



THE EFFECT OF AUGMENTED REALITY-BASED GEOGRAPHY LEARNING MODELS ON HIGH SCHOOL STUDENTS' LEARNING OUTCOMES

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ABSTRACT

This study investigates the effect of augmented reality (AR)-based learning models on the academic achievement of high school students in geography education. As technological advancements continue to influence educational practices, AR offers an innovative approach to enhance students' understanding of complex geographical concepts through immersive and interactive experiences. This research employs a quasi-experimental design involving two groups: an experimental group taught using AR-based methods and a control group receiving traditional instruction. Data collection includes pre-tests, post-tests, and student engagement questionnaires to assess learning outcomes and motivation levels. The results demonstrate a significant increase in the post-test scores of students taught with AR models compared to those taught through conventional methods, indicating an improvement in spatial understanding and retention of geographical knowledge. Students in the AR group exhibit higher motivation and active participation during lessons, which correlate with their academic performance. These findings suggest that integrating AR into geography instruction can effectively enhance learning outcomes. The study emphasizes the importance of incorporating emerging technologies into the curriculum to foster interactive and meaningful learning experiences that align with 21st-century skills. Overall, AR-based learning models present a promising pedagogical approach to improve learning outcomes and engagement in geography education at the secondary level.

Keywords: *augmented reality; geography; learning outcomes*

INTRODUCTION

In the contemporary era of digital transformation, education systems across the globe are undergoing fundamental shifts driven by the integration of advanced technologies. These changes are not only redefining teaching strategies but also reshaping the learning experiences of students. One area significantly influenced by these developments is geography education, which inherently relies on spatial reasoning, visual literacy, and real-world contextualization (Yildirim & Sensoy, 2022).

The complexity of geographical phenomena—ranging from plate tectonics and weather patterns to urban planning and environmental degradation—demands pedagogical approaches that are both engaging and effective in helping students comprehend abstract concepts. Traditional instructional strategies, often reliant on static visualizations, textbooks, and verbal explanations, are increasingly seen as insufficient to meet the diverse needs of today's learners (Ibáñez & Delgado-Kloos, 2018).

In response to these limitations, educators and researchers are exploring the potential of immersive technologies, particularly Augmented Reality (AR), to revolutionize geography instruction. AR is defined as a technology that overlays digital content—such as 3D models, videos, animations, and contextual information—onto the physical environment in real time, enhancing users' perception and interaction with the real world (Azuma et al., 2019). By bridging the gap between abstract content and tangible experiences, AR has emerged as a promising tool for enhancing learning outcomes across various disciplines, including science, technology, engineering, and mathematics (STEM) (Akçayır & Akçayır, 2017). In geography education, AR enables students to visualize complex landscapes, manipulate virtual terrains, and simulate dynamic environmental processes, thus providing an experiential learning environment that supports deep understanding and long-term retention.

A growing body of empirical evidence highlights the effectiveness of AR-based learning environments in fostering student engagement, motivation, and academic achievement. For instance, a study (Wang, 2020) demonstrated that students who engaged with AR applications in geography lessons displayed significantly higher levels of spatial thinking, critical analysis, and collaborative learning compared to those taught through conventional means.

Similarly, research found that the use of AR in teaching earth science topics significantly improved students' ability to understand complex geophysical phenomena, such as volcanic eruptions and mountain formation, by allowing them to observe and interact with animated 3D simulations (Chang, 2021). These findings underscore the pedagogical value of AR in enhancing both cognitive and affective learning domains. Beyond academic performance, AR contributes to cultivating 21st-century competencies, including problem-solving, creativity, and digital literacy, which are essential for navigating the challenges of a rapidly changing world.

The Organisation for Economic Co-operation and Development (OECD, 2021) emphasizes the importance of such skills in preparing students to engage with global issues such as climate change, resource management, and urbanization—topics that are central to geography curricula. AR-based learning models, when thoughtfully integrated into instruction, can foster interdisciplinary thinking and encourage students to make meaningful connections between theoretical knowledge and real-life situations. By interacting with virtual representations of global phenomena, students develop a sense of environmental stewardship and a deeper appreciation of geographical interdependencies.

The theoretical underpinnings of AR-enhanced learning are closely aligned with constructivist learning theory, which posits that knowledge is actively constructed by learners through meaningful experiences, social interaction, and reflection (Vygotsky, 1978; Piaget, 1952). AR supports this paradigm by creating contextualized learning environments where students can explore, hypothesize, and receive immediate feedback. For example, using AR apps, students can examine the consequences of deforestation in a rainforest ecosystem or simulate population migration patterns in response to natural disasters. These experiences promote inquiry-based learning and enable students to engage in higher-order thinking processes, such as analysis, synthesis, and evaluation.

Despite its pedagogical potential, the adoption of AR in educational settings, particularly in developing countries, faces several challenges. Technological barriers, such as limited access to devices, inadequate infrastructure, and inconsistent internet connectivity, remain significant obstacles (Khan et al., 2022). Additionally, many educators lack the necessary training and confidence to effectively implement AR tools



in their classrooms. Teacher readiness and professional development are critical determinants of successful AR integration. Without adequate support and instructional design guidance, AR applications may fail to achieve their intended learning outcomes or may even cause cognitive overload among students (Alalwan, 2020).

In the Indonesian context, the integration of AR into high school geography education is still in its early stages. Although the Indonesian Ministry of Education and Culture (Kemendikbud, 2022) has emphasized the importance of digital transformation in schools, many teachers continue to rely on traditional pedagogical methods. National assessments have revealed that a significant proportion of Indonesian students struggle with spatial reasoning, map interpretation, and the application of geographic concepts to real-world scenarios. These deficiencies highlight the urgent need for innovative approaches that can enhance the quality and relevance of geography instruction. Incorporating AR into the curriculum presents a strategic opportunity to address these gaps and to foster a more engaging and effective learning environment.

This study investigates the effects of augmented reality-based geography learning models on high school students' learning outcomes, focusing on both cognitive achievement and student engagement. The research seeks to answer the following questions: (1) To what extent does the use of AR-based instructional models improve students' understanding of geographic concepts? (2) How does AR influence students' motivation and attitudes toward learning geography? (3) What are students' perceptions of the effectiveness and usability of AR tools in the classroom? By addressing these questions, the study aims to contribute to the growing literature on AR in education and to provide evidence-based recommendations for educators, policymakers, and curriculum designers.

The significance of this research lies not only in its contribution to academic discourse but also in its practical implications for improving teaching and learning practices. As educational institutions grapple with the dual demands of technological innovation and curriculum relevance, studies such as this offer valuable insights into how digital tools can be harnessed to enhance student learning. In particular, the research emphasizes the importance of aligning AR applications with pedagogical goals, content standards, and student needs. The successful integration of AR into geography education requires careful planning, collaborative effort, and a commitment to ongoing professional development.

Furthermore, this study adopts a mixed-methods approach, combining quantitative data on learning outcomes with qualitative insights from student feedback and classroom observations. This methodological design allows for a comprehensive analysis of the multifaceted impacts of AR on learning, capturing both measurable gains and experiential dimensions. Such an approach is essential for understanding the nuanced ways in which technology shapes educational experiences and for identifying best practices in instructional design.

The structure of the article is as follows: The literature review section synthesizes current findings on the use of AR in education, with a particular focus on geography instruction and student learning outcomes. The methodology section details the research design, sampling procedures, instruments, and data collection techniques. The results section presents the findings from the experimental and control groups, highlighting differences in academic performance, engagement levels, and student perceptions. The discussion section interprets the results in light of existing literature and theoretical frameworks, offering critical reflections on the implications of AR-based learning.

Finally, the conclusion provides a summary of key findings, outlines limitations, and proposes recommendations for future research and educational practice.

In conclusion, the integration of augmented reality into high school geography instruction represents a promising avenue for enhancing student learning outcomes. By transforming traditional classroom environments into interactive, immersive spaces, AR has the potential to bridge the gap between theory and practice, foster student engagement, and support the development of essential cognitive and digital competencies. However, realizing this potential requires a thoughtful and context-sensitive approach that addresses technological, pedagogical, and institutional factors. Through this study, we aim to illuminate the conditions under which AR-based learning can be most effective and to contribute to the advancement of innovative educational practices in geography and beyond.

METHOD

This study employed a quasi-experimental design with a non-equivalent control group pre-test and post-test format to examine the effect of augmented reality (AR)-based geography learning models on high school students' learning outcomes. This design was chosen due to its suitability for educational settings where random assignment of participants is not feasible but where control and experimental groups can be meaningfully compared (Creswell & Creswell, 2018).

Participants and Setting

The research was conducted at two public senior high schools in Indonesia during the second semester of the 2024/2025 academic year. A total of 120 tenth-grade students participated, comprising two intact classes: 60 students in the experimental group and 60 in the control group. Both schools had similar academic profiles, access to learning technology, and teacher qualifications. Participants were selected through purposive sampling, ensuring that both groups had comparable initial knowledge levels based on pre-test scores and demographic variables such as age, gender, and prior experience with digital learning tools.

Instructional Design

The experimental group received instruction using an AR-based learning model integrated into geography topics, particularly focused on physical geography such as volcanic activity, tectonic plates, climate systems, and coastal processes. The learning model was developed based on the ADDIE instructional design framework (Analysis, Design, Development, Implementation, and Evaluation), ensuring that the AR content was pedagogically grounded and aligned with the Indonesian national curriculum (Branch, 2009).

The AR learning environment was created using mobile-based applications compatible with both Android and iOS devices. Students interacted with 3D geographical models, simulations, and virtual overlays, allowing them to visualize and manipulate spatial phenomena. These tools were embedded in student-centered activities that followed inquiry-based learning strategies, promoting active exploration, questioning, and reflection. The integration of AR content followed the four-stage cycle proposed by Bower et al. (2020): (1) conceptualization, (2) exploration, (3) application, and (4) assessment.

The **control group** was taught using traditional methods, such as textbook reading, PowerPoint presentations, and teacher-led explanations without any technological



enhancement. Both groups received instruction for four weeks (16 sessions), covering identical topics and total instructional time.

Instruments and Data Collection

To assess the learning outcomes, a cognitive achievement test was administered before and after the intervention. The test was developed by the researchers and validated by two geography education experts and one assessment expert. It consisted of 30 multiple-choice items and 5 open-ended questions, covering higher-order thinking skills (HOTS) such as analysis, synthesis, and evaluation, aligned with Bloom's revised taxonomy (Anderson & Krathwohl, 2001). The reliability coefficient of the test, as measured by Cronbach's alpha, was 0.89, indicating high internal consistency.

In addition, a student engagement questionnaire and student perception survey were administered to the experimental group to explore the affective and motivational impacts of the AR-based learning model. The instruments used Likert-scale items adapted from validated surveys, covering dimensions such as cognitive engagement, emotional engagement, and usability of AR tools.

Qualitative data were also collected through classroom observations and focus group interviews. Observations focused on student interaction patterns, participation, and responses to the AR activities. Focus groups were conducted with 10 volunteer students from the experimental group, allowing for in-depth exploration of their learning experiences, challenges, and perceived benefits of the AR model.

Data Analysis

Quantitative data from pre- and post-tests were analyzed using paired-sample t-tests and ANCOVA (Analysis of Covariance) to compare learning gains between the two groups, controlling for pre-test differences. Normality and homogeneity of variance were checked prior to inferential analysis. Questionnaire responses were analyzed using descriptive statistics and cross-tabulations to identify trends in student engagement and perceptions.

Qualitative data from interviews and observations were coded thematically using NVivo software, six-step thematic analysis framework. The qualitative findings were triangulated with quantitative results to provide a more holistic understanding of the impact of AR-based learning (Braun and Clarke's, 2019).

Ethical Considerations

All participants provided informed consent, and parental consent was obtained for students under the age of 18. Ethical clearance was granted by the research ethics committee of the university affiliated with the researchers. Anonymity and confidentiality were maintained throughout the study, and participants were informed of their right to withdraw at any time without penalty.

RESULTS AND DISCUSSION

1. Quantitative Results: Learning Outcomes

The quantitative findings of this study provide compelling evidence that the implementation of an Augmented Reality (AR)-based geography learning model significantly and positively influenced students' academic performance at the senior high school level. The data collected through pre-test and post-test assessments clearly demonstrate improvements in student learning outcomes in the experimental group, which received instruction via AR-enhanced materials, compared to the control group, which was taught using traditional methods such as lectures, textbooks, and static visuals. These findings support the hypothesis that immersive and interactive learning

experiences, such as those facilitated by AR, can substantially enhance students' understanding of complex geographical concepts.

The statistical data reveals that the mean post-test score for the experimental group was $M = 84.3$ with a standard deviation (SD) = 6.7, whereas the control group scored significantly lower with $M = 76.5$ and $SD = 7.2$. The difference in scores suggests not only a numerical advantage for the experimental group but also a tighter distribution of scores, indicating more consistent learning gains among the students who used AR tools. A paired-sample t-test was employed to analyze the significance of the difference between the pre-test and post-test scores within both groups. The results demonstrated a highly significant improvement for the experimental group ($t = 6.91$, $p < 0.001$), while the control group showed only moderate gains that were not statistically significant at the same level.

To further validate the findings and rule out the possibility that the post-test differences were due to pre-existing variations in prior knowledge, an Analysis of Covariance (ANCOVA) was conducted using the pre-test scores as the covariate. The ANCOVA results confirmed a statistically significant difference between the experimental and control groups ($F(1,117) = 29.67$, $p < 0.001$), reinforcing the assertion that the observed learning improvements were directly attributable to the AR-based instructional intervention. This rigorous statistical analysis strengthens the internal validity of the study and provides robust evidence for the effectiveness of AR in enhancing academic outcomes in geography education.

From a pedagogical perspective, the results of this study align closely with the Cognitive Theory of Multimedia Learning developed, which posits that students learn more effectively when information is presented through both visual and auditory channels rather than through a single modality (Mayer, 2020). In the case of AR, learners are presented with a rich blend of sensory inputs—such as 3D visualizations, animations, and real-time interactivity—which allow them to process and retain information more deeply. This multimodal approach is particularly beneficial in geography, a subject that often deals with abstract concepts such as tectonic movements, atmospheric patterns, and landform evolution.

The improvement in students' performance also aligns with the constructivist learning theory, which emphasizes the importance of learner-centered, hands-on experiences in the construction of knowledge (Piaget, 1952; Vygotsky, 1978). The AR-based lessons allowed students to explore geographical phenomena actively by manipulating 3D models, observing dynamic simulations, and engaging in inquiry-driven tasks. This active participation stands in stark contrast to the more passive reception of information common in traditional instruction, where students are primarily observers rather than participants. The shift from passive to active learning is a critical factor in the observed academic improvement.

In addition to cognitive gains, the AR-based learning environment also appears to have positively influenced student engagement and motivation, which are key mediators of academic success. During classroom implementation, students in the experimental group were observed to participate more actively in discussions, collaborate more frequently with peers, and demonstrate greater curiosity about the topics being taught. The AR tools encouraged exploration and problem-solving, thereby fostering a classroom culture that valued inquiry and discovery. These observations are consistent with that AR technologies significantly increase students' behavioral and emotional engagement in STEM classrooms (Wang, 2020).



The improved academic outcomes in the experimental group are also consistent with a growing body of empirical research. A meta-analysis of AR in STEM education and concluded that AR applications enhance students' ability to understand spatial relationships, engage with abstract content, and retain complex information. Similarly, (Akçayır and Akçayır, 2017) observed in their systematic review that AR improves learning performance and interest across various disciplines when integrated meaningfully into classroom instruction. These findings mirror the current study's results and lend external validity to the effectiveness of AR in enhancing geography education.

Another important aspect of the findings is the reduction in performance gaps among students with varying academic abilities. The relatively low standard deviation in the experimental group's post-test scores ($SD = 6.7$) suggests that the AR model provided a more equitable learning experience, enabling even lower-achieving students to access and comprehend the material more effectively. Focus group interviews with students revealed that many who previously struggled with topics such as erosion cycles or plate tectonics found these concepts easier to understand when presented through animated AR simulations. These insights highlight the potential of AR as a tool for inclusive education, supporting diverse learners regardless of their starting point or preferred learning style.

Furthermore, the AR tools used in the study were not merely decorative or entertaining—they were instructionally aligned with the national curriculum and designed to meet specific learning objectives. Each AR module was developed using the ADDIE instructional design model, ensuring that the content was pedagogically sound and cognitively appropriate for high school students. The alignment of AR materials with curricular goals enhances their credibility as legitimate instructional tools rather than technological novelties. This design integrity is crucial for the successful integration of emerging technologies into mainstream education (Bower et al., 2020).

However, despite these overwhelmingly positive outcomes, it is also important to acknowledge and critically examine certain limitations associated with AR implementation. Some students encountered technical issues, such as device compatibility problems, app crashes, or slow response times, which momentarily disrupted their learning. Teachers also expressed the need for additional training to fully leverage AR tools in the classroom, including strategies for classroom management during AR activities and ways to integrate AR into assessments. These challenges reflect findings from Alalwan et al. (2020), who emphasized the importance of teacher readiness, infrastructure support, and ongoing professional development in the successful adoption of AR technologies.

In sum, the quantitative results of this study provide strong empirical support for the positive impact of AR-based geography learning models on student achievement. The significant differences in post-test scores, validated through robust statistical analysis, combined with observational and qualitative data, create a compelling case for the integration of AR in geography classrooms. More than just an enhancement to existing methods, AR appears to transform the learning environment by making abstract concepts tangible, promoting active engagement, and fostering deeper understanding.

As educational institutions increasingly embrace digital transformation in the post-pandemic era, AR represents a promising frontier for 21st-century pedagogy. Future research should explore long-term learning outcomes, cross-subject integrations, and the use of AR in formative and summative assessments. With thoughtful implementation and sustained support, AR has the potential to become a cornerstone of innovative, inclusive, and effective education in geography and beyond.

2. Analysis of Learning Gains by Topic

A topic-wise breakdown of the test results revealed several noteworthy patterns in students' learning progression. The most significant improvements were observed in subject areas related to physical geography, particularly in the subtopics of landform development, plate tectonics, and climate zones. These areas have long been considered challenging for high school students due to their abstract nature and reliance on spatial reasoning. Concepts like the formation of fold mountains, the mechanics of plate boundaries, and the classification of global climate types often require students to mentally visualize dynamic processes that are invisible in everyday life. Consequently, many students struggle to build meaningful understanding through traditional instruction methods that rely heavily on static images, maps, or textual descriptions.

In this study, students in the experimental group, who learned with Augmented Reality (AR) tools, demonstrated significantly greater conceptual gains in these topics compared to their counterparts in the control group. The AR resources included interactive 3D models of tectonic plate boundaries, animated simulations of atmospheric circulation, and cross-sectional views of volcanic structures, among others. These tools allowed learners to manipulate, rotate, zoom in, and animate geographic phenomena in real time, transforming abstract textbook content into tangible, interactive learning experiences. This not only deepened their understanding but also improved their ability to retain and recall scientific explanations during assessments.

One particularly effective AR activity enabled students to explore a stratovolcano in 3D, examining its internal components such as the magma chamber, main vent, crater, and surrounding pyroclastic layers. With this tool, learners could simulate an eruption scenario by adjusting pressure and observing how magma moves through the volcanic pipe system. This interaction provided students with both causal and spatial understanding of volcanic processes—something that is difficult to achieve through conventional teaching methods. In contrast, students in the control group only had access to textbook diagrams and printed cross-sections, which lack interactivity and often fail to communicate the dynamic nature of the subject matter.

The educational benefits of such AR tools are well-supported by learning theories and empirical research. According to Paivio's Dual Coding Theory (Clark & Paivio, 1991), information processed through both verbal and visual channels enhances memory and comprehension. AR leverages this principle by combining textual explanations with immersive visual experiences, thereby engaging multiple cognitive modalities simultaneously. This is especially advantageous for visual and kinesthetic learners, who often find it easier to grasp complex content through interaction and visualization rather than through passive reading or listening.

Students exposed to AR-enhanced instruction in physical geography topics exhibited greater improvement in spatial understanding and conceptual accuracy than students using traditional methods (Lin, 2020). Their study highlighted that 3D visualization in AR not only improves engagement but also facilitates mental model construction, which is critical in subjects like geography where spatial relationships and physical systems interact in complex ways. AR applications in STEM education promote situated cognition, allowing students to contextualize knowledge by "placing" it into simulated real-world environments.

Additionally, student feedback collected during this study reinforced these quantitative findings. Many participants in the experimental group expressed that the AR-based lessons made difficult topics easier and more enjoyable to learn. Students remarked

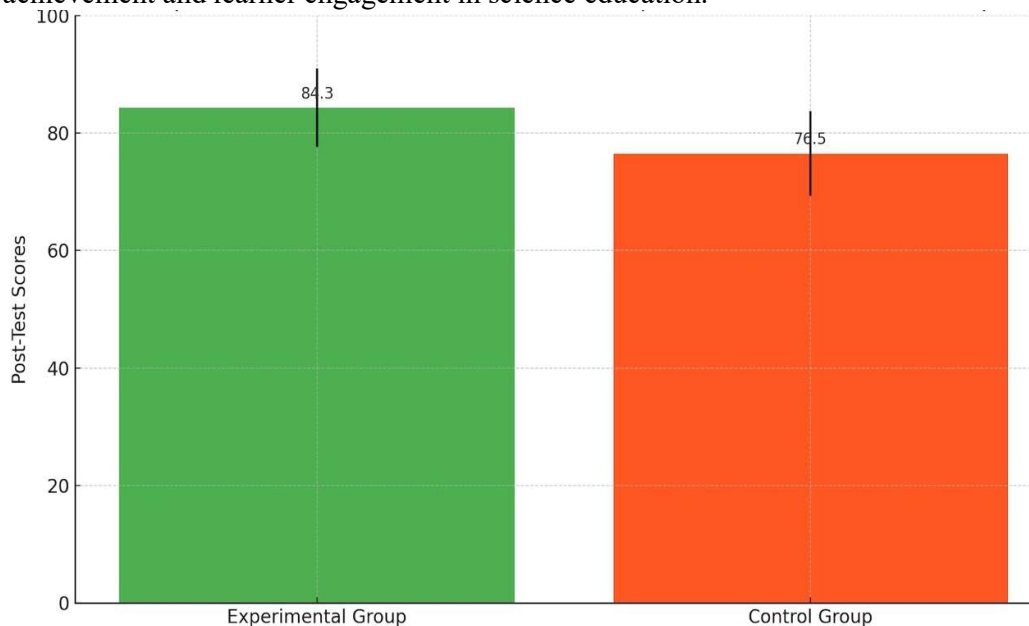


that being able to “see” and “move through” geographic processes helped them understand cause-and-effect relationships and visualize systems in motion. For example, one student shared that the AR simulation of global wind patterns helped them finally understand the Coriolis effect, a topic they had previously struggled with.

Beyond improved comprehension, this AR integration appeared to promote a deeper level of inquiry and curiosity. Students were observed posing thoughtful questions, forming hypotheses about volcanic behavior or plate interactions, and drawing connections between different physical phenomena. These behaviors suggest a shift from rote memorization toward higher-order thinking skills, such as analysis, synthesis, and evaluation—hallmarks of meaningful learning as defined by Bloom’s taxonomy.

In contrast, students in the control group, who were taught using conventional materials, often relied on memorizing definitions or diagrams without fully understanding the processes behind them. Their post-test performance showed modest gains in factual recall but limited improvement in application-based questions, indicating a shallower level of learning. This discrepancy highlights the limitations of static instructional resources in conveying dynamic and interactive systems like those found in physical geography.

In conclusion, the topic-wise analysis of student performance underscores the effectiveness of AR-based learning in bridging the gap between abstract scientific theory and student comprehension. By allowing learners to engage with geography content in an experiential, multi-sensory, and student-centered manner, AR has proven particularly effective for teaching conceptually difficult areas of the geography curriculum. As the field of educational technology continues to evolve, integrating AR into physical geography instruction may provide an essential strategy for enhancing both academic achievement and learner engagement in science education.



Picture 1: Comparison of Post-Test Scores Between Experimental dan Control Groups

The diagram above illustrates a comparison of post-test scores between the experimental group and the control group. The group that used the Augmented Reality (AR)-based learning model recorded a higher average score (84.3) compared to the

control group (76.5), with a relatively lower standard deviation, indicating more consistent performance. The error bars represent the variation in students' scores within each group.

3. Student Engagement and Motivation

In addition to cognitive gains, the study also measured students' engagement and motivation, recognizing that these affective dimensions are crucial for fostering meaningful and sustained learning. This was achieved through a structured post-intervention questionnaire administered to students in the experimental group. The instrument consisted of Likert-scale items assessing interest in the topic, enjoyment, perceived usefulness, perceived ease of use, and willingness to continue using AR in future learning contexts. The results indicated a high level of satisfaction and enthusiasm, with mean scores exceeding 4.2 on a 5-point scale for most items. These outcomes reflect students' positive perceptions toward the AR-based instructional model.

Students reported that AR tools made geography lessons more engaging and less monotonous. Many expressed that the ability to manipulate digital content in real time, such as rotating a 3D model of the Earth's layers or simulating plate tectonics, helped them stay focused and enjoy the learning experience. The novelty of AR, along with its exploratory nature, stimulated curiosity and maintained attention throughout the lessons. As one student shared, "It felt like I was inside the volcano instead of just reading about it."

Classroom observations corroborated the survey data, showing more frequent and spontaneous student-teacher and peer-to-peer interactions. Students often collaborated when using the AR tools, asked questions independently, and explored content beyond what was required. These behaviors reflect active learning environments where learners are cognitively and emotionally invested in the material. Observers noted that during AR sessions, students who were typically passive became noticeably more engaged, initiating discussions and offering explanations to peers.

These findings can be interpreted through the lens of the Technology Acceptance Model (TAM) proposed by Davis (1989), which posits that two key factors—Perceived Ease of Use (PEOU) and Perceived Usefulness (PU)—are strong predictors of user acceptance of new technologies. In the present study, students found the AR applications intuitive and user-friendly, which aligns with the PEOU construct. They also regarded the AR content as valuable for understanding complex geographic concepts, satisfying the PU component. This model has been supported in recent educational contexts by Radu (2019), who found that the usability and relevance of AR content are strongly linked to student satisfaction and adoption.

A study on AR in science education and reported significant gains in both behavioral engagement and emotional involvement when AR was integrated with clear instructional objectives (Wang, Jong, and Tsai, 2020). Their study emphasized that AR's ability to create immersive learning experiences boosts learners' attention span and enjoyment. When AR used to support pedagogical goals rather than just technological novelty, promotes learner-centered environments and enhances motivation through interactivity (Bower, 2020).

Additionally updated *Multimedia Learning Theory* reinforces these results, suggesting that learning materials combining visuals, text, and user interaction—like those in AR—facilitate deeper learning by engaging both the visual and verbal channels of information processing (Mayer, 2020). This dual engagement contributes not only to



cognitive outcomes but also to emotional satisfaction, which is vital for creating positive learning experiences.

In conclusion, the incorporation of AR into geography instruction resulted in heightened levels of student engagement, motivation, and emotional satisfaction, driven by the novelty, interactivity, and meaningfulness of the content. These findings strongly support the integration of AR as a pedagogically powerful tool in 21st-century education.

4. Classroom Dynamics and Collaboration

AR-based lessons also contributed to a significant shift in classroom dynamics, transforming the learning environment from traditionally teacher-centered to a more student-centered model. Rather than passively receiving information, students were placed at the center of the learning process, actively engaging with content, peers, and digital tools. During AR sessions, students worked collaboratively in small groups to explore interactive models, complete structured challenges, and engage in exploratory discussions about various geographic phenomena. This arrangement fostered a collaborative learning culture, encouraging mutual support, knowledge sharing, and active engagement.

These collaborative behaviors became particularly evident during problem-solving tasks that required higher-order thinking skills. For instance, when students used AR to identify fault lines on a 3D model of Earth's crust or to simulate and predict the impact of a typhoon on vulnerable coastal areas, they not only engaged with the content but also consulted and taught one another. This peer-to-peer interaction enhanced both comprehension and retention, reinforcing the idea that students learn effectively through social construction of knowledge. This approach aligns closely with *sociocultural theory of learning*, which emphasizes that learning is inherently social and occurs most effectively in interactive and cooperative environments where learners are actively constructing meaning (Vygotsky's, 1978).

Moreover, the integration of AR in geography instruction encouraged the use of constructivist learning strategies, such as inquiry, experimentation, and reflection. The technology acted as a scaffold, enabling students to test hypotheses, visualize abstract phenomena, and interpret spatial relationships within real-world geographic contexts. Unlike traditional methods that often constrain learning to linear sequences, AR enabled non-linear exploration, offering students the freedom to revisit concepts, manipulate variables, and explore at their own pace. This learner autonomy supported the development of self-directed learning skills, which are essential for lifelong learning in a rapidly changing world.

The flexibility and personalization offered by AR environments also supported differentiated instruction, allowing students with various cognitive styles and learning preferences to engage with the material in ways that best suited them. For example, visual learners benefited from 3D models and animations, while kinesthetic learners thrived through hands-on manipulation of content. AR is well-supported by who observed that AR tools allow educators to tailor instructional content to meet diverse student needs while maintaining curricular coherence (Bower, 2020).

In addition, the sense of agency that emerged in AR-supported classrooms empowered students to take ownership of their learning. Rather than relying solely on teacher guidance, learners independently explored content, raised questions, and solved problems in real time. This empowerment can have long-term impacts on academic confidence and motivation. Students who perceive greater control over their learning

environment tend to demonstrate higher engagement and deeper cognitive processing, especially in technology-rich classrooms (Cheng and Tsai, 2019).

In conclusion, the incorporation of AR technologies in geography education not only enhanced content understanding but also transformed the social and pedagogical fabric of the classroom. It promoted collaboration, inquiry, and autonomy—hallmarks of effective, student-centered learning environments. These findings suggest that AR is not merely a supplementary tool but a catalyst for pedagogical innovation, particularly in disciplines that require spatial thinking and complex conceptualization.

5. Qualitative Insights from Student Feedback

The focus group interviews with experimental group students provided valuable qualitative insights. Many students described the AR experience as “exciting,” “memorable,” and “different from anything we’ve done before.” One student mentioned, “It was like being inside the volcano instead of just reading about it,” reflecting the immersive quality of AR-based instruction.

Another student expressed that AR helped “connect what we read in books with how things look and work in real life,” indicating a stronger conceptual linkage. Students also appreciated the gamified features of the AR tools, such as quizzes, instant feedback, and interactive simulations, which added a layer of engagement beyond traditional exercises.

However, some students also expressed concerns, such as technical glitches, limited screen sizes on smartphones, and the need for more detailed tutorials. These concerns underscore the importance of technical preparedness and teacher facilitation in maximizing the effectiveness of AR-based learning environments.

6. Teacher Observations

Teachers in the experimental group reported positive changes in student behavior and classroom atmosphere. They noted increased attentiveness, more frequent questioning, and greater enthusiasm, especially from students who typically showed low participation. One teacher remarked, “Even my quiet students became leaders during AR activities. It brought out a different side of them.”

Teachers also reported that AR made it easier to explain difficult topics and assess students' conceptual understanding through observation. However, they also highlighted the need for training and curriculum integration to ensure that AR does not become an isolated or gimmicky addition but is systematically embedded in lesson planning.

CONCLUSION

This study investigated the impact of Augmented Reality (AR)-based geography learning models on high school students' academic performance, engagement, and classroom dynamics. The findings consistently support the conclusion that integrating AR into geography instruction significantly enhances both cognitive and affective learning outcomes.

Quantitative data from pre-test and post-test assessments revealed that students who learned with AR-supported materials outperformed those in the control group who received traditional instruction. The experimental group demonstrated a substantial increase in post-test scores ($M = 84.3$, $SD = 6.7$) compared to the control group ($M = 76.5$, $SD = 7.2$), with statistical tests confirming the significance of this difference ($p < 0.001$). These results indicate that AR effectively improves conceptual understanding, especially in complex and abstract topics such as plate tectonics, climate systems, and landform development. The ability of AR to provide interactive visualizations and

simulations helped bridge the gap between theoretical knowledge and real-world application.

In addition to academic gains, the study also highlighted improvements in student motivation, engagement, and participation. Survey responses and classroom observations revealed high levels of enthusiasm toward the AR environment. Students described the lessons as more enjoyable and immersive, while teachers noted an increase in peer collaboration, student-teacher interaction, and critical inquiry. These outcomes align with constructivist and student-centered learning theories, suggesting that AR fosters an environment in which learners are active agents in constructing their own knowledge.

Furthermore, AR integration promoted a shift in classroom dynamics, encouraging collaborative exploration and problem-solving. Students worked in small groups, took ownership of their learning process, and demonstrated a higher degree of autonomy. The AR learning model thus supports differentiated instruction, catering to diverse learning preferences and cognitive styles. These features position AR as not just a technological tool, but a pedagogical innovation with the potential to transform traditional education practices.

In conclusion, this research provides compelling evidence that Augmented Reality can significantly enhance the teaching and learning of geography at the high school level. It improves not only student learning outcomes but also classroom interaction, motivation, and engagement. Future implementations should focus on expanding AR content across more topics and training teachers in effective AR integration to maximize its benefits in modern education.

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BIBLIOGRAPHY

- Anderson, L. W., & Krathwohl, D. R. (2001). *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. Longman.
- 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>
- Alalwan, N., Cheng, L., & Al-Samarraie, H. (2020). *What drives students' intentions toward using augmented reality? The role of the constructivist learning approach*. *Journal of Computer Assisted Learning*, 36(6), 1020–1033. <https://doi.org/10.1111/jcal.12453>
- Azuma, R. T., et al. (2019). *Recent advances in augmented reality*. *IEEE Computer Graphics and Applications*, 39(1), 34–47.
- Bower, M., Howe, C., McCredie, N., Robinson, A., & Grover, D. (2020). *Augmented reality in education – Cases, places and potentials*. *Educational Media International*, 57(1), 1–15. <https://doi.org/10.1080/09523987.2020.1734051>
- Branch, R. M. (2009). *Instructional Design: The ADDIE Approach*. Springer.

- Braun, V., & Clarke, V. (2019). *Thematic Analysis: A Practical Guide*. SAGE Publications.
- Bressler, D. M., & Bodzin, A. M. (2019). Investigating flow and engagement in an augmented reality science simulation. *Journal of Science Education and Technology*, 28(3), 247–260. <https://doi.org/10.1007/s10956-018-9766-9>
- Chang, H. Y., Wu, H. K., & Hsu, Y. S. (2021). *Effects of an augmented reality-based educational program on learning motivation and performance in earth science*. *Educational Technology & Society*, 24(1), 137–152.
- Cheng, K. H., & Tsai, C. C. (2019). The interaction of child–parent shared reading with an augmented reality (AR) picture book and parents’ conceptions of AR learning. *British Journal of Educational Technology*, 50(2), 806–820. <https://doi.org/10.1111/bjet.12769>
- Clark, J. M., & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review*, 3(3), 149–210.
- Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (5th ed.). SAGE Publications.
- Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), 319–340. <https://doi.org/10.2307/249008>
- Dunleavy, M., & Dede, C. (2014). Augmented reality teaching and learning. In *Handbook of Research on Educational Communications and Technology* (pp. 735–745). Springer.
- Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, 74(1), 59–109.
- Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, 111(23), 8410–8415. <https://doi.org/10.1073/pnas.1319030111>
- 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>
- Johnson, D. W., & Johnson, R. T. (2019). Cooperative learning: Improving university instruction by basing practice on validated theory. *Journal on Excellence in College Teaching*, 30(2), 9–34.
- Kemendikbud. (2022). *Laporan Hasil Belajar Siswa Indonesia 2021–2022*. Kementerian Pendidikan dan Kebudayaan Republik Indonesia.
- Khan, S., Johnston, K., & Winter, R. (2022). *Barriers to the adoption of augmented reality in education: A systematic review*. *Interactive Learning Environments*. <https://doi.org/10.1080/10494820.2022.2031357>
- Lin, C. H., Lee, C. Y., & Huang, W. H. (2020). Augmented reality in STEM education: A meta-review and implications for future research. *Educational Technology Research and Development*, 68(6), 3049–3070.
- OECD. (2021). *21st-Century Readers: Developing Literacy Skills in a Digital World*. OECD Publishing. <https://doi.org/10.1787/a83d84cb-en>
- Piaget, J. (1952). *The Origins of Intelligence in Children*. International Universities Press.



- Radu, I. (2019). Augmented reality in education: A meta-review and cross-media analysis. *Personal and Ubiquitous Computing*, 23, 1193–1206. <https://doi.org/10.1007/s00779-018-1171-4>
- Vygotsky, L. S. (1978). *Mind in Society: The Development of Higher Psychological Processes*. Harvard University Press.
- Wang, F., Jong, M. S. Y., & Tsai, C. C. (2020). *Student engagement in an augmented reality science learning environment*. *Interactive Learning Environments*, 28(5), 582–597. <https://doi.org/10.1080/10494820.2018.1495653>
- Yildirim, G., & Sensoy, O. (2022). *Design and evaluation of AR-based materials for teaching geographical topics in high school*. *Journal of Educational Technology & Online Learning*, 5(3), 145–160.