

# Implementation of Augmented Reality-Based Learning to Enhance Student Engagement and Achievement at SMA Hang Tuah Makassar

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## Abstract

The development of digital technology in education demands learning innovations that can increase student engagement and understanding. This community service activity aims to implement Augmented Reality (AR)-based learning media to improve the quality of learning at Hang Tuah Senior High School, Makassar. The method used is a collaborative, participatory approach that follows the stages of needs identification, media development, training, implementation, and evaluation. AR media allows students to interact with three-dimensional objects, creating a more interactive and contextual learning experience. The results of the activity show an increase in student learning outcomes, with the average score rising from 54.43 to 83.36 and a gain of 0.65, which falls within the high category. In addition, there was an increase in student engagement and motivation to learn, as well as in teacher competence in integrating technology into learning. Despite obstacles such as limited devices and internet connectivity, the implemented adaptive strategy supported the program's success. The use of AR has the potential to be an innovative solution in supporting interactive and sustainable learning in the digital era. This research provides a practical contribution to the application of Augmented Reality-based learning in secondary education.

*Keywords:* Augmented Reality; Deep Learning; Interactive Learning Media; Learning Motivation; Educational Technology

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## Introduction

The development of information and communication technology has driven significant transformations in the world of education, particularly in the use of innovative and interactive digital-based learning media (Nurhayati et al., 2024). One technology with great potential is Augmented Reality (AR), which integrates virtual objects into real-world environments, creating a more contextual and engaging learning experience (AlGerafi et al., 2023a; Arena et al., 2022; Syed et al., 2022). The use of AR in learning allows students to interact directly with three-dimensional visualizations, which has been shown to help them understand abstract concepts more effectively (Singh et al., 2024; Supli & Yan, 2024). Furthermore, the use of AR has also been reported to increase student motivation and engagement in the learning process (Ji et al., 2025; tom Dieck et al., 2024). Despite its significant potential, the implementation of digital-based learning technology in schools still faces various challenges (Nurhayati et al., 2024; Swandi et al., 2024). Limited infrastructure, low technological literacy, and the dominance of conventional learning methods are key factors hindering the optimal use of digital media in learning (Mhlanga, 2024; Okoye et al., 2023; Timotheou et al., 2023). Observations at Hang Tuah High School in Makassar revealed that the learning process remains largely teacher-centered, with the lecture method as the primary approach. This situation leads to low student engagement, reduced interest in learning, and suboptimal learning outcomes (Tang, 2023).

Furthermore, the implemented learning approach has not fully fostered the development of critical thinking and problem-solving skills (Xu et al., 2023). In the context of modern education, the deep learning approach (from a pedagogical perspective) emphasizes the importance of active student involvement in building understanding through analysis, reflection, and exploration (Weng et al., 2023). This approach focuses not only on mastery of the material but also on students' ability to relate knowledge to real-life contexts, resulting in more meaningful learning (Hsbollah & Hassan, 2022; Maftuh et al., 2023). Given these challenges, learning innovations are needed to effectively integrate technology and pedagogical approaches (Hamzah et al., 2024). Integrating augmented reality with immersive learning approaches is a promising approach to creating more interactive, adaptive, and student-centered learning experiences (Lampropoulos, 2023; Thangavel, 2025). Through AR, students can gain visual and exploratory learning experiences that encourage active engagement in the learning process (AlGerafi et al., 2023b).

Therefore, this community service activity aims to implement Augmented Reality-based learning media at Hang Tuah Senior High School, Makassar. This program is expected to increase student engagement, motivation, and learning outcomes, as well as strengthen teachers' competencies in integrating technology into teaching practices (Geletu, 2022;

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Wagino et al., 2024). Furthermore, this activity is also expected to serve as an innovative learning model that can be replicated in similar educational contexts in the digital age.

## Method

This community service activity was conducted at Hang Tuah High School in Makassar, involving teachers and students as the primary partners. The participants comprised 14 high school students and several subject teachers who served as facilitators in the learning process. The program employed a collaborative, participatory approach in which the community service team and partners worked together to design, implement, and evaluate technology-based learning activities. The implementation of the activities is carried out through several systematic stages. The first stage is needs identification, conducted through observations and interviews with school officials to determine learning conditions, levels of technology use, and challenges encountered. The results of this identification serve as the basis for designing program interventions that meet user needs. The second stage is media design and development, namely the creation of Augmented Reality (AR)-based learning media. The media was developed using the Assemblr Edu platform, which enables interactive, real-time visualization of three-dimensional objects. Furthermore, a learning module was developed to guide teachers and students in the systematic and targeted use of media (Abuhassna et al., 2024; Elistiana et al., 2024).

The third stage is training and implementation, which includes socialization activities on the use of AR media, demonstrations, and hands-on practice in the classroom. Students interact with AR media to understand the material visually and contextually, while teachers act as facilitators, guiding and directing the technology-based learning process. The fourth stage is to evaluate and measure the program's impact. The evaluation was conducted through pre- and post-tests to measure improvements in student learning outcomes. Additionally, a Likert-scale questionnaire (1–5) and direct observation were used to assess student engagement, motivation, and response to the use of AR-based learning media.

The data obtained were analyzed using a quantitative descriptive approach. Improvement in learning outcomes was analyzed by comparing pre-test and post-test scores and calculated using the normalized gain ( $g$ ) formula to determine the level of learning effectiveness. Meanwhile, questionnaire data were analyzed as percentages to interpret the level of student response and engagement. This procedure was carried out to ensure that the implemented program had a measurable, transparent, and replicable impact in similar educational contexts. To ensure the research instrument's quality, the questionnaire was validated by two experts in educational technology to establish content validity. Furthermore, the instrument was also tested on a limited basis on respondents outside the research sample. Reliability testing, conducted using internal consistency analysis, showed that the instrument had good reliability (Krieglstein et al., 2022).

## Results and Discussion

The implementation of a community service program using an Augmented Reality (AR)-based deep learning model at Hang Tuah Senior High School in Makassar demonstrated significant improvements in student learning outcomes, learning engagement, and teachers' competency in using educational technology. In this study, the term "deep learning" refers to a pedagogical approach that emphasizes in-depth understanding, rather than an artificial intelligence-based computational model (Sari, 2025). The results and discussion are presented in an integrated manner to provide a comprehensive overview of the program's impact.

### Implementation of AR-Based Learning Programs

The implementation of Augmented Reality (AR)-based learning programs is carried out through training, mentoring, and direct classroom application as a form of technology integration into learning practices (AlGerafi et al., 2023b; Nikimaleki & Rahimi, 2022). These stages serve not only as a technical process for technology adoption but also as an effort to transform the learning approach from conventional to more interactive and student-centered. In practice, students interact directly with three-dimensional virtual objects displayed in real time via mobile devices. This interaction allows students to observe, explore, and understand learning concepts more concretely. The teacher acts as a facilitator, guiding the learning process, while technology serves as a medium that enriches the learning experience.

Theoretically, this implementation can be explained through a constructivist approach, which emphasizes that knowledge is built through direct experience and active interaction with the learning environment. AR technology, in this case, functions as a mediating tool, bridging abstract concepts into more easily understood visual representations. Furthermore, this approach aligns with experiential learning theory, which argues that learning is more effective when students are directly involved in the exploration and learning experience.

Impact on Student Learning Outcomes

The program's effectiveness was evaluated quantitatively by comparing pre-test and post-test scores administered to students before and after the use of Augmented Reality (AR)-based learning media integrated with a deep learning approach. This measurement aimed to determine the extent to which students' conceptual understanding improved after participating in the interactive technology-based learning process.

Table 1. Comparison Results of Pre-test and Post-test Scores

No	Indicator	Average value
1	Pre-Test	54.43
2	Post-Test	83.36
3	Difference	28.93
4	Gain Score (g)	0.65
5	Category	Tall

Table 1 shows a significant increase of 28.93 points in scores from the pre-test to the post-test. This indicates that the use of AR media positively contributes to improving student learning outcomes. To measure the effectiveness of this improvement, the normalized gain (g) calculation was used using the following formula (1).

$$g = (\text{Post} - \text{Pre}) / (100 - \text{Pre}) \tag{1}$$

The calculation results show a gain value of 0.65, which is considered high. This value indicates that Augmented Reality (AR)-based learning media, when combined with a deep learning approach, can significantly and effectively improve students' understanding. More deeply, this improvement reflects not only success in the cognitive domain but also a change in how students understand the learning material. Visualizing objects in three dimensions allows students to see, observe, and interact directly with previously abstract material. This strengthens the learning process because students not only receive information passively but are also actively involved in exploring concepts.

The deep learning approach to learning encourages students to think more critically and reflectively. Students not only memorize material but also understand the relationships between concepts and apply their knowledge in broader contexts. The combination of AR technology and the deep learning approach creates a more meaningful learning experience. From a learning-theory perspective, these results align with the constructivist approach, which emphasizes that knowledge is constructed through direct experience and active engagement with the learning environment. AR media acts as a facilitator, presenting these experiences visually and interactively, thereby increasing student retention and understanding. Therefore, it can be concluded that the application of Augmented Reality (AR)-based learning media supported by the deep learning approach is not only effective in improving student learning outcomes but also in creating a more interactive, contextual, and understanding-oriented learning process.

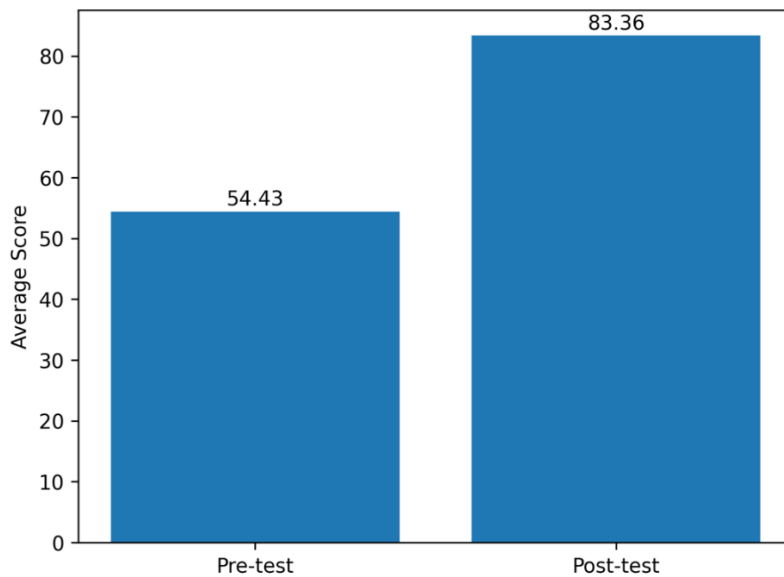


Figure 1. Comparison Chart of Students' Pre-test and Post-test Scores

Figure 1 shows a comparison of students' average pre-test and post-test scores. A significant improvement was observed after the implementation of Augmented Reality (AR)-based learning media. This indicates that the learning intervention effectively improved student understanding.

#### Augmented Reality Media Visualization

The Augmented Reality (AR)-based learning media developed in this program is designed to display three-dimensional (3D) objects in real time via mobile devices (Pramuditya et al., 2022). When students point the camera at a specific marker or object, the system displays a 3D visualization complete with supporting information such as the object's name, function, and interactive explanations of the concept. This feature allows students to observe objects from various angles, zoom in, and interact directly with the displayed visual elements. AR-based visualizations provide a more concrete learning experience than conventional methods (Hajirasouli & Banihashemi, 2022; Mokmin et al., 2024). Previously abstract concepts can be more easily understood when visualized in a tangible, interactive form. Furthermore, this technology integration also increases student engagement in the learning process, as students no longer passively receive information but actively explore the material presented. Classroom implementation results show that the use of AR media can increase student interest in learning, strengthen conceptual understanding, and create a more engaging and less monotonous learning environment. This demonstrates that AR-based learning media has great potential to support learning transformation in the digital era.

The visualization of Augmented Reality (AR)-based learning media, as shown in Figure 2 below, displays three-dimensional objects interactively. Students can observe, rotate, and enlarge objects to understand concepts more deeply. This feature increases the appeal of learning and encourages active student involvement in the learning process. The use of AR technology also provides a more immersive learning experience than conventional methods. Direct interaction with virtual objects encourages active student involvement in the learning process, increases curiosity, and strengthens focus and attention during learning activities. Thus, AR-based learning media not only serve as visual aids but also as a means of creating a more dynamic, interactive, and student-centered learning environment. These findings indicate that integrating AR technology into learning has significant potential to improve learning quality, particularly by supporting conceptual understanding and sustained student engagement.

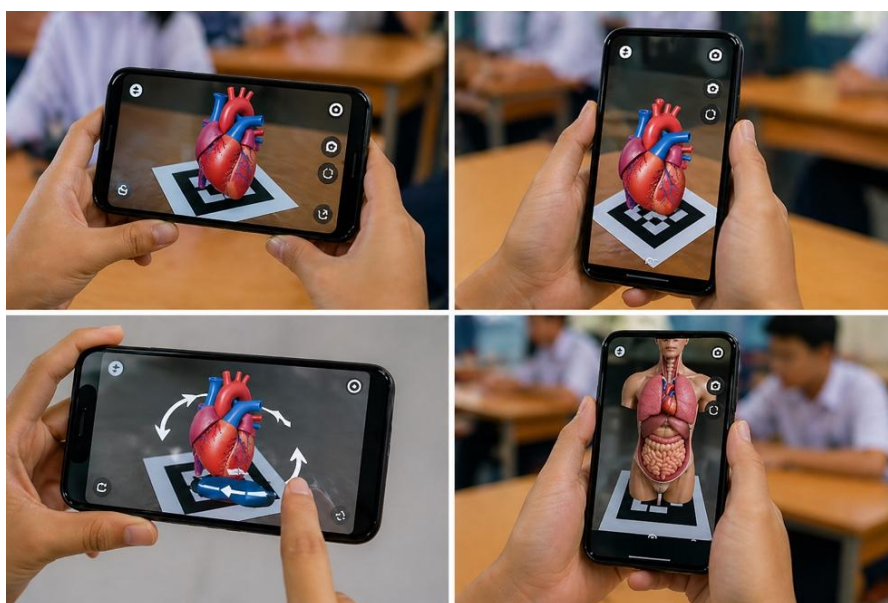


Figure 2. Augmented Reality Media Display in Learning

#### Analysis of student engagement and response

Evaluation of student engagement in Augmented Reality (AR)-based learning was conducted through direct observation during implementation and via a Likert-scale questionnaire (1–5). The research subjects comprised 14 students from Hang Tuah Makassar High School who were directly involved in the use of AR-based learning media. The instruments used were aligned with indicators of learning engagement, including cognitive, affective, and interactive aspects. Observation results show a significant increase in active student participation during the learning process. This increase can be identified through several main indicators, namely: (1) increased student activity in asking questions related to learning materials, (2) direct interaction with AR media such as rotating, enlarging, and exploring three-dimensional

objects, and (3) high student enthusiasm in participating in learning activities. Students not only act as recipients of information, but also as active participants in building their understanding.

Furthermore, the use of AR media provides a more varied and contextual learning experience. Visualizing objects in three dimensions helps students understand abstract concepts more concretely. This has an impact on increasing student motivation and attention during the learning process. The learning environment, which had previously been monotonous, has become more dynamic, thereby reducing student boredom. To strengthen the findings, a summary of student responses to the use of AR media is presented in Table 2 below.

Table 2. Student Responses to Augmented Reality (AR)-Based Learning

No	Assessment Aspects	Percentage (%)	Category
1	Interest in media	88%	Very good
2	Ease of Use	85%	Very good
3	Interactivity	90%	Very good
4	Understanding the Material	87%	Very good
5	Motivation to learn	89%	Very good

The percentages in Table 2 were calculated by comparing the total scores from student responses to the maximum possible score. The results indicate that all aspects are in the "very good" category, with the highest score for interactivity. This demonstrates that AR media can provide a more engaging learning experience and actively involve students. To clarify the data, student responses are compared graphically in Figure 3.

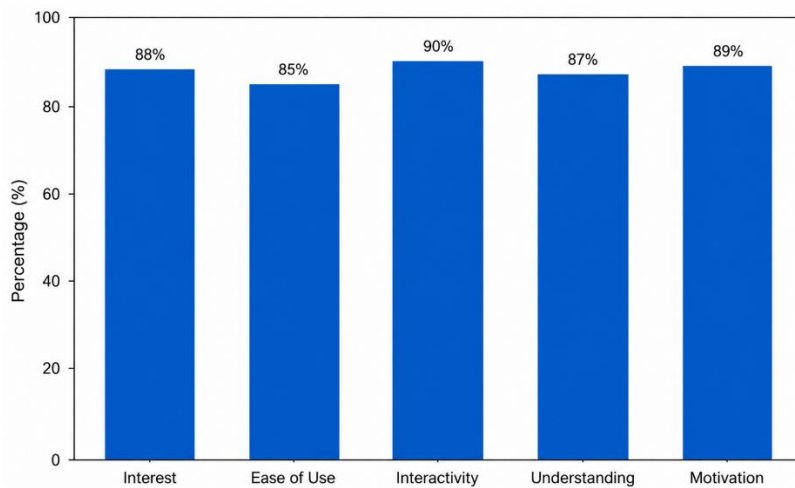


Figure 3. Analysis of Student Response and Engagement

Figure 3 shows that all indicators of student engagement achieved high scores, particularly in interactivity and learning motivation. This indicates that the use of AR technology not only improves understanding but also provides a fun and meaningful learning experience. This finding aligns with constructivist learning theory, which holds that knowledge is constructed through direct experience and active engagement with the learning environment. AR media acts as a facilitator, enabling students to construct knowledge independently through visual exploration and contextual experiences. Furthermore, these results are consistent with previous research showing that the use of visual and interactive technologies can increase student engagement and motivation to learn.

However, there are several limitations in implementing this program, including the limited number of devices available to students and the stability of the internet connection, which affect the smooth use of AR media. Therefore, adequate infrastructure support is needed to ensure the implementation of AR-based learning media runs optimally and sustainably. Overall, the results of this study indicate that implementing deep learning-based Augmented Reality media not only improves learning outcomes but also significantly increases student engagement and positive responses to the learning process. Thus, this technology has great potential to be integrated into modern learning systems that are more interactive, adaptive, and student-centered.

#### Improving Teacher Competence

In addition to positively impacting student learning outcomes, this program significantly improved teachers' competency in integrating technology into the learning process. Evaluation was conducted through observations during

training and classroom implementation, as well as teacher reflections after using Augmented Reality (AR) media. The results showed an increase in teacher competency in various aspects. The ability to use AR media rose from around 60% to 88%, indicating growth in the high category. Furthermore, the ability to design technology-based learning increased from 58% to 85%. In digital classroom management, the percentage increased from 62% to 87%, while the ability to use technology as an evaluation tool increased from 55% to 83%.

This improvement demonstrates that teachers are not only able to operate technology but are also beginning to understand how to integrate it pedagogically into the learning process. Teachers are becoming more adaptable in designing interactive learning strategies and creating a more dynamic, student-centered learning environment. To provide a clearer picture of the teacher competency improvement, a comparison before and after the program implementation is presented in Figure 5.

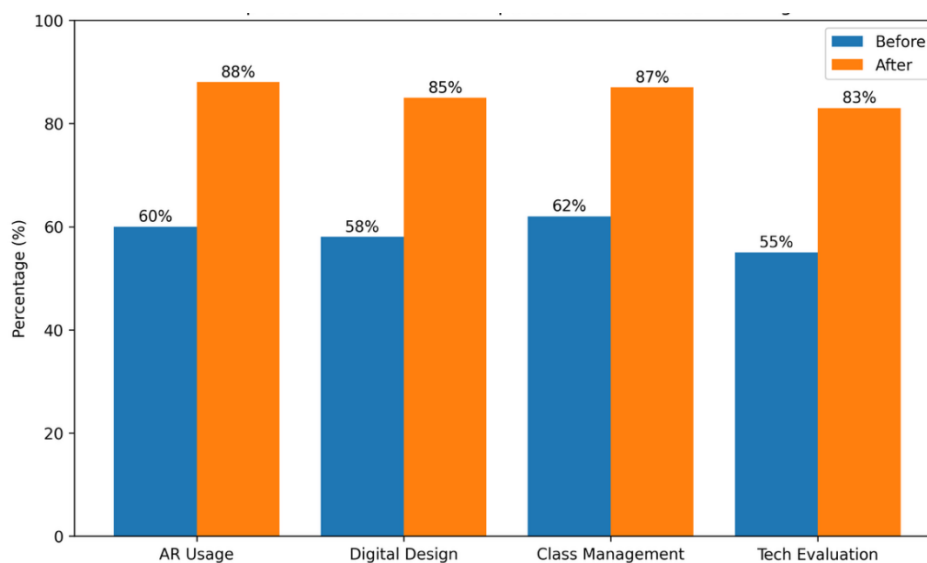


Figure 4. Improvement of Teacher Competencies in AR-Based Learning

Figure 4 shows that all aspects of teacher competency have significantly improved. This demonstrates that the training and mentoring programs provided have effectively improved teachers' technological literacy. Teachers also demonstrated increased confidence in using technology as part of their learning strategies. Furthermore, this increased competency demonstrates a transformation in the teacher's role from conventional learning methods to more innovative, technology-based learning. Teachers no longer merely act as transmitters of material but also as facilitators who actively and interactively manage students' learning experiences. However, several challenges remain, such as teachers' limited prior experience with technology and insufficient supporting infrastructure. Therefore, further training and ongoing mentoring are necessary to ensure the development of teacher competencies and the optimal implementation of learning technology. Overall, this program not only improves the quality of student learning but also enhances teachers' capacity and professionalism in addressing the challenges of learning in the digital age.

#### Implementation Challenges and Solutions

Several challenges were identified in implementing Augmented Reality (AR)-based learning programs that affected the field implementation (Iqbal et al., 2022; Lai & Cheong, 2022). The main challenges identified included limited device availability among some students, varying levels of technological literacy among both students and teachers, and unstable internet connections. These three factors may hinder the optimal use of AR media in the learning process. Limited device availability is a barrier because not all students have smartphones with sufficient specifications to run AR applications optimally. Furthermore, differences in technological capabilities create a gap in the speed at which individuals adapt to digital learning media. Furthermore, unstable internet connections affect smooth access to certain features within the application, particularly those that require real-time data synchronization.

To address these challenges, several adaptive and contextual solution strategies were implemented. First, direct mentoring was provided to students and teachers throughout the learning process. This mentoring aimed to help users understand how to use the application and address technical difficulties in real time. Second, the use of lightweight AR applications compatible with various devices helped accommodate the limited specifications of students' devices. Third,

the instructions for using learning media were simplified to make them easier to understand for users with varying levels of technological literacy.

Furthermore, learning strategies were also adapted to existing conditions, such as alternating media use (device sharing) and organizing learning activities that were not entirely dependent on an internet connection. This approach allowed the learning process to continue effectively despite infrastructure limitations. Implementation results showed that the adaptive approach used minimized emerging obstacles and increased the effectiveness of AR media use in learning. This was evident in the increase in student participation and the overall smoothness of the learning process. Thus, the success of the program was determined not only by the sophistication of the technology used but also by the ability to adapt the implementation strategy to real-world conditions. These findings emphasize that when implementing learning technology, aspects of user readiness and infrastructure support must be primary concerns to ensure the innovation has an optimal and sustainable impact.

#### Impact and Sustainability of the Program

The implementation of an Augmented Reality (AR)-based learning program has demonstrated a positive impact on improving the quality of the learning process at Hang Tuah Senior High School, Makassar. This impact is evident not only in improved learning outcomes and student engagement but also in a more interactive, innovative, and student-centered approach to learning. Teachers and students have demonstrated good adaptation to using technology as a learning medium, creating a more dynamic and conducive learning environment. Furthermore, the learning media developed in this program have long-term benefits. The AR applications used can be re-accessed and utilized by teachers in subsequent learning activities without requiring complex redevelopment. This makes the media a digital learning asset that can be used sustainably to support a range of teaching materials.

The sustainability of this program is supported by several key factors. First, the ease of use of the implemented technology allows teachers and students to operate the learning media independently, without relying heavily on experts. The simple and intuitive interface makes the technology adoption process faster and more efficient. Second, the flexibility of AR media implementation allows this technology to be used across various subjects, not limited to a single field of study. Thus, it has potential for wider use in supporting cross-disciplinary learning. Third, support from the school, both in policy and facilities, is crucial to maintaining the program's sustainability. The school's commitment to fostering innovation in technology-based learning demonstrates its readiness to embrace digital transformation in education. This support also opens opportunities for broader program development in the future.

In addition to internal factors, the program's sustainability can be strengthened through further development, such as enhancing AR media features, integrating with Learning Management Systems (LMS), and implementing ongoing teacher training (Alotaibi, 2024; Arjanto et al., 2025). These efforts are crucial to ensure that the technology remains relevant to evolving learning needs in the digital era. Overall, this program has significant potential for replication and development in other schools with similar characteristics. With an adaptive, needs-based approach, this Augmented Reality-based learning model can serve as an alternative to improving the quality of education, particularly by creating a more interactive, effective learning experience that aligns with the demands of current technological developments. This study has several limitations that warrant consideration. First, the sample size was relatively small, and the study was conducted in only one school, thus limiting the generalizability of the results. Second, the relatively short implementation period does not fully reflect the long-term impact of Augmented Reality media use. Therefore, further research is recommended to involve a larger sample size, more diverse contexts, and use a longitudinal approach to assess the impact of learning sustainably.

#### Conclusions

The implementation of an Augmented Reality (AR)-based learning model integrated with a deep learning approach at Hang Tuah Senior High School in Makassar has yielded positive, significant results. The program's implementation not only improves student learning outcomes but also strengthens engagement and motivation, providing a more interactive and meaningful learning experience. The visualization of three-dimensional objects through AR technology has been shown to help students understand previously abstract learning concepts more concretely and more easily. In addition to its impact on students, the program also contributes to improving teacher competency in integrating technology into the learning process. Teachers become more adept at designing digital learning, effectively utilizing interactive media, and managing technology-based classes with greater confidence. This shows that the program focuses not only on learning but also on strengthening human resource capacity within the school environment.

Despite this, several challenges remain, including limited device availability, varying levels of technological literacy, and limited internet connectivity. However, through an adaptive approach and contextual implementation strategies, these obstacles can be minimized, ensuring the program continues to run effectively. In terms of sustainability, this program has strong potential for continued development and broader implementation. Ease of use, flexibility in application across various subjects, and support from schools are key factors supporting its long-term success. Therefore, this AR-based learning model can be recommended as an innovative alternative to improve learning quality in the digital era. Going forward, further research and development are needed to integrate this technology with broader learning systems and optimize artificial intelligence-based features to create more adaptive, personalized, and sustainable learning.

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### Contribution

All authors contributed to the conceptualization, methodology, data collection, and manuscript writing. The second author contributed to data analysis and validation. All authors reviewed and approved the final version of the manuscript.

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