, and delayed post-test were all displayed in tables and subjected to frequency, percentage, mean, and standard deviation. The t-test statistic was used to examine any notable variations in the academic performance of male and female students, as well as any differences between their academic performance before and after the intervention. A correlation study was also utilised to ascertain the association between the scores of male and female students using the Pearman's Correlation coefficient.

RESULTS AND DISCUSSIONS

Research Question 1: What is the Effect of AREHCA on Students' Academic Performance in Hybridisation and Molecular Shapes?

Table 1 presents the frequency distribution of students' pre-test scores. A majority of the students performed poorly in the pre-test, with 49 students (75.38%) scoring between 0 and 5, and only 16 students (24.62%) scoring in the higher range of 6-10. This suggests that students had very limited prior knowledge or understanding of hybridisation and molecular shapes before the intervention. After the first week of AREHCA intervention, results from Post-test 1 showed improvement, where the number of students in the 0-5 score range decreased significantly to 27 (43.55%), while those in the 6-10 range rose to 35 (56.45%). This marks a positive shift in performance, suggesting the early impact of the intervention. In Post-test 2, only 2 students (3.08%) remained in the 0-5 category, and a substantial 63 students (96.92%) scored within the 6-10 range. This improvement illustrates that the majority of the students had not only understood the concepts but were performing at higher academic levels.

In Post-test 3, the students' performance increased, with all 65 students (100%) scoring within the 6-10 range. The 0-5 range recorded no students, demonstrating the strong effectiveness of the continued intervention and students' ability to master the concept over time. Two weeks after the final intervention activity, the delayed post-test was carried out to determine the retention of hybridization and molecular shapes. The results remained higher, with 63 students (96.92%) scoring in the 6-10 range and only 2 students (3.08%) scoring 0-5 range. This suggests a high level of content retention among the students, even after the direct intervention had ended.

The mean score from the pre-test was 3.92, indicating generally low initial understanding. After the first week, the mean rose to 5.78 in Post-test 1, then increased more significantly to 7.35 in Post-test 2. The mean score in the post-test3 was 8.28, reflecting consistent and substantial learning gains over the weeks. The Delayed Post-test had the highest mean score of 9.29, surpassing all the earlier post-tests. This further reinforces the positive long-term effect of the AREHCA intervention. It not only demonstrates immediate academic improvement but also lasting learning, as students retained and potentially enhanced their understanding of hybridisation and molecular shapes even two weeks after the final intervention implementation.

The means and standard deviations of the pre-intervention test and the delayed post-test scores of students are presented in **Table 2**. From the results, the standard deviation is 1.86 for the pre-intervention test, and it indicates a considerable range of scores, highlighting variability in the students' performance. In contrast, the mean score of 9.29 after the implementation of AREHCA demonstrates a marked improvement. The lower standard deviation of 0.71 in the delayed post-intervention test suggests that the scores were more closely clustered around the mean, indicating greater consistency in student performance. The significant mean difference of 5.37 between the pre- and post-intervention tests points to the positive impact of AREHCA on the academic performance of students in understanding hybridisation and molecular shapes. The results thus show an improvement in students' academic outcomes, implying that the implementation of AREHCA had a beneficial effect on their learning and comprehension of the chemistry concept.

Table 3. Summary of t-test analysis of pre-intervention test and delayed post-intervention test scores of students

Group	Test	N	Mean	SD	df	t	p-value	Effect Size	Remarks
Intact Class	Pre-intervention test	65	3.92	1.86	64	30.70	0.000	3.81	Significant
	Post-intervention test	65	9.29	0.71					

N=Number of Students, SD=Standard Deviation, Significant at $p < 0.05$, Not Significant at $p > 0.05$ level of significance

Null hypothesis 1 was tested using data from senior high school students' pre-intervention and delayed post-intervention test scores using a paired samples t-test. **Table 3** displays the t-test analysis of pre-intervention test and delayed post-intervention test scores of students.

The results show a significant difference between the pre-intervention (M = 3.92, SD = 1.86) and the delayed posttest (M = 9.29, SD = 0.71), t (df= 64) = 30.70, p = 0.000. The null hypothesis is rejected because the p-value (0.000) is less than the alpha value of 0.05. This implies that students' performance before and after using AREHCA to teach hybridisation and molecular structures differed statistically significantly. The obtained effect size of 3.81 indicates an extremely large magnitude of the intervention's impact on students' performance. In interpreting effect size, researchers commonly rely on the criteria proposed by Cohen. According to Cohen's guidelines, an effect size of 0.20 is considered small, 0.50 is moderate, and 0.80 or above is regarded as large (Brydges, 2019). Therefore, the recorded effect size of 3.81 far exceeds the threshold for a large effect, indicating a very strong practical impact of the intervention. Empirical studies in science education support this interpretation. For instance, studies on technology-supported and activity-based learning consistently report effect sizes ranging between 0.80 and 1.50, which are already classified as very large in educational research (Benli & Dökme, 2011). An effect size above 2.00 is rarely observed in classroom interventions and is considered evidence of an exceptionally powerful instructional impact. Thus, the value of 3.81 suggests that AREHCA produced a substantial and meaningful improvement in students' understanding of hybridisation and molecular shapes, not only statistically significant but also educationally significant in practical terms.

The findings are in line with Liu et al. (2023), who examined the impact of augmented reality (AR) applications on students' knowledge gains, learning motivation, and perceptions of technology, finding that students in the AR group achieved significantly higher scores compared to those in the non-AR group. This parallels the current study's results, where AREHCA led to improved academic outcomes. Similarly, Shah and Rahat (2014) found that students engaged in hands-on activities performed better than those in the control group, which aligns with the observed benefits of AREHCA in this study. Talan et al. (2022) also demonstrated that AR applications in educational settings significantly boosted students' achievement levels, echoing the positive impact of AREHCA.

The findings of this study are further supported by Kırılmazkaya and Dal (2022), who reported enhanced academic achievement and scientific attitudes following hands-on activities. This suggests that the interactive and immersive elements of AREHCA likely contributed to the improved student performance observed. Moreover, Faria and Miranda (2023) showed that AR interventions positively affect students' academic performance in science, which is consistent with the significant gains seen after the implementation of AREHCA. Similarly, Iyamuremye et al. (2023) found a notable improvement in student performance post-intervention with hands-on activities, reinforcing the effectiveness of such approaches in the current study. The enhanced academic performance associated with AREHCA also aligns with Silva et al. (2023), who found that AR applications led to higher achievement levels in university-level chemistry courses. This consistency across studies suggests that the structured, hands-on, and AR-enhanced methods employed in AREHCA are effective in boosting academic outcomes. Additionally, Petrov and Atanasova (2020) highlighted the positive impact of AR technology on learning outcomes in STEM education, a finding that resonates with the results of this study. Nweke et al. (2022) and Abdullah et al. (2022) both reported improvements in achievement scores in science following the use of hands-on and AR strategies, which further supports the conclusion that AREHCA effectively enhances student performance.

Finally, the results of this study align with the findings of Osuntuyi (2021), who noted that hands-on activities positively influenced the academic performance of technical education students. These discussions underscore the potential of AREHCA in improving the academic performance of students in chemistry, particularly in learning hybridisation and molecular shapes.

Research Question 2: What is the Differential Effect of AREHCA on the Academic Performance of Male and Female Students in Hybridisation and Molecular Shapes?

Table 4 presents the means and standard deviations of delayed post-intervention test scores of male and female students. According to the results, female students scored 9.36 with a standard deviation of 0.70 on the post-intervention test, whereas male students scored 9.25 with a standard deviation of 0.78. When comparing the gender mean score, the girls did marginally better (9.36) than the males (9.25). Nonetheless, the observed mean difference of 0.11 suggests that there is little variation in their academic achievement. As a result, AREHCA has an equal effect on male and female students' academic performance when it comes to understanding the concept. An independent samples t-test was performed on the delayed post-intervention test scores of male and female students. The results of the independent samples t-test is displayed in **Table 5**. Following the application of AREHCA in the teaching of hybridisation and molecular shapes, there was no significant difference in the post-test between males (M = 9.25, SD = 0.78) and females (M = 9.36, SD = 0.70), t (df = 63) = -0.59, p = 0.57. The results indicate that there is no statistically significant difference in the academic performance of male and female students. Additionally, an effect size (Cohen's d = 0.15) shows little effect. The Pearson Correlation coefficient was used to analyse the correlation between the post-test

Table 4. Means and standard deviations of delayed post-intervention test scores of male and female students

Group	Test	N	Mean	SD	Mean Difference
Male	Post-test	40	9.25	0.78	0.11
Female	Post-test	25	9.36	0.70	

N=Number of Students, SD=Standard Deviation

Table 5. Analysis of delayed post-intervention test scores of male and female students

Group	Test	N	Mean	SD	df	t	p-value	Effect Size	Remarks
Male	Post-intervention test	40	9.25	0.78	63	-0.59	0.57	0.15	Not Significant
Female	Post-intervention test	25	9.36	0.70					

N=Number of Students, SD=Standard Deviation, Significant at $p < 0.05$, Not Significant at $P > 0.05$ level of significance

Table 6. Correlation analysis of male and female students' post-test scores

Sex	Correlation Coefficient	p-value
Male	-0.02916	0.57
Female		

results of male and female students. This is displayed in **Table 6**.

The results show a weak correlation between the performance of male and female students on the post-test, as indicated by the correlation coefficient of (-0.029, p = 0.57). Since the p-value (0.57) is greater than the alpha level of 0.05, the correlation is not statistically significant. This means that the slight negative relationship observed occurred by chance and does not represent a meaningful association.The extremely slight negative association found suggests that AREHCA has a comparable effect on male and female students' performance in hybridisation and molecular shapes. This finding suggests that there was no difference in the post-test scores of male and female students as a result of the augmented reality-enhanced hands-on chemical activities. Both genders' performance seems to be similarly impacted by AREHCA. This demonstrates how well AREHCA works to give both genders similar opportunities in terms of academic performance.

These findings are consistent with the study by Bawa and Haliru (2022), which examined the impact of augmented reality (AR) on the academic performance of undergraduate students in econometrics in Northwest Nigeria. Their research showed a slight improvement in performance in favor of female students. Similarly, Ajayi (2017) investigated the effect of hands-on activities on the interest of senior secondary students in organic chemistry, but found no significant difference in mean scores between male and female students in the hands-on activity-based group. This aligns with the current study, which also found no significant difference in the performance of male and female students using AREHCA.

These results are further supported by Bressler and Bodzin (2013), who reported that both genders show interest in AR learning, and by Ogbeba and Ajayi (2018), whose study indicated no significant difference in the performance of male and female students in chemistry when using a hands-on teaching approach. Moreover, the findings resonate with Tamam and Corebima (2023), who studied the implementation of augmented reality to enhance biology learning outcomes, concluding that there was no gender-based difference in learning outcomes. They suggested that AR can help bridge the gender gap in biology education by creating a learning environment that meets the educational needs of both genders. Nweke et al. (2022) also observed that hands-on activities in the chemistry classroom did not result in significant differences in mean achievement scores between male and female students. Hou and Wang (2013) found that AR was equally effective in improving performance on assembly tasks for both genders.

CONCLUSION

The study identified a challenge in students' understanding of hybridisation and molecular shapes. However, after implementing augmented reality-enhanced hands-on chemistry activities (AREHCA), there was a significant improvement in academic performance related to these concepts. The 3D visualisations of molecular shapes and atomic orbital overlaps of AREHCA deepened students' understanding of spatial arrangements and molecular geometry. The innovative nature of AREHCA also significantly enhanced traditional teaching methods. Thus, AREHCA has been effective in enhancing the performance of the senior high school students in the concepts of hybridisation and molecular shapes.

The study also revealed that AREHCA has a consistent effect on both male and female students. This is supported by the negligible negative correlation of -0.029, which further confirms that there is no significant difference in how effective AREHCA has been for each gender in enhancing their performance of hybridisation and molecular shapes. These findings are all in agreement with the previous studies, which suggest that the use of augmented reality and hands-on activities helps improve students' learning outcomes and also provides an opportunity for male and female students to benefit on a similar basis (Abdullah et al., 2022; Bawa & Haliru, 2022; Nweke et al., 2022; Ogbeba & Ajayi, 2018).

Therefore, this innovative strategy that combines the incorporation of augmented reality and hands-on activities in the teaching and learning of chemistry should be considered in the chemistry classroom to effect positive changes in the educational environment, as far as students' overall academic performance in terms of hybridisation and molecular shapes is concerned.

Author contributions: DM: study design, data curation, formal analysis, writing – original draft; **CEA:** resources, data curation, writing – review & editing; **GS-A:** supervision, validation, writing – review & editing; **NAS-H:** literature review, data curation,

writing – review & editing. All authors have sufficiently contributed to the study, and agreed with the results and conclusions.

Funding: No external funding is received for this article.

Ethical statement: The authors stated that they duly sought permission from Winneba Senior High School. An introductory letter was also received from the Integrated Science department, University of Education, Winneba. Also, the participants were informed, where the purpose of the research, the expected time for the study and the procedure for the research activities were discussed. All participants were given a guarantee of confidentiality and anonymity in reporting the information provided for the study. Moreover, there was a strict adherence to ethical guidelines concerning human subjects in research.

AI statement: The authors stated that they did not use any Generative AI or AI-based tools in the design, data collection, analysis, or interpretation of this study. An AI-based writing assistant was used only during manuscript preparation, to check grammar and improve the clarity of the English text. All AI-assisted suggestions were reviewed, edited, and verified by the authors, who take full responsibility for the accuracy, originality, and integrity of the final manuscript.

Declaration of interest: The authors declare that they have no competing interests.

Availability of data and materials: All data generated or analyzed during this study are available for sharing when appropriate request is directed to corresponding author.

REFERENCES

Abdullah, N., Baskaran, V. L., Mustafa, Z., Ali, S. R., & Zaini, S. H. (2022). Augmented reality: The effect in students' achievement, satisfaction and interest in science education. *International Journal of Learning, Teaching and Educational Research, 21*(5), 326-350. https://doi.org/10.26803/ijlter.21.5.17

Ajayi, V. O. (2017). *Effect of hands-on activities on senior secondary chemistry students' achievement and retention in stoichiometry in Zone C of Benue State*. SSRN. https://papers.ssrn.com/abstract=2992803

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

Anwer, F. (2019). Activity-based teaching, student motivation and academic achievement. *Journal of Education and Educational Development, 6*(1), 154-170. https://doi.org/10.22555/JOEED.V6I1.1782

Astuti, F. N., Suranto, S., & Masykuri, M. (2019). Augmented reality for teaching science: Students' problem solving skills, motivation, and learning outcomes. *JPBI (Jurnal Pendidikan Biologi Indonesia), 5*(2), 305-312. https://doi.org/10.22219/jpbi.v5i2.8455

Batdı, V., & Talan, T. (2019). Augmented reality applications: A meta-analysis and thematic analysis. *Turkish Journal of Education, 8*(4), 276-297. https://doi.org/10.19128/turje.581424

Bates, A. W. (2015). *Teaching in a digital age: Guidelines for designing teaching and learning*. Tony Bates Associates Ltd.

Bawa, N., & Haliru, U. (2022). Effect of augmented reality on the academic performance of undergraduate students in econometrics in Northwest, Nigeria. *Journal of Artificial Intelligence, Machine Learning and Neural Network, 2*(4), 19-28. https://doi.org/10.55529/jaimlnn.24.19.28

Beem, H. (2020). Effect of hands-on science activities on Ghanaian student learning, attitudes, and career interest: A preliminary control study. *Global Journal of Transformative Education, 2*, 19-32. https://doi.org/10.14434/gjte.v2i1.31224

Benli, E., & Dökme, İ. (2011). The effect of the technology supported science education on achievement and attitudes of students. *International Journal of Educational Administration and Policy Studies, 3*(12), 219-221. https://doi.org/10.5897/IJEAPS11.042

Boonmoh, A., & Jumpakate, T. (2019). Using scaffolded instructions to improve students' skills. *rEFLections, 26*(1), 1-16. https://doi.org/10.61508/refl.v26i1.199840

Bougsiaa, H. (2016). Teaching and learning context in augmented reality environment. *Ars Educandi, 13*, 23-31. https://doi.org/10.26881/ae.2016.13.02

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

Bruner, J. S. (1961). The act of discovery. *Harvard Educational Review, 31*(1), 21-32.

Brydges, C. R. (2019). Effect size guidelines, sample size calculations, and statistical power in gerontology. *Innovation in Aging, 3*(4), Article igz036. https://doi.org/10.1093/geroni/igz036

Cai, S., Wang, X., & Chiang, F.-K. (2014). A case study of augmented reality simulation system application in a chemistry course. *Computers in Human Behavior, 37*, 31-40. https://doi.org/10.1016/j.chb.2014.04.018

Chen, S., & Liu, S. (2020). Using augmented reality to experiment with elements in a chemistry course. *Computers in Human Behavior, 111*, Article 106418. https://doi.org/10.1016/j.chb.2020.106418

Dayal, P. D., & Ali-Chand, Z. (2022). Effective teaching and learning strategies in a chemistry classroom. *New Zealand Journal of Educational Studies, 57*(2), 425-443. https://doi.org/10.1007/s40841-022-00242-7

Ekwueme, C. O., Ekon, E. E., & Ezenwa-Nebife, D. C. (2015). The impact of hands-on-approach on student academic performance in basic science and mathematics. *Higher Education Studies, 5*(6), 47-51. https://doi.org/10.5539/hes.v5n6p47

Erbas, C., & Demirer, V. (2019). The effects of augmented reality on students' academic achievement and motivation in a biology course. *Journal of Computer Assisted Learning, 35*(3), 450-458. https://doi.org/10.1111/jcal.12350

Faria, A., & Miranda, G. L. (2023). Effects of using augmented reality on students' learning. *Trends in Computer Science and Information Technology, 8*(1), 1-4. https://doi.org/10.17352/tcsit.000061

Garzón, J., & Acevedo, J. (2019). Meta-analysis of the impact of augmented reality on students' learning gains. *Educational Research Review, 27*, 244-260. https://doi.org/10.1016/j.edurev.2019.04.001

Graham, M., Zook, M., & Boulton, A. (2022). Augmented reality in urban places: Contested content and the duplicity of code. In S. Carta (Ed.), *Machine learning and the city: Applications in architecture and urban design* (pp. 341-366). Wiley. https://doi.org/10.1002/9781119815075.ch27

Holmes, A. G. (2019). Constructivist learning in university undergraduate programmes: Has constructivism been fully embraced? Is there clear evidence that constructivist principles have been applied to all aspects of contemporary university undergraduate study? *Shanlax International Journal of Education, 8*(1), 7-15. https://doi.org/10.34293/education.v8i1.819

Hou, L., & Wang, X. (2013). A study on the benefits of augmented reality in retaining working memory in assembly tasks: A focus on differences in gender. *Automation in Construction, 32*, 38-45. https://doi.org/10.1016/j.autcon.2012.12.007

Hurst, B., Wallace, R., & Nixon, S. B. (2013). The impact of social interaction on student learning. *Reading Horizons: A Journal of Literacy and Language Arts, 52*(4), 375-398.

Iyamuremye, A., Nsabayezu, E., Ngendabanga, C., & Hagenimana, F. (2023). Effectiveness of hands-on practical activities in teaching and learning chemistry: An exploration of students' engagement, experience, and academic performance. *African Journal of Educational Studies in Mathematics and Sciences, 19*(1), 97-107. https://doi.org/10.4314/ajesms.v19i1.7

Jiménez, Z. A. (2019). Teaching and learning chemistry via augmented and immersive virtual reality. In *Technology integration in chemistry education and research (TICER)* (pp. 31-52). American Chemical Society. https://doi.org/10.1021/bk-2019-1318.ch003

Jokiranta, K. (2014). *The effectiveness of practical work in science education* [Bachelor's thesis, University of Jyväskylä]. JYX Digital Repository.

Kao, G. Y.-M., & Ruan, C.-A. (2022). Designing and evaluating a high interactive augmented reality system for programming learning. *Computers in Human Behavior, 132*, Article 107245. https://doi.org/10.1016/j.chb.2022.107245

Kibga, E. S., Sentongo, J., & Gakuba, E. (2021). Effectiveness of hands-on activities to develop chemistry learners' curiosity in community secondary schools in Tanzania. *Journal of Turkish Science Education, 18*(4), 605-621. https://doi.org/10.36681/tused.2021.93

Kırılmazkaya, G., & Dal, S. N. (2022). Effect of hands-on science activities on students' academic achievement and scientific attitude. *International Journal of Education & Literacy Studies, 10*(4), 56-66. https://doi.org/10.7575/aiac.ijels.v.10n.4p.56

Lee, N. Y., & Tucker-Kellogg, G. (2020). An accessible, open-source mobile application for macromolecular visualization using augmented reality. *Biochemistry and Molecular Biology Education, 48*(3), 297-303. https://doi.org/10.1002/bmb.21335

Liu, Q., Ma, J., Yu, S., Wang, Q., & Xu, S. (2023). Effects of an augmented reality-based chemistry experiential application on student knowledge gains, learning motivation, and technology perception. *Journal of Science Education and Technology, 32*, 153-167. https://doi.org/10.1007/s10956-022-10014-z

Luecke, S., Schiffman, A., Singh, A., Huang, H., Shannon, B., & Wilder, C. L. (2023). Four guiding principles for effective trainee-led STEM community engagement through high school outreach. *PLoS Computational Biology, 19*(5), Article e1011072. https://doi.org/10.1371/journal.pcbi.1011072

Luviani, S. D., Mulyani, S., & Widhiyanti, T. (2021). A review of three levels of chemical representation until 2020. *Journal of Physics: Conference Series, 1806*, Article 012206. https://doi.org/10.1088/1742-6596/1806/1/012206

Mahr, D., Heller, J., & de Ruyter, K. (2023). Augmented reality (AR): The blurring of reality in human-computer interaction. *Computers in Human Behavior, 145*, Article 107755. https://doi.org/10.1016/j.chb.2023.107755

Mensah, B., Poku, A. A., & Quashigah, A. Y. (2022). Technology integration into the teaching and learning of geography in senior high schools in Ghana: A TPACK assessment. *Social Education Research, 3*(1), 80-90. https://doi.org/10.37256/ser.3120221218

Ministry of Education of Ghana. (2010). *Teaching syllabus for senior high school chemistry*. Curriculum Research and Development Division.

Misra, P. K., & Vaishali. (2019). Teaching teachers to use constructivist approaches: A proposal. *i-manager's Journal on School Educational Technology, 14*(4), 56-63. https://doi.org/10.26634/jsch.14.4.15651

Mogashoa, T. (2014). Applicability of constructivist theory in qualitative educational research. *American International Journal of Contemporary Research, 4*(7), 51-59.

Nweke, H. C., Ijeh, S. B., Ajaja, O. P., & Agboghoroma, T. E. (2022). Effect of hands-on activity learning strategy (HALS) on students' achievement and interest in chemistry in Delta State. *International Journal of Academic and Applied Research, 6*(11), 38-41.

Ogbeba, J., & Ajayi, V. O. (2018). Effect of hands-on activities on skills acquisition of senior secondary chemistry students in physical chemistry. *UNIZIK Journal of STM Education, 2*(1).

Osuntuyi, E. O. (2021). Impact of hands-on activities on students' academic achievement in science and technical education in College of Education, Ikere-Ekiti, Ekiti State, Nigeria. *IJO-International Journal of Social Science and Humanities Research, 4*(7), 26-36.

Petrov, P. D., & Atanasova, T. V. (2020). The effect of augmented reality on students' learning performance in STEM education. *Information, 11*(4), Article 209. https://doi.org/10.3390/info11040209

Piaget, J. (1950). *The psychology of intelligence*. Routledge.

Puranik, S. (2020). Innovative teaching methods in higher education. *BSSS Journal of Education, 9*(1), 67-75. https://doi.org/10.51767/je0907

Resnyansky, D., İbili, E., & Billinghurst, M. (2018). The potential of augmented reality for computer science education. In *2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)* (pp. 350-356). IEEE. https://doi.org/10.1109/TALE.2018.8615331

Selco, J. I. (2020). Using hands-on chemistry experiments while teaching online. *Journal of Chemical Education, 97*(9), 2617-2623. https://doi.org/10.1021/acs.jchemed.0c00424

Serdyukov, P. (2017). Innovation in education: What works, what doesn't, and what to do about it? *Journal of Research in Innovative Teaching & Learning, 10*(1), 4-33. https://doi.org/10.1108/JRIT-10-2016-0007

Shah, I., & Rahat, T. (2014). Effect of activity-based teaching method in science. *International Journal of Humanities and Management Sciences, 2*(1), 39-41.

Shana, Z. J., & Abulibdeh, E. S. (2020). Science practical work and its impact on students' science achievement. *Journal of Technology and Science Education, 10*(2), 199-215. https://doi.org/10.3926/jotse.888

Silva, M., Bermúdez, K., & Caro, K. (2023). Effect of an augmented reality app on academic achievement, motivation, and technology acceptance of university students of a chemistry course. *Computers & Education: X Reality, 2*, Article 100022. https://doi.org/10.1016/j.cexr.2023.100022

Smuseva, D. A., & Rolich, A. Y. (2018). Research and software development using AR technology. *Journal of Physics: Conference Series, 1050*, Article 012080. https://doi.org/10.1088/1742-6596/1050/1/012080

Squire, K. D., & Jan, M. (2007). Mad city mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers. *Journal of Science Education and Technology, 16*(1), 5-29. https://doi.org/10.1007/s10956-006-9037-z

Talan, T., Yilmaz, Z. A., & Batdi, V. (2022). The effects of augmented reality applications on secondary students' academic achievement in science course. *Journal of Education in Science, Environment and Health, 8*(4), 333-347. https://doi.org/10.21891/jeseh.1193695

Tamam, B., & Corebima, A. D. (2023). Implementing augmented reality to improve students' biology learning outcomes: Gender-based effect. *International Journal of Evaluation and Research in Education, 12*(4), 2157-2164. https://doi.org/10.11591/ijere.v12i4.25645

Tang, Y., Tseng, H., & Tang, X. (2022). The impact of information-seeking self-efficacy and online learning self-efficacy on students' performance proficiency. *The Journal of Academic Librarianship, 48*(5), Article 102584. https://doi.org/10.1016/j.acalib.2022.102584

Vázquez-Cano, E., León-Urrutia, M., Parra-González, M. E., & López-Meneses, E. (2020). Analysis of interpersonal competences in the use of ICT in the Spanish university context. *Sustainability, 12*(2), Article 476. https://doi.org/10.3390/su12020476

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y., & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education, 62*, 41-49. https://doi.org/10.1016/j.compedu.2012.10.024

Yilmaz, Z. A., & Batdi, V. (2016). A meta-analytic and thematic comparative analysis of the integration of augmented reality applications into education. *Education and Science, 41*(188), 273-289. https://doi.org/10.15390/EB.2016.6707

Zhang, J., Ogan, A., Liu, T.-C., Sung, Y.-T., & Chang, K.-E. (2016). The influence of using augmented reality on textbook support for learners of different learning styles. In *2016 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)* (pp. 107-114). IEEE. https://doi.org/10.1109/ISMAR.2016.26

Zheng, M., & Waller, M. P. (2017). ChemPreview: An augmented reality-based molecular interface. *Journal of Molecular Graphics and Modelling, 73*, 18-23. https://doi.org/10.1016/j.jmgm.2017.01.019

Ziden, A. A., Ziden, A. A. A., & Ifedayo, A. E. (2022). Effectiveness of augmented reality (AR) on students' achievement and motivation in learning science. *EURASIA Journal of Mathematics, Science and Technology Education, 18*(4), Article em2097. https://doi.org/10.29333/ejmste/11923