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The Influence of Augmented Reality (AR) Learning Media with Assemblr Studio on Students' Technological Literacy

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ABSTRACT

Technological literacy is one of the essential competencies of the 21st century; however, the level of technological literacy among students at MAN 2 Kota Tasikmalaya remains relatively low. This condition underscores the need for innovative learning approaches grounded in digital technology. This study aims to analyze the effect of Augmented Reality (AR) learning media using Assemblr Studio on students' technological literacy in biology subjects. The research employed a quasi-experimental, post-test-only, non-equivalent-group design. The sample consisted of two classes: class XI 4 as the experimental group (using AR media) and class XI 1 as the control group (using PowerPoint), selected through purposive sampling. Data were collected using a technological literacy questionnaire with a Likert scale comprising 20 statements across four indicators: content, process, context, and attitude. The results of the Independent Samples T-Test showed a significant value of 0.000 (<0.05), indicating a significant effect. Additionally, the effect size (Cohen's d) was 1.14, which falls into the high category. Therefore, AR-based learning media developed with Assemblr Studio proved effective in enhancing technological literacy through interactive, visual, and engaging learning experiences.

Keywords: Learning Media, Augmented Reality (AR), Assemblr Studio, Technology Literacy

Introduction

The Industrial Revolution 4.0 has had a significant impact on various sectors, including education. The development of information and communication technologies has driven a transformation in teaching and learning methods, enabling the integration of digital tools to create more flexible, efficient, and adaptive learning experiences (Hakim & Yulia, 2024). The use of technology in education, such as computers, the internet, and interactive learning applications, has opened new opportunities to enhance both the quality and efficiency of the learning process. Technology enables easier, faster access to various learning resources and provides flexibility in how materials are delivered (Nuraeni et al., 2022). Amid these changes, technological literacy has emerged as one of the key 21st-century competencies students must possess to address global challenges (Padang et al., 2022). Technological literacy not only involves the ability to use digital devices but also requires critical understanding in accessing, evaluating, and creating technology-based information for educational purposes (Pötzsch, 2019).

However, the integration of technology into learning in Indonesia still faces numerous challenges, particularly in schools located in 3T (Frontier, Outermost, and Disadvantaged) regions. A report by the Ministry of Education and Culture (Kemendikbud) in 2021 showed that more than 50% of schools experience technological infrastructure issues, including limited access to computers and internet connectivity, as well as limited teacher training. Additionally, the PISA (2024) study indicated that most Indonesian students lag behind students in other countries in technological literacy. These issues include limited access to computers, inadequate internet connectivity, and a lack of educator training to integrate technology into teaching (Rachmawati et al., 2017). Research by Hermila et al. (2023) showed that students tend to use technology more for social media and entertainment than for learning purposes. The low level of technological literacy among students is mainly due to the lack of integration of technology into the learning process.

A preliminary study on students' technological literacy at MAN 2 Kota Tasikmalaya, conducted using a questionnaire that assessed indicators of content, process, context, and attitude, yielded an average score of 2.38. According to the criteria set by Suryana et al. (2023), a score of 1.75-2.40 falls within the low category. This indicates that students' technological literacy at MAN 2 Kota Tasikmalaya remains low. Many students face challenges due to unequal access to technology and inadequate school infrastructure. These disparities limit their ability to engage with digital learning tools, which are critical to developing technological literacy (Wang, 2024). This is particularly evident in biology subjects, where complex topics require deep visual understanding. The lack of engaging, technology-based learning media can lead students to feel bored, subsequently decreasing their learning motivation.

Based on observations conducted by the researcher and the biology teacher, it was found that the learning process commonly uses media such as PowerPoint (PPT), educational videos, and similar tools. Although these media can initially capture students' interest in the material, a lack of variation may lead to boredom. Moreover, MAN 2 Kota Tasikmalaya faces limitations in facilities, such as the absence of projectors in every classroom and other supporting facilities, such as laboratories. These limitations pose challenges for teachers, especially when delivering topics that require visual comprehension and need media capable of clearly visualizing abstract concepts (Firman & Arnyana, 2023). Without adequate support facilities, the use of technology in learning becomes constrained. Consequently, students' learning motivation decreases, which indirectly affects their technological literacy (Pawitra et al., 2024). This condition highlights the need for innovative learning media that are not only engaging but also relevant for improving student involvement and technological skills in the learning process. Theoretically, this urgency can be analyzed through the SAMR model framework (Substitution, Augmentation, Modification, Redefinition). Current media usage, such as standard PPT, typically remains at the Substitution or Augmentation level, acting merely as a direct tool substitute with little functional improvement. To effectively enhance technological literacy, the learning process must shift towards Modification and Redefinition, where technology allows for the creation of significant new tasks that were previously inconceivable. Technology-based learning experiences equip students to navigate and leverage technology effectively (Castañeda & Villar-Onrubia, 2023; Trust, 2017).

In line with the need for such transformative technology, Augmented Reality (AR) has emerged as an innovative and relevant alternative. According to (Mahartika et al., 2023), Augmented Reality (AR) is a technology that integrates computer-generated data—such as graphics, images, sound, or video—into the real world in real time. AR blends digital elements with the physical world, creating immersive, interactive, and contextual learning experiences (Rofi'i et al., 2023). AR allows students to interact with virtual objects in real-world contexts, which can redefine how scientific concepts are taught and understood. The immersive nature of AR can significantly enhance student engagement and motivation (Brandt et al., 2015). In biology education, AR is considered effective for visualizing abstract concepts, such as the reproductive system, in more concrete terms, thereby overcoming the limitations of conventional media (Firman & Arnyana, 2023). One AR platform suitable for school environments is *Assemblr Studio*, which allows teachers and students to create and access AR-based learning content without technical expertise, using smartphones or computers (Nengsih et al., 2023). With its interactive and collaborative features, *Assemblr Studio* supports more creative and meaningful learning. This aligns with recent findings by Triyanto et al. (2025), who emphasize that AR media utilizes metaverse technology to convert 2D objects into 3D visualizations. This capability is crucial for educational transformation in the Industrial Revolution 4.0, as it helps students deeply understand microscopic and abstract concepts—such as cell structures—that are difficult to grasp through conventional 2D media.

Previous studies have shown that the use of Augmented Reality (AR) in education has been widely researched, particularly for improving students' motivation and understanding of learning materials (Wahyuni et al., 2024) and increasing students' interest in learning (Masri et al., 2023). Unlike previous studies, this research specifically examines the impact of AR-based media on students' technological literacy. Research on Augmented Reality (AR) is unique in that it explores its potential to overcome limitations in educational facilities, such as the lack of laboratories and other tools. AR allows students to interact with virtual objects in real-world contexts, which can redefine how scientific concepts are taught and understood. This immersive nature enables students to engage with content more interactively, making abstract concepts more tangible and easier to grasp, while significantly enhancing student engagement and motivation. Ultimately, such technology-based learning experiences equip students to navigate and leverage technology effectively (Garg et al., 2023; Khang et al., 2023).

Based on this background, this study aims to analyze the effect of Augmented Reality (AR)-based learning media developed with *Assemblr Studio* on students' technological literacy in the biology subject at Grade XI of MAN 2 Kota Tasikmalaya. Therefore, this research is important to implement to offer a learning approach that is aligned with 21st-century demands and the needs of technology-integrated education.

Methods

This study employed a quantitative research method. According to Creswell & Creswell (2018), quantitative research is a method used to test theories by examining the relationships among variables and analyzing data collected through statistical procedures. The research was conducted at MAN 2 Kota Tasikmalaya in February, involving all 11th-grade students as the study population. At MAN 2 Kota Tasikmalaya, there are four 11th-grade classes with a total of 127 students. The population size, along with the average scores of students' daily tests, is presented in Table 1 below.

Table 1. Population data of 11th grade students in the academic year 2024/2025

No.	**Class**	Number of Students	Average Score
1	XI 1	29	70,00
2	XI 2	31	68.87
3	XI 3	32	69,69
4	XI 4	35	75,29
Amount		127	285,46
Average			71,36

Data Source: Biology Teacher at MAN 2 Kota Tasikmalaya

The sampling technique used in this study is purposive sampling, which is a non-random sampling method based on specific considerations or predetermined criteria (Sugiyono, 2019). These considerations are based on the characteristics of the population deemed capable of providing more representative and relevant data for the study. In this case, two classes were selected based on their relatively similar levels of learning activity, making them suitable for use as research subjects. Based on these considerations, Class XI-4 and Class XI-1 were selected as research samples. To maintain objectivity in assigning the experimental and control groups, the researcher used a random selection method through the Wheel of Names website. The random draw assigned Class XI-4 as the experimental group, which received treatment through learning with Augmented Reality-based media using *Assemblr Studio*. Meanwhile, Class XI-1 was assigned as the control group, receiving conventional instruction via PowerPoint without Augmented Reality.

The research employed a post-test-only, a non-equivalent groups design. According to (Creswell & Creswell, 2018), this design involves two non-randomized groups: one group receives the treatment, and the other does not. The design of this study is presented in Table 2 below.

Table 2. Research Design

Class	Treatment	Post-test
Experiment	X	O_1
Control	C	O_2

(Creswell & Creswell, 2018)

Explanation:

- Experiment = The experimental group uses Augmented Reality learning media
- Control = The control group does not use Augmented Reality learning media
- X = Treatment
- C = Control
- O_1 = Post-test administered to the experimental group
- O_2 = Post-test administered to the control group

This research consists of three main stages: planning, implementation, and reporting. In the planning stage, the researcher prepared the research instrument. The instrument used in this study was a non-test method in the form of a questionnaire designed to measure technological literacy. A questionnaire was chosen because technological literacy is non-cognitive, encompassing aspects such as attitude, process, and context, which are difficult to measure with cognitive tests. The questionnaire consisted of 40 statements developed from the technological literacy indicators proposed by Clay and Brian, covering content, process, context, and attitude. The details of these indicators are presented in Table 3 below.

Table 3. Blueprint of Technological Literacy Instrument

Technological Literacy Indicator	Item Number	Number of Valid Items	**Number of Invalid Items**
Content	1*,2,3,4,5,6*,7*,8*,9*,10*	4	6
Process	11,12,13,14,15,16*,171,18,19,20	9	1
Context	21*,22,23*,24*,25,26*,27,28*,29*,30*	4	6
Attitude	31,32*,33,34,35*,36,37*,38*,39*,40*	3	7
	Total	20	20

Note: (*) Not Valid

Before data collection, the instrument was tested to assess its validity and reliability. Validity testing was conducted to measure the extent to which the questionnaire items accurately assess aspects of technological literacy. The validity test was conducted using SPSS version 23 for Windows, employing the Pearson Product-Moment correlation technique. Next, reliability testing was performed using Cronbach's Alpha, also in SPSS version 23. Based on the data analysis results, the reliability coefficient (r) obtained was 0.824, which falls within the range of $0.71 \leq r < 0.90$, indicating that the instrument has a high level of reliability. According to the analysis results presented in Table 3, of the 40 questionnaire items, 20 met the validity criteria, while the other 20 were deemed invalid and thus eliminated. Consequently, only 20 valid items were used as the final instrument in this study.

Subsequently, data processing was carried out using SPSS version 23 for Windows through several stages of analysis. First, a normality test using the Kolmogorov–Smirnov test was performed to determine whether the data were normally distributed. Second, a homogeneity test was conducted using *Levene*'s Test to ensure that the variances between groups were homogeneous. After that, a hypothesis test was conducted using the Independent Samples T-Test to determine whether there were significant differences between the experimental and control classes. Finally, to determine the magnitude of the effect of Augmented Reality (AR) learning media on students' technological literacy, Cohen's d was calculated using the formula.

Results and Discussion

The research was conducted at MAN 2 Kota Tasikmalaya, specifically in Grade XI during the 2024/2025 academic year. The sample included Class XI-4 as the experimental group and Class XI-1 as the control group. The instrument used in this study was a technological literacy questionnaire consisting of 20 statements. The instrument was developed based on the technological literacy indicators from Clay and Brian 2001 (Suhendi, 2017). The experimental group (Class XI-4) consisted of 35 students, while the control group (Class XI-1) consisted of 29 students. The experimental group received treatment in the form of Augmented Reality (AR) learning media created with *Assemblr Studio*, while the control group was taught using PowerPoint. A posttest was administered to both the experimental and control groups to assess students' technological literacy after receiving different treatments. The purpose of the posttest was to assess students' abilities following the interventions. The data were collected using a non-test instrument in the form of a Likert scale questionnaire with 20 items, developed based on technological literacy indicators. The technological literacy data were then analyzed using descriptive and inferential statistical techniques. The results of the descriptive analysis of technological literacy in the posttest for both the experimental class (XI-4) and the control class (XI-1) are presented in Table 4 below.

Table 4. Post-test scores of technological literacy in experimental and control classes

Statistics	Posttest Experimental Class	Posttest Control Class
Number of Samples	35	29
Maximum Value	77	80
Minimum Value	35	23
Mean Value	59	46.5
Standard Deviation	10.25	11.84

Source: Personal data processing results

Based on posttest data analysis, the experimental class consisted of 35 students, while the control class had 29. In the experimental class, the maximum score was 77, the minimum was 35, and the mean posttest score was 59. In the control class, the maximum score was 80, the minimum score was 23, and the mean posttest score was 46.5. The standard deviation in the experimental class was 10.25, while in the control class it was 11.48. From these data, it can be observed that although the maximum score in the control class was higher than in the experimental class, the experimental class's standard deviation (10.25) was lower than that of the control class (11.48). This indicates that the data in the experimental class were more homogeneous, with a more stable score distribution, compared to the control class, which showed greater variability in students' understanding. Moreover, the average score in the experimental class was higher than that of the control class, indicating that, in general, technological literacy in the experimental group was better than in the control group. A comparison of the average technological literacy scores is illustrated in Figure 1 below.

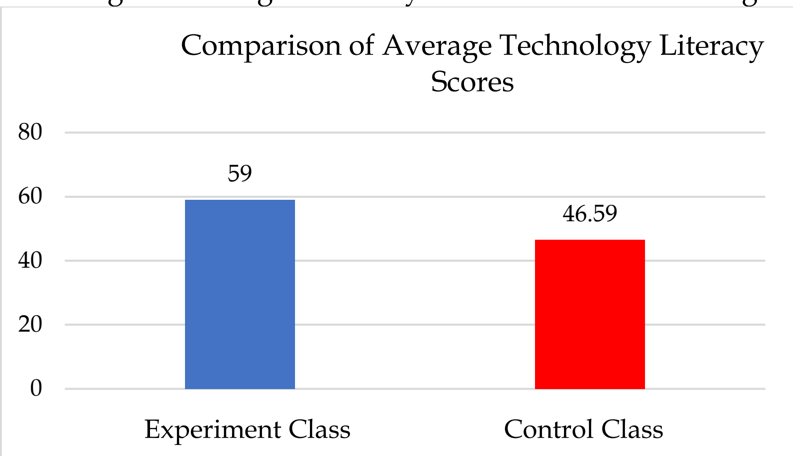

Figure 1. Comparison of average technological literacy scores (Personal Data Processing Results)

Based on Figure 1, which shows the frequency distribution of average technological literacy scores, the experimental group has a higher average score (59) than the control group (46.59). The difference in average scores between the two classes is 12.41 points, indicating that the use of Augmented Reality learning media via *Assemblr Studio* effectively enhanced students' technological literacy. Furthermore, the average technological literacy scores by indicator are presented in Figure 2 below.

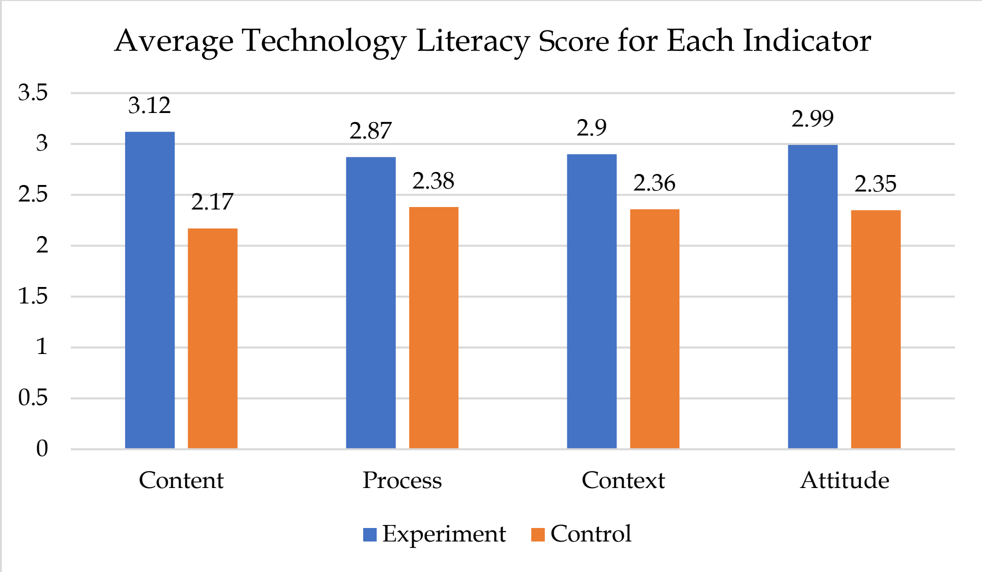

Figure 2. Average technological literacy scores per indicator
(Personal Data Processing Results)

Figure 2 illustrates the average technological literacy scores for each indicator. The highest score in the experimental class was in the content indicator, with a value of 3.12, while in the control class, the highest score was in the process indicator, with a value of 2.38. Meanwhile, the lowest score in the experimental class was in the process indicator, at 2.87, whereas the lowest score in the control class was in the content indicator, at 2.17. Based on these results, it can be concluded that the use of Augmented Reality (AR) learning media using *Assemblr Studio* has a positive impact on improving students' technological literacy across all indicators: content, process, context, and attitude. The learning process became more interactive, engaging, and meaningful, thereby enhancing students' understanding, critical thinking, and positive attitudes toward technology.

Thus, Augmented Reality learning media created with *Assemblr Studio* can serve as an effective alternative to improve the quality of biology learning, particularly in reproductive system material. The inferential statistical analysis in this study included several tests: normality testing, homogeneity testing, and hypothesis testing. These tests were conducted using *IBM SPSS* version 23 for *Windows*. The results of these tests are presented in Table 5 below.

Table 5. Inferential statistical analysis results

Statistical Analysis	Testing Techniques	Significance
Normality Test	*Kolmogorov-Smirnov*	Experiment Posttest = 0.478 Posttest Control = 0.418
Homogeneity Test	*Levene's Test*	0.568
Hypothesis Test	*Independent Samples T Test*	0.000

(Personal Data Processing Results)

The statistical analysis in this study involved several key tests, namely: normality tests, homogeneity tests, and hypothesis tests. First, the normality test was conducted to determine whether the posttest data from the experimental and control classes were normally distributed. The Kolmogorov-Smirnov method was used for this test. The results showed significant differences between the experimental and control classes, with values of 0.478 and 0.418, respectively. Since both p-values are greater than 0.05, the data are normally distributed. Second, a homogeneity test was carried out to ensure that the variances between the two groups were equal. This test used Levene's Test for Equality of Variances. The result showed a significant value of 0.568. Since the p-value is greater than 0.05, the variances of both groups are homogeneous.

Third, a hypothesis test was conducted to determine whether there was a significant difference in the posttest mean scores between the experimental and control groups. The test was conducted using the Independent Samples T-Test. The result showed a significant value of 0.000. Because the significance value is less than 0.05, H_0 is rejected, indicating a significant effect of Augmented Reality (AR) learning media using *Assemblr Studio* on students' technological literacy in the biology subject.

The implementation of Augmented Reality (AR) learning media with *Assemblr Studio* during the learning process has been shown to improve students' technological literacy significantly. This effect was observed after administering the posttest, which consisted of 20 statements designed to evaluate students' understanding. The data analyzed included a comparison between the control and experimental classes.

Based on the t-test analysis using IBM SPSS version 23 for Windows, the significance value was < 0.05 (0.000 < 0.05), indicating that H_0 is rejected. Therefore, it can be concluded that the use of Augmented Reality (AR) learning media with *Assemblr Studio* had a significant effect on students' technological literacy. This finding is consistent with the research by (Wahyuni et al., 2024), which stated that interactive AR visualization enhances students' understanding of abstract concepts.

In this study, the researcher also measured the effect size. Effect size is a statistical measure of the magnitude of the treatment effect or the difference observed in the study. The calculation of the size effect is presented below.

$$ES = \frac{Me - Mc}{SD}$$

$$= \frac{59-46.5}{10.99} = \frac{12.5}{10.99} \approx 1.14$$

The criteria for determining the magnitude of the effect size in this study follow the guidelines proposed by Cohen, Manion, & Morrison, which are presented in Table 6 below.

Table 6. Effect size criteria

Effect Size Value	Description
0.00 – 0,20	Very Low Effect
0,21 – 0,50	Low Effect
0,51 – 1,00	Moderate Effect
>1,00	High Effect

(Cohen et al., 2018)

Based on the calculation results, the effect size (Cohen's d) was found to be 1.14. Referring to Cohen's interpretation presented in Table 4, this value falls into the high effect category. This indicates that the use of Augmented Reality (AR) learning media through *Assemblr Studio* has a strong impact on improving students' technological literacy. This substantial effect reinforces the finding that AR-based media can provide a more immersive, visual, and interactive learning experience, thereby facilitating active student engagement in Biology learning. Specifically, AR media plays a crucial role in helping students understand material on the reproductive system, which is conceptually complex and abstract. The 3D visualization, animation, and digital interaction provided by *Assemblr Studio* enable students to explore the material more concretely, thus strengthening conceptual mastery and supporting technological skills. Thus, the deployment of AR in education transcends improving learning outcomes; it plays a pivotal role in advancing technological literacy, a vital 21st-century competency effectively developed through the immersive and collaborative experiences AR provides (Papanastasiou et al., 2019; Wu et al., 2021). This aligns with the perspective of Triyanto et al. (2025), who argue that transforming 2D objects into 3D visualizations using metaverse-based technology is essential in the Industrial Revolution 4.0 era.

In the context of the reproductive system, AR bridges the gap between abstract biological descriptions and concrete spatial understanding, significantly reducing the cognitive load required for students to visualize complex structures. The use of augmented reality significantly improved learning outcomes, motivation, and student interest, with substantial increases in posttest scores and in critical thinking skills from 60% to 86% in a classroom action research study. Augmented reality significantly improved learning outcomes, motivation, and student interest, with substantial increases in posttest scores and in critical thinking skills from 60% to 86% in a classroom action research study (Permata et al., 2025).

The analysis confirms that instructional media use has a significant effect on students' technological literacy. This is due to the media's ability to present content in a more engaging, interactive, and understandable way, thus enhancing students' interest and attention. When students are engaged, they become more actively involved in the learning process—both cognitively and emotionally. This active involvement encourages students to explore the technology being used, understand how it works, and apply it in their learning activities. Analyzed through the SAMR model, this significant impact suggests that the learning process in the experimental class shifted from the 'Substitution' level (passive consumption of PPT) to the 'Redefinition' level. At this stage, technology enables the creation of new tasks, such as manipulating 3D virtual organs in real time, that were previously inconceivable (Tsybulsky & Levin, 2017). This shift demands higher-order technological interaction from students, thereby directly training their technological literacy skills beyond mere basic operation (Setiyawati et al., 2023).

Using AR learning media with *Assemblr Studio* offers clear advantages in the learning process. This media provides a more lively and meaningful learning experience. Through 3D visualization, students are better able to grasp abstract concepts. Moreover, implementing AR media indirectly increases students' confidence and their ability to respond to questions, participate in discussions, and express ideas in class.

Using Augmented Reality (AR) learning media with *Assemblr Studio* not only enhances understanding of the content but also fosters active participation and critical thinking skills. This is in line with Yudhanto et al. (2023), who found that AR-based learning media provides a fun and interactive learning experience and is well accepted and effectively implemented by users. Specifically, using *Assemblr Studio* requires students to navigate user interfaces, scan markers, and troubleshoot connectivity issues in real time (Guo & Chen, 2014). These activities effectively cultivate core dimensions of technological literacy, ranging from operational proficiency with digital tools to real-time technical problem-solving. This level of interaction enriches the educational experience, offering a degree of engagement and intuitiveness that surpasses conventional instructional methods (Osbaldiston, 2023).

AR media created with *Assemblr Studio* can serve as an interactive alternative for learning, increasing student motivation, and enhancing technological literacy. AR learning media can improve student interest and understanding by fostering a more interactive and engaging learning process, helping students better understand complex concepts (Hermawan & Hadi, 2024). Augmented Reality (AR) media significantly enhances student motivation by making learning more engaging and interactive (Vashisht, 2024). Studies have shown that students exposed to AR-based learning demonstrate higher motivation than those taught using conventional methods (Annail et al., 2025).

However, the use of AR media also has some limitations. One of the main challenges is its dependence on technological devices, such as smartphones or tablets compatible with AR applications (Albishri & Blackmore, 2024). This can pose difficulties for students or schools lacking adequate devices. In addition, teachers' ability to develop and integrate AR media effectively into lessons is also a challenge. Teachers need sufficient understanding to operate this technology optimally (Garg et al., 2025). Furthermore, technical issues or internet connectivity problems may disrupt the smooth delivery and effectiveness of AR-based instruction (Albishri & Blackmore, 2024).

Despite these challenges, the advantages of AR media are significant. It allows students to learn visually and contextually, providing a deeper and more meaningful learning experience. AR enables students to visualize complex, abstract concepts that are often difficult to grasp through traditional methods (Miner et al., 2025). AR also supports self-directed and collaborative learning, encouraging students to explore the subject matter actively (Wen et al., 2023). In addition, AR media promotes the development of 21st-century competencies, such as digital literacy, creativity, and technology-based problem-solving skills (Tohir et al., 2024). Although there are drawbacks to using AR media, the difference in results between the experimental and control classes can be attributed to its strengths in creating a more interactive, engaging, and effective learning environment. This, in turn, significantly improves students' technological literacy, as reflected in better conceptual understanding and technological skills compared to conventional instruction.

Conclusion

Based on the research results, it can be concluded that the use of Augmented Reality (AR) learning media in *Assemblr Studio* has a significant effect on students' technological literacy in Biology subjects at MAN 2 Kota Tasikmalaya. This is evidenced by the average technological literacy score in the experimental class reaching 59, higher than the control class' 46.5. The statistical tests further support this conclusion. The Kolmogorov–Smirnov normality test showed that the data were normally distributed, with p-values of 0.478 and 0.418 for the experimental and control classes, respectively. Additionally, the homogeneity test using *Levene*'s Test indicated that the data variances were homogeneous (p-value = 0.568). The hypothesis test using the Independent Samples T-Test produced a significant value of 0.000 (< 0.05), indicating that the difference was statistically significant. Thus, it can be concluded that the use of Augmented Reality (AR) learning media via *Assemblr Studio* is effective in improving students' technological literacy. This interactive, visual-based technology provides a more realistic, engaging, and meaningful learning experience, enhancing students' understanding and motivation to learn.

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