Journal of Education and Teaching (JET)
Vol. 6 No. 3 2025

The Impact of Imagineering Learning with Inquiry-Based Learning through Augmented Reality on Students' Academic Achievement and Digital Empathy

Draft article history
Submitted: 17-04-2025;
Revised: 11-05-2025;
Accepted: 27-05-2025;

Chusnul Muali[1], Mohammad Bakron Andre Setiawan[2]
Pendidikan Agama Islam, Universitas Nurul Jadid, Indonesia[1,2]
Email: chusnulmuali@unuja.ac.id

ABSTRACT: This study aims to explore the impact of Imagineering-based learning combined with Inquiry-Based Learning through Augmented Reality (AR) technology on students' academic achievement and digital empathy. AR-based learning is believed to enhance the understanding of abstract concepts while also enriching students' social skills, particularly in the context of digital empathy. A quasi-experimental design was employed with two groups: the experimental group using AR and the control group using conventional learning methods. Data were collected through academic achievement tests, digital empathy scales, learning activity observations, and interviews. The study involved 60 students from a public junior high school in Probolinggo. The results indicate that the experimental group experienced significant improvements in academic achievement ($p = 0.001$) and digital empathy ($p = 0.000$) compared to the control group. AR-based learning also enhanced students' creativity in solving challenges and improved their interaction with the learning material. These findings suggest that AR-based learning is effective in improving students' academic performance and digital empathy skills. Therefore, the study recommends integrating AR into education to create more engaging and relevant learning experiences for 21st-century students.

Keywords: academic achievement, augmented reality, digital empathy, imagineering learning, inquiry-based learning

ABSTRAK: *Penelitian ini bertujuan untuk mengkaji dampak pembelajaran berbasis Imagineering yang dikombinasikan dengan pendekatan Inquiry-Based Learning melalui teknologi Augmented Reality (AR) terhadap pencapaian akademik dan empati digital siswa. Pembelajaran berbasis AR diyakini mampu meningkatkan pemahaman terhadap konsep-konsep abstrak sekaligus memperkaya keterampilan sosial siswa, khususnya dalam konteks empati digital. Penelitian ini menggunakan desain kuasi-eksperimen dengan dua kelompok: kelompok eksperimen yang menggunakan teknologi AR dan kelompok kontrol yang menggunakan metode pembelajaran konvensional. Pengumpulan data dilakukan melalui tes pencapaian akademik, skala empati digital, observasi aktivitas pembelajaran, dan wawancara. Penelitian ini melibatkan 60 siswa dari salah satu sekolah menengah pertama negeri di Probolinggo. Hasil penelitian menunjukkan bahwa kelompok eksperimen mengalami peningkatan yang signifikan dalam pencapaian akademik (p = 0,001) dan empati digital (p = 0,000) dibandingkan dengan kelompok kontrol. Pembelajaran berbasis AR juga terbukti meningkatkan kreativitas siswa dalam menyelesaikan tantangan serta memperbaiki interaksi mereka dengan materi pembelajaran. Temuan ini mengindikasikan bahwa pembelajaran berbasis AR efektif dalam meningkatkan kinerja akademik dan keterampilan empati digital siswa. Oleh karena itu, studi ini merekomendasikan integrasi teknologi AR dalam praktik pendidikan untuk menciptakan pengalaman belajar yang lebih menarik dan relevan bagi siswa abad ke-21.*

Kata Kunci: *augmented reality, empati digital, pembelajaran imagineering, pembelajaran berbasis inkuiri, pencapaian akademik.*

INTRODUCTION

The rapid transformation of society in the digital era has placed increasing demands on education systems to equip students not only with academic knowledge but also with cognitive flexibility, creativity, and socio-emotional competencies. Traditional instructional strategies (dominated by passive, teacher-centered delivery) often fall short in addressing these complex educational demands. One persistent challenge is the difficulty students face in understanding abstract or highly technical concepts, particularly in science and mathematics, which are frequently presented using static, text-heavy resources. Such limitations hinder the development of deeper conceptual understanding and student engagement (Grimaldos et al., 2025).

Moreover, the demands of 21st-century education have expanded beyond the cognitive domain. The capacity for digital empathy (understanding and responding to others ethically and emotionally in digital environments) has emerged as a critical skill in fostering inclusive and respectful interactions online. With the rising prevalence of cyberbullying, misinformation, and online polarization, nurturing digital empathy is increasingly recognized as a necessary component of holistic education (Ramirez-Montoya et al., 2024). However, integrating this affective dimension into classroom practices remains a significant pedagogical challenge, particularly in settings constrained by conventional didactic methods.

Amid these challenges, technological innovations offer promising avenues to reimagine educational practices. Among them, Augmented Reality (AR) stands out as a technology capable of blending physical and digital worlds in real-time, enabling learners to visualize, manipulate, and interact with content in ways not possible through traditional methods. Unlike Virtual Reality (VR), which immerses users in fully artificial environments, AR overlays digital information onto real-world contexts, creating immersive yet grounded learning experiences (Imamoglu, 2020; Dubreucq et al., 2025). This unique capacity has positioned AR as a powerful tool in enhancing both cognitive and affective learning outcomes.

A growing body of research highlights AR's effectiveness in improving academic achievement through the visualization of complex scientific phenomena, such as light refraction, geometric constructions, and biological systems (Alzahrani, 2025; Souza et al., 2025). Educational AR applications like ARfract, Eukaryo, and The Star Chart AR enable interactive, exploratory learning that supports spatial reasoning, conceptual understanding, and student motivation. These applications exemplify how AR can concretize abstract ideas, making them accessible through visual and tactile engagement.

Beyond its cognitive benefits, AR also has the potential to foster affective competencies, including empathy and emotional awareness. When integrated with character-driven, socially situated scenarios, AR can simulate real-life interactions that evoke emotional responses and encourage perspective-taking. For instance, interacting with virtual characters experiencing social challenges may help students reflect on their own behavior and develop a deeper understanding of others' experiences—key components of digital empathy (Sarıgöz, 2019).

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

The pedagogical impact of AR can be further amplified when embedded within innovative instructional models such as inquiry-based learning and Imagineering-based learning. Inquiry-based learning fosters independent knowledge construction through cycles of exploration, elaboration, and evaluation (Pujiastuti & Haryadi, 2023), while Imagineering emphasizes imaginative thinking and creative problem-solving through real-world design processes (Shawarba et al., 2025; Sreejun & Chatwattana, 2023). Both models align well with AR's affordances, enabling students to engage more actively and autonomously in the learning process.

Despite its growing popularity, most prior research on AR in education has focused predominantly on academic performance and learner motivation. Far less attention has been paid to its role in shaping socio-emotional skills, especially digital empathy. Moreover, the effectiveness of AR in fostering these dual domains (cognitive and affective) remains underexplored in holistic and integrative frameworks. Previous studies also often neglect the voices of students in evaluating the learning experience itself, overlooking how learners perceive and internalize the impacts of such technologies.

This study seeks to address these gaps by exploring the impact of AR-based instruction on both academic achievement and digital empathy among secondary school students. Specifically, it investigates: (1) whether the use of AR materials significantly improves students' academic performance; (2) whether AR fosters higher levels of digital empathy; and (3) how students perceive and respond to the use of AR in their learning environments. By employing a mixed-methods approach that integrates statistical testing with qualitative insights, this research aims to provide a nuanced understanding of how AR can support the development of both intellectual and emotional dimensions of student learning.

Ultimately, the integration of AR into educational practice has the potential to enrich the learning experience by making it more contextual, engaging, and responsive to the needs of 21st-century learners. Through this research, we aim to contribute to the broader discourse on digital pedagogy by highlighting the value of immersive technologies not only in enhancing knowledge acquisition but also in cultivating empathy, creativity, and social awareness in the digital age.

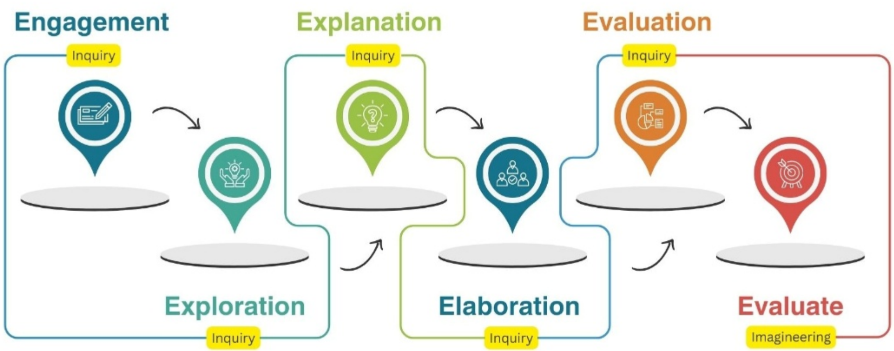

Figure 1. Stages of Inquiry-based Imagineering Learning

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

Based on various theoretical foundations and previous findings, this study aims to develop and test an inquiry-based Imagineering learning model supported by Augmented Reality (AR) technology. The primary focus is on its impact on students' academic achievement and digital empathy. This model is expected to serve as an innovative alternative in modern learning management, with significant potential to produce creative, skilled, and character-driven learners.

RESEARCH METHOD

This research adopts a quantitative approach with a non-equivalent control group design, a form of quasi-experimental design frequently utilized in educational settings where random assignment is impractical. The design involves the comparison of two intact classes: one experimental group receiving the intervention (Imagineering and Inquiry-Based Learning via Augmented Reality) and one control group exposed to conventional instruction. Both groups underwent pre-tests (O1) and post-tests (O2) to assess changes in academic achievement and digital empathy. The design is illustrated in Table 1.

Table 1. Research Design

Group	Pre-Test (O1)	Treatment	Post-Test (O2)
Experiment	O1	Imagineering + Inquiry-Based Learning via AR	O2
Control	O1	Conventional Learning	O2

The notation O1 and O2 refers to the pre-test and post-test, respectively. The absence of randomization necessitated careful matching of schools and classes to control for extraneous variables as much as possible.

Participants and Sampling Strategy

The study was conducted in three public junior high schools located in Probolinggo Regency, East Java, Indonesia. The population consisted of all seventh-grade students in these schools. Two classes were purposively selected based on specific inclusion criteria: 1) Availability of AR-compatible infrastructure, including access to smartphones or tablets and reliable internet connectivity; 2) Teacher readiness and willingness to participate in training on AR and the associated instructional strategies; 3) No concurrent exposure to other experimental programs or interventions that might confound the results.

Each class consisted of between 28 and 32 students. The purposive sampling technique was deemed appropriate due to the technological prerequisites of the intervention. However, it should be noted that this sampling method restricts the external validity of the study, meaning the findings may not generalize to schools lacking similar technological readiness.

Research Instruments and Data Collection

To measure the outcomes of the intervention, the researchers employed a variety of instruments that included both test and non-test measures: 1) Academic Achievement Test. A set of 30 validated multiple-choice questions aimed at

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

assessing conceptual understanding relevant to the science curriculum; 2) Digital Empathy Scale. A 24-item Likert-type questionnaire adapted from Sreejun and Chatwattana (2023), measuring students' empathetic behaviors and attitudes in digital contexts; 3) Observation Checklist. Completed by independent observers to evaluate student engagement, collaboration, and social interaction during the learning process; 4) Structured Interviews conducted with selected students after the intervention to gather qualitative insights into their experiences using the AR-based learning application.

Table 2. Summary of Research Instruments

Dimension	Indicators	Method
Conceptual Understanding	Material Understanding	Questionnaire
	Use of AR in Understanding Material	Interview
	Solving Learning Challenges	Observation
	Creativity in Designing Solution	Questionnaire
	Frequency of Interaction with AR Objects	Observation
	Quality of Interaction (speed, effectiveness)	Interview
	Collaboration in Groups	Observation
	Division of Tasks in Groups	Interview
	Level of Engagement in Learning	Questionnaire
	Motivation to Learn	Questionnaire
Digital Empathy	Understanding Character Perspective in AR	Observation
	Response to Social Scenarios	Interview
	Receiving Feedback	Questionnaire
	Implementing Feedback in Learning	Observation
	Skills in Operating AR Technology	Questionnaire
	Level of Satisfaction with AR Technology	Questionnaire

Instrument Validation and Reliability

All research instruments were subjected to a rigorous validation process. The achievement test items were reviewed by subject-matter experts and piloted with a comparable cohort. The Cronbach's alpha reliability coefficient was calculated to assess internal consistency. The academic test yielded an alpha value of 0.81, while the digital empathy scale showed a reliability score of 0.85, both indicating acceptable reliability.

The observation and interview protocols were also pretested to ensure clarity and content validity. Observers received standardized training and inter-rater reliability was computed using Cohen's Kappa, resulting in a score of 0.84, denoting strong agreement.

Data Analysis Techniques

Data analysis was carried out in two main stages. The first stage involved preliminary testing to ensure the data met the assumptions for parametric analysis. The Shapiro-Wilk test was used to assess the normality of data distribution, while Levene's test was employed to examine the homogeneity of variances between groups.

The second stage involved inferential statistical analysis. A paired sample t-test was conducted to evaluate within-group differences between pre-test and

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

post-test scores. An independent sample t-test was then used to compare post-test scores between the experimental and control groups. In addition to quantitative analysis, qualitative data from interviews and observations were analyzed using a thematic approach. Two researchers independently coded the data using an inductive method, allowing categories and themes to emerge naturally. Thematic refinement was achieved through iterative discussion, and triangulation with observational data was applied to enhance the credibility of the findings.

In addition, qualitative data from interviews and observations were analyzed thematically. Coding was performed independently by two researchers using an inductive approach, allowing categories to emerge from the data. Themes were refined through iterative discussion, and triangulation with observational data was used to enhance credibility.

Ethical Considerations

All research procedures adhered to ethical standards for research involving human subjects. Informed consent was obtained from both students and their guardians prior to participation. Confidentiality was maintained through anonymized coding of all responses and data logs. Audio recordings from interviews were stored securely, and digital interaction logs collected by the application were encrypted. Ethical approval was granted by the university's Research Ethics Committee.

Application Design

To support the pedagogical goals of the research, a dedicated Augmented Reality (AR) learning application was developed. The application was designed to integrate core principles of Imagineering and Inquiry-Based Learning (IBL) within a mobile-accessible AR environment. The goal was to create a learning ecosystem that is immersive, exploratory, and empathy-driven.

User Interface and Accessibility

The application was designed with a cross-platform interface, enabling access via Android smartphones and tablets. The interface emphasized usability, employing consistent visual cues, iconography, and instructional prompts. Accessibility features, including multilingual support and simplified navigation, were incorporated to accommodate diverse learners.

Augmented Reality Integration

AR technology was employed to visualize abstract scientific concepts in 3D and situate them in students' physical environments. For instance, students could manipulate 3D models of atoms, observe cell structures, or simulate ecosystems. These AR objects were interactive—allowing zooming, rotating, and layering of information—to support deep conceptual understanding.

Inquiry-Based Learning Modules

Each learning module followed the IBL cycle: Questioning – Investigating – Creating – Discussing – Reflecting. Tasks encouraged students to pose hypotheses,

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

gather evidence from AR visualizations, and engage in problem-solving activities. Interactive prompts guided students to explore "what if" scenarios and apply scientific reasoning to simulated phenomena.

Imagineering-Based Creativity Features

To foster creativity and innovation, the app included design-based challenges. For example, students were asked to imagine a sustainable energy solution for a virtual city, design simple machines using AR parts, or create hybrid species to understand genetic traits. These tasks encouraged divergent thinking and the synthesis of disciplinary knowledge.

Collaborative and Social Learning Tools

The application featured a project-sharing platform where students could collaborate on AR-based tasks. Group features allowed multiple users to view, manipulate, and annotate shared 3D models. Real-time chat and feedback functions were included to simulate classroom discussions and promote peer-to-peer interaction.

Digital Empathy Development

A distinguishing feature of the application was its incorporation of digital empathy modules. These modules included narrative-driven AR experiences in which users interacted with emotionally expressive avatars facing real-world dilemmas (e.g., peer exclusion, cyberbullying, environmental injustice). Students were prompted to consider multiple perspectives and make decisions with emotional consequences, encouraging empathetic reasoning.

Assessment and Feedback System

Embedded formative assessments enabled students to demonstrate understanding through interactions, such as selecting the correct AR object or reordering simulation steps. An adaptive feedback engine provided tailored suggestions based on performance, while a learning analytics dashboard offered visual reports for students and teachers. These reports included metrics on time-on-task, accuracy, and engagement.

Security and Data Tracking

All user interactions within the application were securely tracked to support learning analytics and research evaluation. The system collected anonymized data on user behaviors, interaction patterns, and progression through the modules. These data informed both the individualized feedback process and the broader analysis of instructional effectiveness.

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

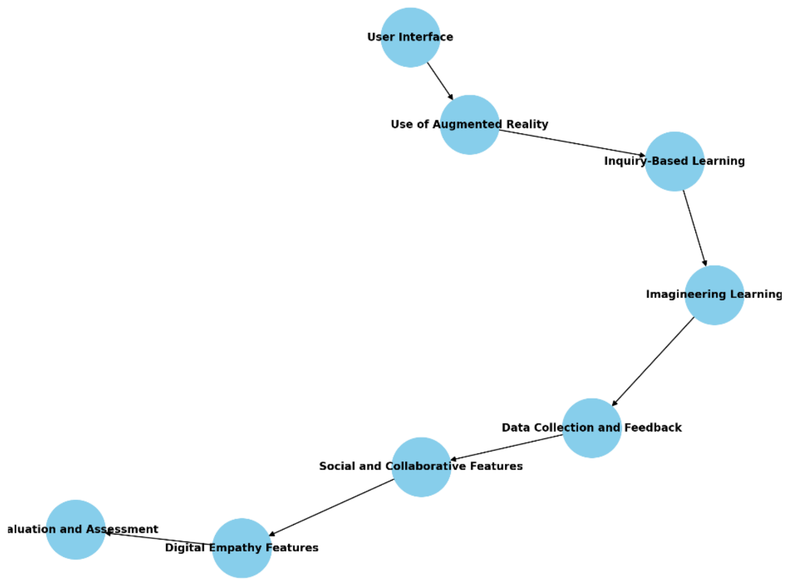

Figure 2. The Flowchart Diagram Representing The Initial Design of AR Imagineering Inquiry-Based Learning

RESULT AND DISCUSSION

Assumptions of Parametric Data Testing

To ensure that the data meet the assumptions required for parametric testing, normality and homogeneity were assessed using the Shapiro-Wilk and Levene's Tests. These tests are crucial to confirm that the data used in the study satisfy the necessary assumptions before proceeding with inferential analysis. The normality test aims to determine whether the data obtained from the pre-test and post-test for both the experimental and control groups follow a normal distribution.

Table 3. Summary of Data Normality Test Results

Group	Variable	Shapiro-Wilk Statistic	P-Value
Experiment	Academic Achievement	0.972 0.965	0.426 0.293
	Digital Empathy	0.982 0.973	0.785 0.423
Control	Academic Achievement	0.958 0.969	0.081 0.202
	Digital Empathy	0.976 0.970	0.339 0.254

Based on the results of the Shapiro-Wilk test, the p-value for all variables in both the experimental and control groups was greater than 0.05, indicating that the data are normally distributed. Meanwhile, the homogeneity test was conducted to assess whether the variance between the experimental and control groups was homogeneous (i.e., equal).

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

Table 4. Summary of Homogeneity Test Results

Group	Variable	Shapiro-Wilk Statistic	P-Value
Experiment	Academic Achievement	1.022	0.315
	Digital Empathy	0.913	0.343
Control	Academic Achievement	1.076	0.330
	Digital Empathy	1.004	0.298

Based on Table 4, it can be observed that the p-value for all variables is greater than 0.05, indicating that the variance between the groups is homogeneous.

Paired Sample t-Test (Pre-test vs Post-test)

After confirming the assumptions of normality and homogeneity, further analysis was conducted using the Paired Sample t-Test to examine the differences between the pre-test and post-test scores within each group.

Table 5. Summary of Results Paired Sample t-Test Results

Group	Variable	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	t-Statistic	P-Value
Experiment	Academic Achievement	65.2 ± 5.4	82.3 ± 4.2	-10.567	0.001*
	Digital Empathy	3.1 ± 0.6	4.2 ± 0.5	-9.235	0.001*
Control	Academic Achievement	64.1 ± 5.1	68.5 ± 5.6	-2.320	0.034*
	Digital Empathy	3.0 ± 0.5	3.3 ± 0.6	-1.526	0.129

The results of the Paired Sample t-test indicate significant improvements in both measured variables, academic achievement and digital empathy, in the experimental group using AR-based learning. Specifically, the analysis shows that the average post-test score for academic achievement in the experimental group was 82.3 (SD = 4.2), which was much higher than the pre-test score of 65.2 (SD = 5.4). This increase was statistically significant (p = 0.001), demonstrating that the use of AR in learning can enhance students' understanding of the material. A similar improvement was observed in digital empathy, where the average post-test score for the experimental group increased from 3.1 (SD = 0.6) in the pre-test to 4.2 (SD = 0.5) in the post-test (p = 0.001). This finding suggests that AR not only aids students in understanding academic concepts but also enhances their ability to respond to social and emotional situations, reflecting an increase in digital empathy.

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

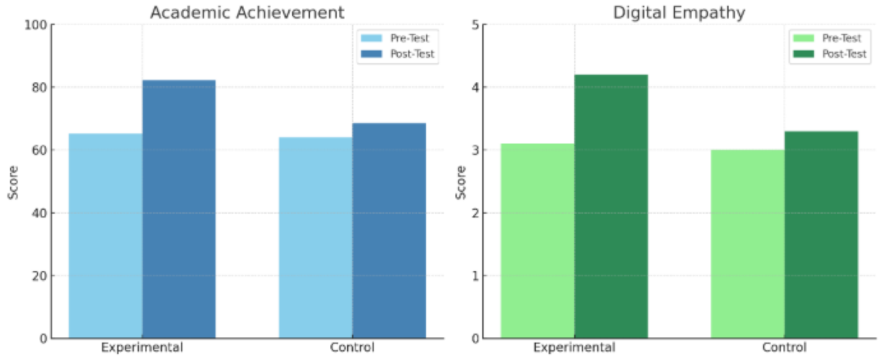

Figure 3. Comparison of Pre-test and Post-test Scores on Academic Achievement and Digital Empathy in Experimental and Control Groups

The academic achievement improvement in the experimental group corroborates findings from Carreon & Smith (2022) and Fatimah et al. (2019), who demonstrated that AR facilitates student comprehension in a more visual and interactive manner. AR enables students to see graphical representations of abstract concepts such as light refraction or cell structures, helping them grasp the material more deeply. This visualization reduces misunderstandings that often occur with concepts that are difficult to explain using traditional methods. These results align with the constructivist theories of Piaget and Vygotsky (Nesenbergs et al., 2021), which emphasize the importance of direct interaction with content to enrich learning experiences. AR-based learning encourages students to construct their own knowledge through exploration, reflection, and inquiry, which is consistent with the principles of Inquiry-Based Learning, which promotes active and exploratory learning (Ramirez-Montoya et al., 2024).

Furthermore, the findings regarding the improvement in digital empathy support previous research by Swanson (2023), which indicates that AR can enhance empathy by allowing students to interact with 3D characters in realistic social situations. This type of interaction enables students to develop a better understanding of the feelings and perspectives of others, which is crucial in developing social skills in today's digital world. These findings connect with Yildiz (2022), Empathy Development theory, which suggests that empathy develops through social interactions that enable individuals to feel and understand the emotions of others. By using AR in learning, students are able to experience the feelings of characters in social scenarios, leading to increased digital empathy.

However, despite the significant improvements in the experimental group, the control group also showed a significant increase in academic achievement, although not in digital empathy. The improvement in academic achievement in the control group ($p = 0.034$) suggests that conventional learning methods also contribute positively to material comprehension, though not as effectively as AR-based learning. This finding aligns with Pujiastuti & Haryadi (2023), who noted that while AR produces better results, traditional learning methods remain effective in providing foundational understanding. Therefore, while AR has advantages in

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

enhancing student engagement and comprehension, traditional methods still hold value in the learning process (Coppen et al., 2025).

Based on these findings, we propose a new theory that integrates elements of AR-based learning with Inquiry-Based Learning. AR-based learning can enrich the stages of the inquiry model, such as exploration and elaboration, by providing interactive visualizations that assist students in constructing their knowledge. AR can accelerate the exploration process by offering students tools to visualize, interact with, and experiment with objects related to the subject matter, which in turn increases their engagement in the learning process (Carreon & Smith, 2022).

This study confirms that AR-based learning has a significant impact on students' academic achievement and digital empathy. AR not only enhances students' academic understanding but also contributes substantially to the development of their social and emotional skills. Therefore, AR should be more widely implemented in education to provide a more holistic, engaging, and relevant learning experience that aligns with the needs of 21st-century students (Sarıgöz, 2019). Further research is needed to explore how AR can be more effectively integrated with other learning models, such as problem-based and project-based learning, to further improve student learning outcomes.

Independent Sample t-Test (Comparison between Experimental and Control Groups)

An Independent Sample t-Test was conducted to examine the differences between the experimental and control groups following the intervention.

Table 6. Summary of Independent Sample t-Test Results

Variable	Group	Mean ± SD	t-Statistic	P-Value
Academic Achievement	Experiment	82.3 ± 4.2	4.215	0.001*
	Control	68.5 ± 5.6		
Digital Empathy	Experiment	4.2 ± 0.5	5.004	0.000*
	Control	3.3 ± 0.6		

The results of the Independent Sample t-Test revealed significant differences between the experimental group (which used AR) and the control group (which used traditional learning) after the intervention. Specifically, the experimental group demonstrated higher academic achievement, with a mean post-test score of 82.3 (SD = 4.2), compared to the control group, which had a mean post-test score of 68.5 (SD = 5.6), with a p-value of 0.001. This finding indicates that AR has a significant positive impact on students' understanding of the material. In addition, the experimental group showed a higher mean score in digital empathy (M = 4.2, SD = 0.5) compared to the control group (M = 3.3, SD = 0.6), with a p-value of 0.000. This result confirms that AR-based learning not only enhances academic performance but also enriches students' social and emotional skills, particularly in the context of digital empathy.

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

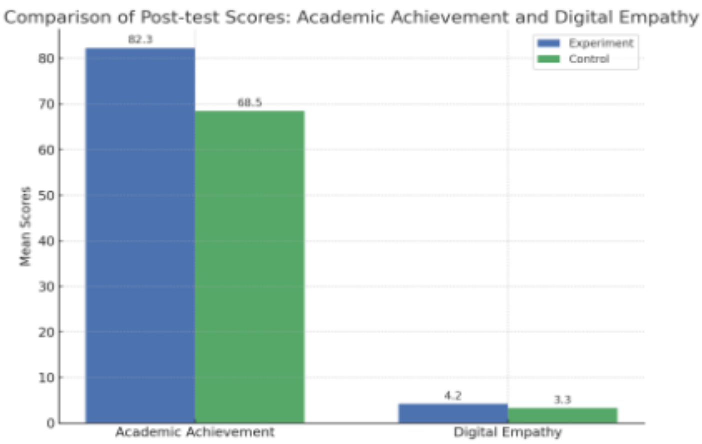

Figure 4. Comparison of Post-test Scores: Academic Achievement and Digital Empathy between Experiment and Control Groups

These findings support previous studies by Wickramasinghe et al. (2025) and Maryani et al. (2024), which suggest that AR can make learning more engaging and easier to understand through immersive 3D object visualizations and digital interactions. AR allows students to see graphical representations of abstract concepts, such as physics or biology concepts, which accelerates understanding and improves academic outcomes. Therefore, this study provides empirical evidence that AR helps students concretize abstract concepts, aligning with the constructivist theories of Piaget and Vygotsky (Sontay & Karamustafaoglu, 2021), which emphasize the importance of direct interaction with material to deepen learning experiences. AR-based learning encourages students to build their own knowledge through exploration, reflection, and investigation, consistent with the principles of Inquiry-Based Learning that emphasize active and exploratory learning (Sreejun & Chatwattana, 2023).

Furthermore, the significant improvement in digital empathy in the experimental group (p-value = 0.000) also demonstrates that AR has a positive impact on developing students' social skills. The experience of interacting with 3D characters in AR's social scenarios enables students to better understand others' perspectives, which in turn improves their ability to respond with empathy. This finding aligns with Çulha (2021) Empathy Development theory, which suggests that empathy develops through social interactions that allow individuals to feel and understand others' emotions. Ummah 92019) also stated that interacting with virtual characters in AR can help improve students' empathy, particularly in complex social situations. In the context of learning, AR provides opportunities for students to engage directly in social experiences, fostering emotional awareness and enhancing their ability to understand others' feelings.

However, despite the significant improvements in the experimental group, the control group also showed a significant increase in academic achievement (p-value = 0.034), although no significant improvement was observed in digital empathy (p-value = 0.129). This increase in the control group suggests that traditional learning methods are still effective in improving students' academic performance, albeit not as optimally as AR-based learning. This finding aligns with

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

 Journal of Education and Teaching (JET) Volume 6 No. 2, 2025
DOI: 10.51454/jet.v6i3.600

Carreon & Smith (2022), which stated that while AR offers numerous advantages in increasing engagement and understanding, conventional learning remains effective in providing a strong foundational understanding. Traditional learning methods still provide essential comprehension, although not as interactive as AR-based learning.

Based on these findings, we propose a modification to technology-based learning theory. AR-based learning can be further optimized by integrating it with other learning models, such as problem-based or project-based learning. This would not only enhance academic outcomes but also strengthen students' problem-solving and creativity skills. A learning model that combines AR with these approaches would allow students to become more active and creative in solving real-world problems.

This research confirms that AR-based learning has a significant impact on students' academic achievement and digital empathy. By enhancing academic understanding and social skills, AR has the potential to become a highly effective tool for learning in the 21st century. Therefore, educational systems should consider the wider use of AR to provide more interactive, contextual, and in-depth learning experiences for students while supporting the development of crucial social skills in today's digital world (Imamoglu, 2020).

Additionally, qualitative analysis was conducted to identify emerging themes from the observations and interviews. The data were coded using a thematic approach to explore students' experiences related to digital empathy and creativity in learning after using the AR application.

Table 7. Summary of Observation and Interview Results

Theme	Aspect	Description
Observation	Interaction with AR Objects	Students in the experimental group exhibited high levels of engagement with AR objects, interacting more frequently and for longer durations with the elements within the application compared to the control group.
	Collaboration in Groups	The experimental group also demonstrated better teamwork, collaborating effectively to complete AR-based tasks with clear task division among group members.
Interview	Increasing Digital Empathy	Many students in the experimental group reported that the AR application helped them better understand the perspectives of characters and social situations, thereby enhancing their digital empathy.
	Creativity in Learning	Students felt that AR provided opportunities for creativity, allowing them to think more freely in solving challenges and developing more innovative solutions.

The results of the observations indicated that the experimental group using AR in learning exhibited higher levels of interaction with AR objects, leading to greater engagement in the learning process. This observation suggests that the use of AR encourages students to actively participate and explore the learning

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

material. Students were not merely passive recipients of information, but interacted with the digital elements present in the AR application. These findings align with previous research by Amara et al. (2025), which demonstrate that AR can enrich the learning experience by providing interactive visualizations that allow students to engage directly with the content, thus enhancing their understanding.

Furthermore, the observations revealed that students in the experimental group were more creative in completing AR-based learning tasks. They demonstrated the ability to design solutions based on their imagination, reflecting an improvement in critical and creative thinking skills. This supports the findings of Živičnjak et al. (2025), who indicated that AR facilitates problem-solving and stimulates students' creativity. The learning experience provided by AR allowed students to think more innovatively, transitioning from a passive approach to a more active one, as they explored and designed solutions to the challenges they encountered.

Interview results also revealed that students felt they greatly benefited from AR-based learning, especially in understanding abstract concepts. For example, several students mentioned that AR made it easier to grasp complex physics concepts, such as light refraction and geometric principles, through visualization. The interviews also revealed that interactive experiences with 3D objects enhanced their understanding of the topics being studied. This finding reinforces Ade-Ibijola et al. (2025), who stated that AR not only improves academic understanding but also helps students build knowledge through deeper visual exploration. In this context, AR serves as a tool to concretize abstract concepts, making them easier to comprehend.

Additionally, the interviews explored students' digital empathy after engaging with AR in learning. Students involved in AR-based learning reported feeling more empathy toward the characters they encountered in the social scenarios presented within the AR application. For instance, students interacting with 3D characters in complex social situations expressed a deeper understanding of the characters' perspectives, particularly in relation to bullying or other social challenges. This finding confirms the research by Jantakun et al. (2023) and Li et al. (2024), which suggests that interacting with characters in AR can enhance students' empathy, especially in social situations involving emotions and conflict. Thus, AR functions not only as an academic tool but also as a means of developing students' social skills.

Based on the observations and interview findings, it can be concluded that AR not only facilitates improvements in students' academic achievement but also enriches their social experiences, particularly in terms of digital empathy. AR allows students to engage more actively with learning content, think more creatively, and develop their social skills through interactions with characters and social situations within the application. These findings propose a modification to the constructivist learning theories of Piaget and Vygotsky (Alzahrani, 2025), which emphasize the importance of direct experience in knowledge construction. In this

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

context, AR can be seen as a tool that supports constructivist principles by providing a more interactive, contextual, and immersive learning experience.

The use of AR in learning contributes significantly to both academic achievement and the development of students' social skills. Therefore, the further integration of AR into educational systems should be considered to provide a more holistic, engaging, and relevant learning experience for 21st-century students. Further research is needed to explore how AR can be more effectively integrated with other learning approaches, such as project-based and problem-based learning, to create richer and more immersive learning experiences for students.

CONCLUSION

This study aimed to explore the impact of Augmented Reality (AR) on students' academic achievement and digital empathy. The findings, supported by both quantitative statistical tests and qualitative observations, demonstrate that AR-based learning has a significant and positive effect on both variables. Specifically, the results of the Paired Sample t-Test and Independent Sample t-Test indicate that students in the experimental group achieved considerably higher academic scores compared to those in the control group. The increase in academic achievement suggests a substantial gain facilitated by AR's ability to transform abstract concepts into interactive, 3D visualizations. This improvement aligns with constructivist theories, wherein students build knowledge through direct engagement with learning materials, and it supports active learning through inquiry and exploration.

In addition to academic gains, the study found a notable enhancement in digital empathy among students using AR. Students who interacted with AR-based social scenarios and virtual characters developed a stronger ability to perceive and respond to others' emotions. For example, interview data revealed that several students expressed greater sensitivity to peer perspectives during role-play scenarios in AR, such as resolving interpersonal conflict or showing compassion toward virtual characters. These experiences not only supported empathy development but also fostered critical social skills needed in the digital age.

Observational data indicated that AR stimulated active participation, creativity, and critical thinking. Students engaged more deeply with the content, frequently asking questions, proposing solutions, and reflecting on their learning process. This immersive interaction encouraged learner autonomy and creativity—skills that are vital in developing 21st-century competencies.

While the findings are promising, the study's limitations must be acknowledged. The use of purposive sampling and a relatively small sample size may affect the generalizability of the results. Additionally, the study was limited to a specific subject area and grade level, which may not fully capture the broader applicability of AR-based learning across diverse educational contexts. Practically, these findings suggest that AR can be effectively integrated into classroom instruction to enhance not only conceptual understanding but also socio-emotional learning. For instance, teachers can incorporate AR applications that allow students to manipulate scientific models or engage in simulated social

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

environments as part of project-based or problem-based learning activities. Such integration can enhance collaborative learning, foster empathy, and promote hands-on application of knowledge.

AR-based learning provides a holistic educational experience by improving both cognitive and emotional domains. Its potential lies not only in making learning more engaging and contextual but also in nurturing students to become more empathetic, independent, and reflective learners. Future research should explore how AR can be synergistically combined with other innovative pedagogical models, such as project-based or problem-based learning, to maximize its impact on student engagement and learning outcomes.

ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to Universitas Nurul Jadid for its financial support through the internal grant competition scheme, which made this research possible. Appreciation is also extended to the principal, teachers, and students of the partner school for their active participation in the data collection process.

REFERENCES

Ade-Ibijola, A., Sukhari, A., & Oyelere, S. S. (2025). Teaching accounting principles using augmented reality and artificial intelligence-generated IsiZulu language translations. *International Journal of Educational Research Open*, *8*(January), 100447. https://doi.org/10.1016/j.ijedro.2025.100447

Alzahrani, A. (2025). A systematic review of the use of information communication technology, including augmented reality, in the teaching of science to preschool children. *International Journal of Educational Research Open*, *9*(March), 100453. https://doi.org/10.1016/j.ijedro.2025.100453

Amara, K., Kerdjidj, O., Amine, M., Zenati, N., & Ramzan, N. (2025). Journal of Radiation Research and Applied Sciences Advancements and challenges in CT image segmentation for COVID-19 diagnosis through augmented and virtual Reality : A systematic review and future perspectives. *Journal of Radiation Research and Applied Sciences*, *18*(2), 101374. https://doi.org/10.1016/j.jrras.2025.101374

Carreon, A., & Smith, S. J. (2022). Augmented Reality as a Digital Tool to Support All Learners in Inquiry-Based Learning Lessons. *Interdisciplinary Journal of Problem-Based Learning*, *16*(1). https://doi.org/10.14434/ijpbl.v16i1.31260

Coppen, C., Snoeijink, T. J., Weijs, W. L. J., Verhulst, A., Verhoeven, T., Rijssel, J. T. v., Maal, T. J. J., & Dik, E. A. (2025). Augmented reality-guided osteotomies for simulated mandibular reconstruction with fibular bone using virtual cutting guides and 3D navigation. *British Journal of Oral and Maxillofacial Surgery*, 7–12. https://doi.org/10.1016/j.bjoms.2025.01.009

Çulha, D. (2021). Augmented Reality: Historical Development and Area of Usage İbrahim. *Journal of Educational Technology & Online Learning*, *4*(3), 2021. http://dergipark.org.tr/jetolDoi:http://doi.org/10.31681/jetol.831645

Dubreucq, E., Barlocco De La Vega, S., Bouaoud, J., Philippon, A. L., & Thiebaud, P.

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

C. (2025). Impact of virtual, augmented or mixed reality in basic life support training: A scoping review. *Clinical Simulation in Nursing*, *99*, 101672. https://doi.org/10.1016/j.ecns.2024.101672

Fatimah, S., Setiawan, W., Juniati, E., & Surur, A. S. (2019). Development of Smart Content Model-based Augmented Reality to Support Smart Learning. *Journal of Science Learning*, *2*(2), 65. https://doi.org/10.17509/jsl.v2i2.16204

Fijačko, N., Rios, M. P., Semeraro, F., Nadkarni, V. M., & Greif, R. (2025). Resuscitation Education Science Meets Virtual And Augmented Reality: Evolution from Potential Concept to Recommendations. *Resuscitation Plus*, 100950. https://doi.org/10.1016/j.resplu.2025.100950

Grimaldos, J., Fernández-Buendía, S., Bretón-López, J., Miguel, C., Cuijpers, P., & Quero, S. (2025). Augmented reality exposure treatments in anxiety and related disorders: A systematic review. *Internet Interventions*, *39*(January). https://doi.org/10.1016/j.invent.2025.100812

Imamoglu, M. (2020). Enhanced Educational Mobile Augmented Reality Application for Musculoskeletal System and Warm-Up Exercises. *Asian Journal of Contemporary Education*, *4*(2), 91–98. https://doi.org/10.18488/journal.137.2020.42.91.98

Jantakun, T., Jantakun, K., & Jantakoon, T. (2023). Systematic Review of Smart Classroom for Hard Skills Training in Augmented and Virtual Reality Environments. *Education Quarterly Reviews*, *6*(1), 280–294. https://doi.org/10.31014/aior.1993.06.01.706

Li, S., Li, Y., Lan, Y., & Lin, A. (2024). Efficient bundle optimization for accurate camera pose estimation in mobile augmented reality systems. *Egyptian Journal of Remote Sensing and Space Science*, *27*(4), 743–752. https://doi.org/10.1016/j.ejrs.2024.10.006

Maryani, I., Karimi, A., & Fathi, K. (2024). Virtual Reality in Elementary Education: A Scientometric Review. *Journal of Learning for Development*, *11*(3), 430–446. https://doi.org/10.56059/jl4d.v11i3.1330

Naveen, L., Khan, M. I., Saleh, M. A., & Subudhi, R. N. (2025). The influence of mobile augmented reality on consumer behavior: Insights into affective, cognitive, and behavioral responses. *Computers in Human Behavior*, *165*(January), 108558. https://doi.org/10.1016/j.chb.2025.108558

Nesenbergs, K., Abolins, V., Ormanis, J., & Mednis, A. (2021). Use of augmented and virtual reality in remote higher education: A systematic umbrella review. *Education Sciences*, *11*(1), 1–12. https://doi.org/10.3390/educsci11010008

Pujiastuti, H., & Haryadi, R. (2023). Enhancing mathematical literacy ability through guided inquiry learning with augmented reality. *Journal of Education and E-Learning Research*, *10*(1), 43–50. https://doi.org/10.20448/jeelr.v10i1.4338

Ramirez-Montoya, M. S., Martinez-Perez, S., & Zepeda-Orantes, L. P. (2024). Horizons Architecture With Virtual Reality for Complexity Environments: Mixed Methods. *Journal of Technology and Science Education*, *14*(1), 244–269. https://doi.org/10.3926/jotse.2512

Sarıgöz, O. (2019). Augmented reality, virtual reality and digital games: A research

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)

on teacher candidates. *Educational Policy Analysis and Strategic Research*, *14*(3), 41–63. https://doi.org/10.29329/epasr.2019.208.3

Shawarba, J., Tomschik, M., Wais, J., Winter, F., Dorfer, C., Mayer, F., Feucht, M., & Roessler, K. (2025). Augmented reality (AR) in microsurgical multimodal image guided focal pediatric epilepsy surgery: Results of a retrospective feasibility study. *Brain and Spine*, *5*(January), 104180. https://doi.org/10.1016/j.bas.2024.104180

Sontay, G., & Karamustafaoglu, O. (2021). Science Teaching With Augmented Reality Applications: Student Views About 'Systems in Our Body' Unit. *Malaysian Online Journal of Educational Technology*, *9*(3), 13–23. https://doi.org/10.52380/mojet.2021.9.3.218

Souza, B. J., Szejka, A. L., & Freire, R. Z. (2025). Towards an Integration of Augmented Reality in Industrial Assembly Processes: Issues and Perspectives. *Procedia Computer Science*, *253*(2024), 1063–1072. https://doi.org/10.1016/j.procs.2025.01.168

Sreejun, S., & Chatwattana, P. (2023). The Imagineering Learning Model with Inquiry-Based Learning via Augmented Reality to Enhance Creative Products and Digital Empathy. *Journal of Education and Learning*, *12*(2), 52. https://doi.org/10.5539/jel.v12n2p52

Swanson, J. A. (2023). Augmented Reality and Virtual Reality in Preservice Teacher Preparation: a Systematic Review of Empirical Literature. *20th International Conference on Cognition and Exploratory Learning in Digital Age, CELDA 2023*, *Celda*, 353–360. https://doi.org/10.33965/celda2023_202306l043

Ummah, M. S. (2019). Multimodal Analysis of Interaction Data from Embodied Education Technologies. In *Sustainability (Switzerland)* (Vol. 11, Issue 1). http://scioteca.caf.com/bitstream/handle/123456789/1091/RED2017-Eng-8ene.pdf?sequence=12&isAllowed=y%0Ahttp://dx.doi.org/10.1016/j.regsciurbeco.2008.06.005%0Ahttps://www.researchgate.net/publication/305320484_SISTEM_PEMBETUNGAN_TERPUSAT_STRATEGI_MELESTARI

Wickramasinghe, Y. S., Lukosch, H. K., Everett, J., & Lukosch, S. (2025). Representing remote locations with location-based augmented reality game design. *Entertainment Computing*, *53*(June 2024), 100932. https://doi.org/10.1016/j.entcom.2025.100932

Yildiz, E. P. (2022). Augmented Reality Applications in Education: Arloopa Application Example. *Higher Education Studies*, *12*(2), 47. https://doi.org/10.5539/hes.v12n2p47

Živičnjak, M., Rogić, K., & Bajor, I. (2025). Augmented reality technologies application in the warehouse system. *Transportation Research Procedia*, *83*, 35–42. https://doi.org/10.1016/j.trpro.2025.02.007

Corresponding author: Chusnul Muali (chusnulmuali@unuja.ac.id)