Global Journal of Information Technology: Emerging Technologies

Volume 15, Issue 1, (2025) 35-46

www.gjit.eu

Enhancing middle school science learning outcomes through mobile augmented reality and authentic learning

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Suggested Citation:

Hidayati, A., Bentri, A., Zen, Z., Arina, N., & Amsal, M. F. (2025). Enhancing middle school science learning outcomes through mobile augmented reality and authentic learning. *Global Journal of Information Technology: Emerging Technologies*, *15*(1), 35-46. https://doi.org/10.18844/gjit.v15i1.9721

Received from; October 10, 2024, revised from; January 2, 2025 and accepted from March 3.
Selection and peer review under the responsibility of Assoc. Prof. Dr. Ezgi Pelin YILDIZ, Kafkas University, Turkey
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iThenticate Similarity Rate: 3%

Abstract

This study examines the effectiveness of authentic learning supported by mobile phone-based augmented reality in enhancing science learning. Authentic learning, which bridges theoretical knowledge and real-world application, remains underexplored in the context of immersive digital tools. Addressing this gap, the study aims to evaluate the impact of augmented reality integrated into mobile devices on students' science learning outcomes. A quantitative approach was employed using a quasi-experimental design with factorial analysis. The research involved high school students, divided into experimental and control groups. The procedure included the development of augmented reality-based instructional media, the design of learning sequences, classroom implementation, and subsequent evaluation. Data were collected and analyzed using statistical software to determine the effectiveness of the intervention. The findings indicate that the integration of augmented reality within an authentic learning framework significantly improves students' understanding and engagement in science education. The study underscores the potential of mobile technology to transform science instruction by providing contextual, interactive, and experiential learning environments.

Keywords: Augmented reality; authentic learning; mobile learning; science education; technology integration.

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1. INTRODUCTION

Mobile phones represent one of the most accessible platforms for facilitating authentic learning experiences. Empirical evidence indicates that individuals aged between 15 and 19 years constitute the largest proportion of smartphone users, accounting for approximately 91 percent of this demographic. This suggests that adolescents, particularly those enrolled at the junior and senior high school levels, are the primary users of smartphones. These devices can serve as dynamic tools for effective, creative, and pedagogically sound educational engagement. The continued evolution of educational applications is supported by the integration of emerging technologies, such as Augmented Reality (AR), which holds significant potential in the educational domain. Consequently, educators must develop digital pedagogical competencies to meet the instructional demands of the Fourth Industrial Revolution (Bentri et al., 2022).

Augmented Reality refers to a technological innovation that seamlessly overlays computer-generated digital elements onto the physical environment in real-time (Haller et al., 2006). By merging tangible, real-world contexts with digitally mediated virtual dimensions, AR enriches physical environments with three-dimensional virtual content. Initially reliant on computer-based platforms, advancements in technology have facilitated the deployment of AR applications on mobile devices, particularly smartphones, thus enhancing accessibility and usability.

This technology presents a significant opportunity to innovate within educational media by enhancing learning outcomes (Thees et al., 2022). AR possesses the unique capacity to integrate multiple categories of instructional media, including print, electronic formats, and tangible objects, into a cohesive and interactive learning experience. The conceptual framework of AR encompasses the convergence of physical and virtual realms through the use of electronic devices such as smartphones and printed materials like textbooks (Ramli et al., 2024).

Furthermore, AR incorporates elements of interactive entertainment, which can substantially increase learner engagement by appealing to multiple sensory modalities. This sensory immersion enables learners to engage with content both cognitively and experientially, thereby fostering meaningful educational experiences (Aslam et al., 2024). When applied as a medium for instruction, AR allows students to engage in cognitive tasks without the need for direct manipulation of physical laboratory tools. This is because AR facilitates clearer information transmission and enhances motivation and interest in learning processes (Gandolfi & Ferdig, 2025).

AR-supported instruction is demonstrably more interactive than traditional methods, thereby encouraging students to engage in realistic and reflective thought processes. This is particularly applicable to subjects such as biology, where abstract concepts, such as the structure and function of plant tissues, can be visualized and better understood through AR implementations.

The application of AR in educational media can foster the development of students' critical thinking skills by encouraging reflection on real-world problems and phenomena. One of the key roles of educational media is to support student learning both in the presence and absence of direct teacher intervention. Thus, AR-enhanced learning tools offer flexible learning opportunities that can be accessed anytime and anywhere, further reinforcing independent learning practices (Tuli et al., 2022).

The design of AR-based authentic learning tools for educational use is characterized by the following components:

1. A mobile application developed for Android devices that facilitates the study of plant tissue structure and function using AR to present cellular structures in both two-dimensional and three-dimensional formats. The Unity platform is employed for application development, Blender is used for 3D modeling, Visual Studio 2020 serves as the primary development environment, and Adobe Photoshop is utilized for designing AR card visuals.

2. The AR Cards, which complement the mobile application, include visual markers and condensed instructional content to aid in the learning process.

3. A set of basic science assessment items embedded within the AR application that target students' conceptual understanding of plant tissue structure and function.

1.1. Purpose of study

The advancement of mobile-based multimedia for educational purposes is a critical area of development. Its significance lies in the alignment with learner preferences and the availability of supporting infrastructure that fosters broader engagement and deeper understanding (Hidayati & Bentri, 2022).

2. METHODS AND MATERIALS

2.1. Data collection tool

This study uses a quasi-experimental method with a factorial design. Experiments were carried out on learning using the implementation of an authentic learning approach using augmented reality based on mobile learning in the experimental class, and in the control class using the implementation of an authentic learning approach using augmented reality. To obtain data on learning outcomes, a test instrument for learning outcomes was used, which had been tested for validity and reliability. Then, a requirements analysis test was performed, namely the Lilliefors test for normality, as well as the F test and Bartlett test for data homogeneity. The data obtained were analyzed using 2-way ANOVA with the F test at a significance level of = 0.05.

2.2. Participants

The population of this study was all junior high school students in the even semester of the 2022/2023 academic year, with a research sample of 20 students. To test the research hypothesis, data analysis techniques were used with two-way analysis of variance (ANOVA).

2.3. Data analysis

The research design employed in this study is a 2 × 3 factorial design with a significance level set at 0.05. To validly apply a two-way Analysis of Variance (ANOVA), several statistical assumptions must first be satisfied. First, the assumption of normality requires that the data be normally distributed. To verify this, the Liliefors test is employed. Second, the assumption of homogeneity of variances must also be met, necessitating the use of variance homogeneity tests, specifically the F-test and Bartlett's test. Once these preliminary assumptions are confirmed, hypothesis testing can proceed to evaluate the interaction effects between the two independent variables on the dependent variable.

3. RESULTS

Figure 1

Augmented reality material structure of plant tissue

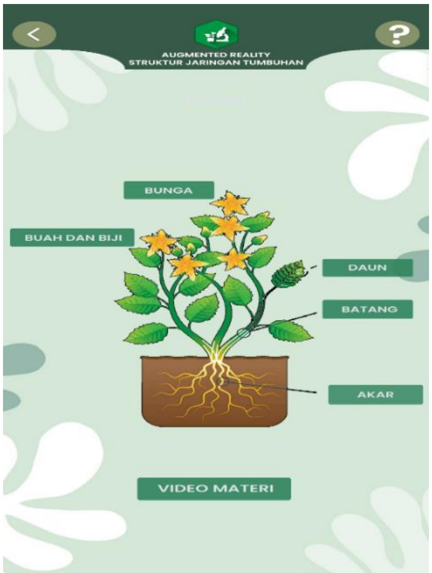


Figure 2

Augmented reality material structure of plant tissue

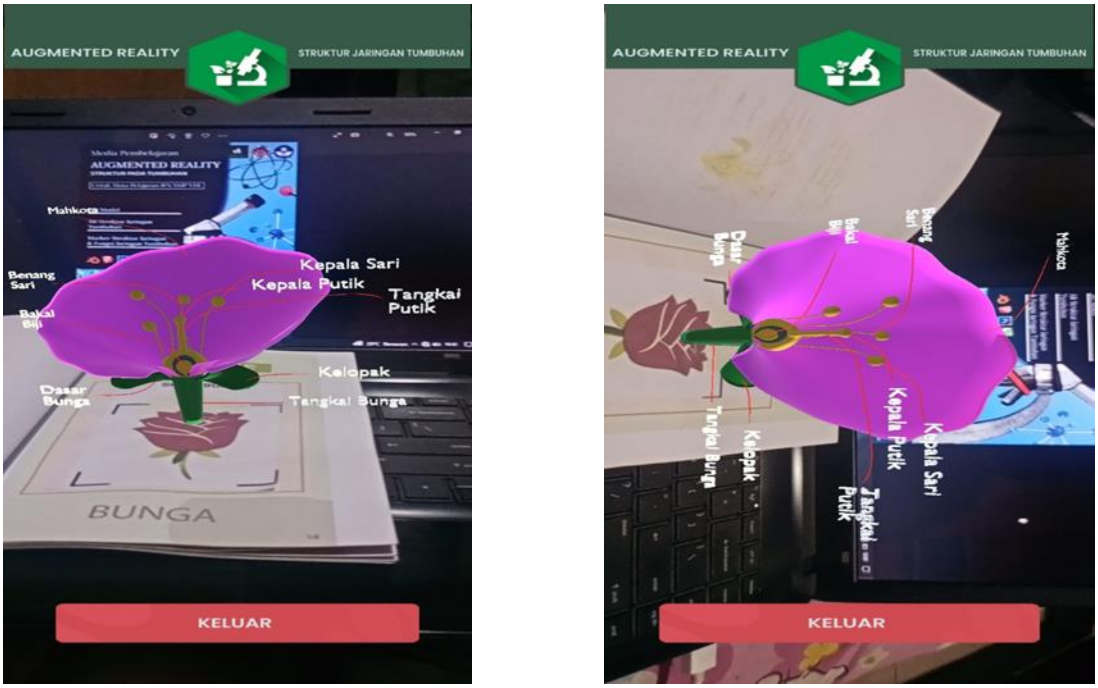
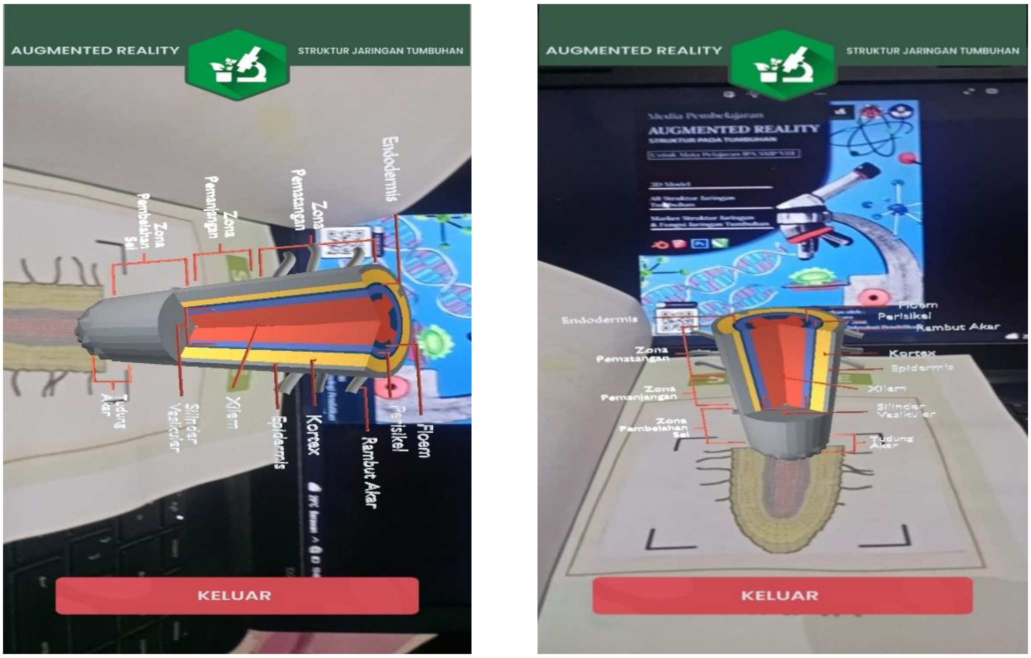


Figure 3

Augmented reality material structure of plant tissue



Figures 1, 2, and 3 present the Augmented Reality visualizations developed to illustrate the structure of plant tissue. Figure 1 displays the foundational interface featuring two-dimensional representations of cellular components. Figure 2 advances this by introducing interactive three-dimensional models that depict both vascular and non-vascular tissues. Figure 3 provides an enhanced view with layered structural details and annotated labels, enabling users to explore the complexity of plant tissue in greater depth. These visualizations are designed to support student comprehension by bridging abstract biological concepts with immersive, interactive digital content.

Table 1

Posttest data of student learning outcomes

No	Class	N	*x*	x min	x max	S
1	Experiment	20	83,27	69,23	100	9,44
2	Control	20	78,46	61,54	100	9,69

Note:

n : total students
x : average
Xmax: maximum value
Xmin: minimum value

The posttest average of student learning outcomes taught using authentic learning was 83.27, with a very good category, and the posttest average of student learning outcomes taught using conventional learning was 78.46, with a good category (Table 1). The maximum score of students in the experimental class is the same as that of the control class, which is 100. Meanwhile, the minimum score of students in the experimental class is also higher than that of the control class. In the experimental class, the minimum score of students is 69.23, in the control class, the minimum score of students is 61.54 (Table 2).

3.2. Pretest and posttest data on student learning outcomes in the experimental class and control class

Table 2

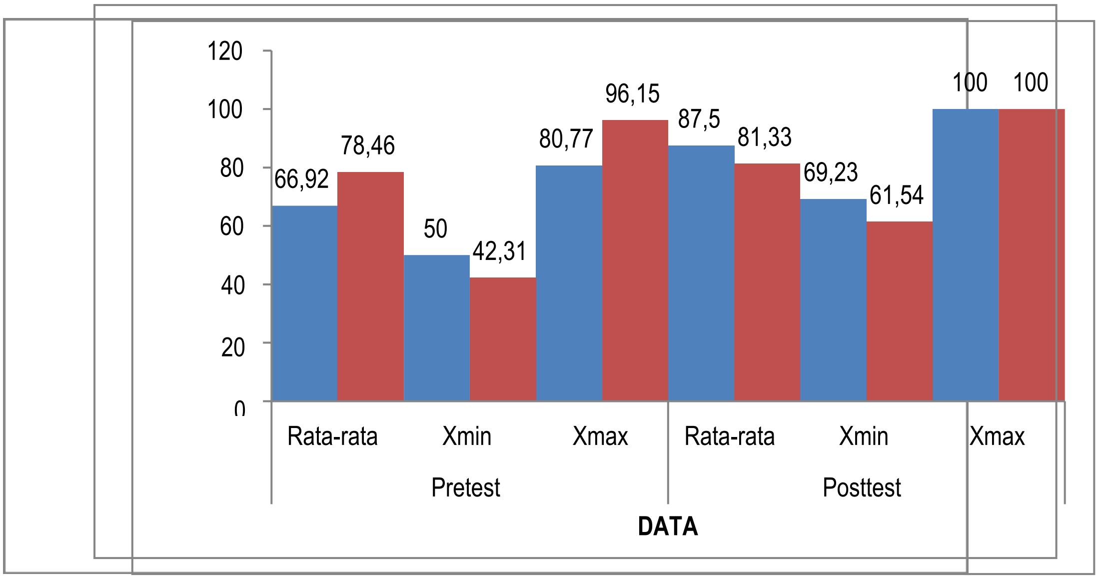
Data pretest and posttest

Class	Pretest			Postest			Percentage
	Average	Xmin	Xmax	Rata-rata	Xmin	Xmax	
Experiment	66,92	50	80,77	87,50	69,23	100	30,75
Control	78,46	42,31	96,15	81,33	61,54	100	3,7

Description:
n: total students
x : average
Xmax: maximum value
Xmin: minimum value

Figure 4

Data pretest and posttest



3.3. Normality test of student learning outcomes in the experimental and control classes after treatment

Table 3

Normality test in the control class

No	Sample	A	Lh	Lt	Description
1	Test the normality of the experimental class learning outcomes after treatment	0,05	0,11191	0,190	Normal
2	Test the normality of learning outcomes, Control class after	0,05	0,16082	0,190	Normal

Based on the data presented in Table 3, the normality test results for the experimental group following the intervention indicate that the calculated L-value (Lh) is 0.11191. This value is below the critical L-value (Lt) of 0.190 at the 0.05 significance level for a sample size of 20, thereby confirming that the data are normally distributed. Similarly, for the control group, the calculated Lh is 0.16082, which is also less than the corresponding Lt value of 0.190. Thus, the data for the control group also meet the assumption of normality.

3.4. The homogeneity of student learning outcomes after treatment in the experimental and control classes

Table 4

Homogeneity test in the experiment class

Class	Fh	Ft (α = 0,05)	Description
Experiment Control	1,014	2,168	**Homogeneous**

Based on Table 4 above, the Fh value is 1.014. While Ft at the level of significance (0.05) for the sample is 2.168. Because Fh is smaller than Ft, it can be concluded that the two data groups have homogeneous variance.

3.5. Hypothesis testing

Table 5

Hypothesis testing

Data	Class	N	Sgab	α	dk	Tcount	Ttable	Desc
Posttest	Experiment	20	33,814	0,05	38	3,419	2,024 4	AcceptH1
	Control	20						

Based on the results of the t-test for the posttest scores as presented in Table 5, the obtained t-value (t_o) is 3.419, which exceeds the critical t-value (t_t) of 2.0244 at the 0.05 significance level. This result indicates that the null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted. Therefore, it can be concluded that there is a statistically significant difference in student learning outcomes between the experimental group, which received instruction through authentic learning and real-world activities, and the control group, which was taught using conventional methods.

Table 6
Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,964a	,929	,925	1,80042

Predictors: (Constant), X

Table 6 presents the correlation coefficient (R), which is 0.86, indicating a strong positive relationship between the independent and dependent variables. The coefficient of determination (R^2), obtained by squaring the correlation coefficient, is 0.925. This suggests that 92.5% of the variance in student learning outcomes can be explained by the implementation of authentic learning through mobile phone-based Augmented Reality. The remaining 7.5% is attributable to other external or uncontrolled variables.

4. DISCUSSION

The integration of Augmented Reality (AR) and mobile learning-based instructional media represents a pedagogical innovation that connects academic content with real-life contexts, thereby enhancing the relevance and meaningfulness of the learning experience. These technologies have been empirically validated in terms of both practicality and validity, supporting their adoption by educators within classroom environments. AR media in this context are designed through an authentic and mobile learning framework, offering content tailored to students' needs by situating learning within real-world problems and project-based assignments that can be applied in everyday contexts (Iucu & Marin, 2014; Wornyo et al., 2018). Authentic learning is defined as a pedagogical approach that encourages learners to engage in exploration, deep discussion, and the construction of knowledge through tasks that reflect genuine problems and relevant projects. This approach facilitates learners in making direct, meaningful connections between everyday challenges and the academic concepts under study (Astuti & Baysha, 2018). The application of authentic learning combined with digital technologies in science education has been shown to foster increased student engagement, promoting more positive attitudes and active participation in learning activities (Coksun et al., 2017; Gunes et al., 2020).

Mobile learning, or m-learning, can be conceptualized as the convergence of mobile computing and electronic learning. It enables learners to access educational resources regardless of time or location, supports dynamic information retrieval, fosters interactive learning, and incorporates assessment tools that emphasize performance outcomes. As a subset of e-learning, mobile learning leverages information and communication technologies (ICTs) to deliver educational content in visually engaging formats that students can access at their convenience.

Defined as the delivery of instruction through portable digital devices, mobile learning removes spatial and temporal constraints, allowing learners to interact with instructional materials, activities, and applications anytime and anywhere (Andy, 2007). It is considered an extension of e-learning that utilizes mobile computing to disseminate educational content. Typical mobile learning devices include smartphones and personal digital assistants (PDAs), though the term may broadly refer to any compact, portable device capable of independent operation and suitable for learning purposes (Ally, 2005). These devices serve as tools not only for accessing both local and cloud-based educational content but also for facilitating communication, including voice, text, and multimedia exchanges.

The distinctive characteristics of mobile learning include: (1) its status as a branch of e-learning utilizing digital and electronic ICT infrastructure; (2) its accessibility across various settings and times; (3) its capacity to support interactive and visually engaging content dissemination; and (4) its selective suitability depending on content type, as some learning materials may be constrained by the physical limitations of mobile interfaces (Quinn, 2000).

As noted by Aixia et al. (2020), global technological advancements are intrinsically linked to educational transformation. The integration of technology into classroom instruction presents a contemporary challenge and opportunity for educators (Hernawati, 2019). When appropriately applied, technology can significantly enhance the design and effectiveness of educational media (Wijaya et al., 2020). AR technology, in particular, has demonstrated substantial promise in addressing the learning challenges associated with abstract subject matter such as mathematics. According to Mustaqim and Kurniawan (2017), AR technology enables the simultaneous projection of two-dimensional and three-dimensional virtual content into the physical environment, offering immersive visual experiences.

AR-based media effectively overlay virtual objects onto real-world surroundings in real time. As noted by Rizal and Yermiandhoko (2018), a key feature of AR is its use of 3D digital objects that are rendered visible upon detection of specific markers via designated applications. This feature enhances student engagement, especially in topics requiring spatial understanding, such as geometry, where abstract concepts can be difficult to grasp. Through AR, students can visually and experientially interact with the subject matter, thus improving cognitive engagement. In alignment with these findings, research by Alawiyah (2024) demonstrates that students who engaged with Mobile Augmented Reality (MAR) learning strategies exhibited improved cognitive learning outcomes.

5. CONCLUSION

The implementation of an authentic learning approach through mobile learning integrated with Augmented Reality (AR) technology in the context of natural science education was systematically carried out through the stages of analysis, design, development, implementation, and evaluation. The final product is a mobile application compatible with Android operating systems and accessible across all Android smartphones.

This AR-based instructional media is specifically designed to support the teaching of natural science, with a particular focus on the core competency related to the structure and function of plant tissues. An evaluation of the application's content and alignment with instructional objectives indicates that it falls within the category of appropriate feasibility. Moreover, its potential to enhance the overall quality of the learning process has been assessed as highly feasible, indicating strong suitability for educational implementation.

Acknowledgments: The authors express their sincere gratitude to the Institute for Research and Community Service (LP2M), Padang State University, for providing financial support for this research under Contract No. 858/UN35.13/LT/2022. The authors also extend their appreciation to the Institute for facilitating the ethical review and approval process through its research ethics committee.

Conflict of Interest: The authors declare no conflict of interest.

Ethical Approval: The study adheres to the ethical guidelines for conducting research.

Funding: This research received no external funding.

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