



The Implementation of the Assemblr Edu AR: Biodigest Application on Student Learning Outcomes in Digestive System Material at SMA Batik 2 Surakarta

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Abstract: This study aimed to examine the effect of implementing the Assemblr Edu AR: BioDigest application on students' cognitive learning outcomes and to evaluate student engagement in the affective and psychomotor domains during instruction on the digestive system in Grade XI at SMA Batik 2 Surakarta. This study employed a quasi-experimental method using a nonequivalent control group design. The research sample consisted of two classes: XI EIPA 1 as the control class, which used PowerPoint media, and XI EIPA 2 as the experimental class, which used the Assemblr Edu AR: BioDigest application. Data were collected through learning achievement tests and validated observation sheets, and were analyzed using an independent samples *t*-test and N-gain analysis. The results showed a significant difference between the experimental and control classes in cognitive learning outcomes ($p < 0.05$). The effectiveness of the instructional media in the experimental class was indicated by an N-gain score of 0.5944, which falls within the moderate category. In the affective and psychomotor domains, the experimental class also demonstrated higher levels of engagement than the control class. These findings indicate that three-dimensional visualization and interactive features in augmented reality can enhance conceptual understanding, learning motivation, and student skills by providing a more meaningful learning experience. Theoretically, this study contributes to strengthening research on augmented reality-based learning. Practically, it offers an innovative alternative instructional medium for biology education, particularly for abstract and complex topics.

Keywords: Assemblr Edu AR; BioDigest; learning outcomes; digestive system; augmented reality

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INTRODUCTION

Education is a fundamental process for developing students' knowledge, attitudes, and skills through structured and meaningful learning experiences. In schools, the effectiveness of learning depends not only on clearly defined objectives but also on the suitability of instructional strategies and media to the characteristics of the subject matter and students' needs (Putri, 2025; Faizah & Kamal, 2024). This issue is particularly important in biology learning, as many biological concepts involve abstract structures, complex processes, and phenomena that cannot be directly observed in classroom settings.

The human digestive system is one biology topic that often presents conceptual difficulties for students. Understanding this topic requires students to connect organ structures, organ functions, and sequential mechanical and chemical processes occurring inside the human body. Because these processes are internal, dynamic, and difficult to observe directly, students may struggle to construct accurate mental representations and may develop misconceptions (Agustina, 2024). Therefore, biology learning requires instructional media that can visualize abstract concepts concretely and support students in actively constructing knowledge.

Learning outcomes represent an important indicator of instructional effectiveness because they reflect changes in students' cognitive, affective, and psychomotor domains. Cognitive outcomes are associated with conceptual understanding, problem-solving, and higher-order thinking skills, whereas affective outcomes include students' interest, attitudes, motivation, and engagement in learning. Psychomotor outcomes are reflected in students' ability to use tools, perform learning procedures, and apply knowledge through practical activities. Thus, evaluation in biology learning should not be limited to test scores, but should also consider students' attitudes and skills as integral components of meaningful learning (Bloom, 1956; Krathwohl et al., 1964; Harrow, 1972; Anderson & Krathwohl, 2001; Pitaloka, 2022; Wulandari, 2024; Suwartia et al., 2023).

Preliminary observations at SMA Batik 2 Surakarta indicate that biology learning has not fully achieved these expected outcomes. Student engagement remains relatively low, as shown by passive classroom behavior and limited participation during learning activities. In addition, approximately $\pm 60\%$ of students have not achieved the minimum mastery criteria in the digestive system topic and still experience difficulty explaining the concepts in their own words. These findings suggest that students' low achievement is not only reflected in their scores but also in their limited ability to reconstruct and communicate biological concepts. This condition highlights the need for more interactive and visual learning media that can help students understand abstract biological processes and participate more actively in learning.

Augmented Reality (AR) is one promising technology for addressing these challenges. AR integrates virtual objects into the real environment in real time, enabling users to interact with digital elements within physical contexts (Azuma, 1997). In education, AR can present abstract and microscopic concepts through three-dimensional objects, animations, annotations, audio, and interactive visual features. Previous studies have shown that AR can enhance students' visualization, motivation, engagement, and learning achievement, particularly in science and STEM education (Akçayır & Akçayır, 2017; Ibáñez & Delgado-Kloos, 2018; Garzón et al., 2019).

The use of AR is also supported by Multimedia Learning Theory and Cognitive Load Theory. Multimedia Learning Theory explains that students learn more effectively when information is presented through coordinated verbal and visual channels, allowing them to select, organize, and integrate information into meaningful mental models (Mayer, 2021). Cognitive Load Theory further emphasizes that effective instructional design should reduce unnecessary cognitive burden and facilitate the processing of complex information (Sweller et al., 1998). In the digestive system topic, AR can support learning by enabling students to observe three-dimensional organ structures and biological processes from multiple perspectives, thereby improving conceptual understanding and reducing difficulties caused by abstract content.

In addition to supporting cognitive learning, AR may also strengthen affective and psychomotor outcomes. Interactive and immersive learning environments can increase students' curiosity, attention, motivation, and engagement because students are encouraged to explore learning materials actively. AR-based activities may also develop psychomotor skills by requiring students to operate digital media, manipulate virtual objects, follow learning procedures, and engage in observation-based tasks. Therefore, AR has the potential to provide learning experiences that are visual, participatory, and skill-oriented.

One AR-based platform that can be used in biology learning is Assemblr Edu. This platform allows teachers to present biological objects in three-dimensional form, supported by annotations, videos, texts, and interactive visual elements. In this study,

Assemblr Edu was used to develop BioDigest, an AR-based learning medium designed for the human digestive system topic. Through BioDigest, students are expected to observe digestive organs and processes more concretely, understand relationships between structures and functions, and participate more actively in learning. The use of this medium is also expected to promote student-centered learning and support students in constructing knowledge independently and collaboratively (Sugiarto, 2022).

Although previous studies have reported the positive effects of AR on learning, most have focused primarily on cognitive outcomes, such as conceptual understanding and test-score improvement. Research that examines the effects of AR on affective and psychomotor outcomes remains relatively limited. Moreover, the effectiveness of AR may vary according to the learning topic, instructional design, technological features, and student characteristics. Therefore, further research is needed to examine the simultaneous effects of AR-based learning media on cognitive, affective, and psychomotor domains, particularly in the digestive system topic at the senior high school level.

Based on this gap, this study aims to examine the effect of implementing Assemblr Edu: BioDigest, an Augmented Reality-based learning medium, on Grade XI students' learning outcomes in the digestive system topic at SMA Batik 2 Surakarta. Specifically, this study investigates its effects on three domains of learning outcomes: cognitive achievement, affective engagement, and psychomotor skills. The research questions are as follows: (1) Does the use of Assemblr Edu: BioDigest significantly affect students' cognitive learning outcomes? (2) How does Assemblr Edu: BioDigest influence students' affective engagement during learning? and (3) How does Assemblr Edu: BioDigest support students' psychomotor skills during the learning process?

The novelty of this study lies in the integration of AR-based learning media with the simultaneous assessment of cognitive, affective, and psychomotor outcomes. While previous studies have largely emphasized cognitive achievement, this study provides a more comprehensive evaluation of AR effectiveness in biology learning. In addition, the study focuses specifically on the digestive system, a topic characterized by abstract, complex, and process-oriented content that is prone to misconceptions. The development and implementation of BioDigest based on Assemblr Edu also offer practical and methodological contributions by providing a replicable model of AR-based learning media for biology instruction.

Therefore, this study is expected to contribute theoretically, methodologically, and practically. Theoretically, it enriches the literature on the use of Augmented Reality in biology education. Methodologically, it offers a comprehensive approach to evaluating learning outcomes across three domains. Practically, the findings may serve as a reference for biology teachers in selecting and implementing innovative digital media to improve students' conceptual understanding, engagement, motivation, and skills.

METHOD

Research Design

This study employed a quantitative approach using a quasi-experimental method with a nonequivalent control group design. The design involved two intact classes that were not randomly assigned: an experimental class that received instruction using the Assemblr Edu AR: BioDigest application and a control class that received PowerPoint-based instruction. Both groups were administered a pretest before the intervention and a posttest after the intervention to measure changes in students' learning outcomes.

This design was selected to compare the improvement in learning outcomes between the experimental and control classes. Thus, the effect of Augmented Reality-based learning media on students' achievement in the digestive system topic could be examined more objectively.

Population and Sample

The population of this study comprised all Grade XI students at SMA Batik 2 Surakarta. The sample consisted of two classes selected through purposive sampling based on predetermined research criteria. Class XI EIPA 1 was assigned as the control class, while Class XI EIPA 2 was assigned as the experimental class. Each class consisted of 40 students, resulting in a total sample of 80 participants.

Research Variables

This study investigated the implementation of the Assemblr Edu AR: BioDigest application and its effect on students' learning outcomes in the digestive system topic. The independent variable was the use of the Augmented Reality-based Assemblr Edu AR: BioDigest learning media. The dependent variable was students' learning outcomes, which covered cognitive, affective, and psychomotor domains. To minimize potential bias and ensure comparability between groups, the learning material, instructional time allocation, learning objectives, and grade level were controlled and kept consistent across the experimental and control classes.

Research Instruments

Data were collected using tests, observation sheets, documentation, and interviews. The tests were used to measure students' cognitive learning outcomes through pretest and posttest activities. The test items consisted of multiple-choice questions, short-answer questions, and extended-response questions developed based on competency achievement indicators for the human digestive system topic.

Observation sheets were used to assess students' affective and psychomotor engagement during the learning process. The affective domain included indicators such as participation, responsibility, cooperation, and enthusiasm, whereas the psychomotor domain focused on students' skills in using the learning media and participating in learning activities. Documentation and interviews were used as supporting data to provide additional information regarding the implementation of the learning process.

Before being used in the study, the instruments were reviewed for content validity through expert judgment. Instrument reliability was examined using Cronbach's Alpha coefficient, with a reliability criterion of $\alpha > 0.70$.

Research Procedure

The research procedure consisted of three main stages: preparation, implementation, and data analysis. In the preparation stage, the researcher identified problems in biology learning, particularly in the digestive system topic, developed learning materials, prepared the Assemblr Edu AR: BioDigest media, and validated the research instruments.

In the implementation stage, both the experimental and control classes were first given a pretest to identify students' initial abilities. The intervention was then conducted over several meetings according to the instructional time allocated for the digestive system topic. The experimental class learned using the Assemblr Edu AR: BioDigest application, while the control class learned using PowerPoint-based media.

During the intervention in the experimental class, students explored three-dimensional models of digestive organs, used annotation features, viewed supporting

videos, read interactive texts, and participated in discussions and question-and-answer activities related to organ structures, functions, and digestive processes. In both classes, the researcher observed students' affective and psychomotor engagement during the learning process. After the intervention was completed, both classes were administered a posttest to measure their final learning outcomes. In the final stage, pretest scores, posttest scores, and observation data were analyzed to determine the effect of the learning media on students' cognitive, affective, and psychomotor outcomes.

Data Analysis Technique

The data were analyzed quantitatively to determine the effect of Assemblr Edu AR: BioDigest on students' learning outcomes. The analysis began with prerequisite tests, including a normality test and a homogeneity test. The normality of the data was examined using the Kolmogorov–Smirnov or Shapiro–Wilk test, while the homogeneity of variance was examined using Levene's test.

The decision criterion for the normality test was based on the significance value. If $p > 0.05$, the data were considered normally distributed; if $p \leq 0.05$, the data were considered not normally distributed. For the homogeneity test, if $p > 0.05$, the variances of the two groups were considered homogeneous; if $p \leq 0.05$, the variances were considered heterogeneous.

After the prerequisite tests were completed, an Independent Sample t-test was used to examine whether there was a significant difference in learning outcomes between the experimental and control classes. If $p < 0.05$, the difference was considered statistically significant, indicating that the research hypothesis was accepted. Conversely, if $p \geq 0.05$, the difference was considered not statistically significant, indicating that the research hypothesis was rejected. All statistical analyses were conducted at a significance level of $\alpha = 0.05$.

In addition, N-gain analysis was conducted to determine the effectiveness of the learning media in improving students' cognitive learning outcomes. The N-gain score was calculated by comparing students' pretest and posttest scores and was interpreted using the criteria presented in Table 1.

Table 1. Criteria for learning outcome improvement

N-Gain Score	Criteria
$g < 0.3$	Low
$0.3 \leq g \leq 0.7$	Moderate
$g > 0.7$	High

(Source: Hasibuan, 2023)

Data from the affective and psychomotor domains were analyzed descriptively. Observation scores were converted into percentages and interpreted using the assessment categories presented in Table 2.

Table 2. Categories of affective and psychomotor abilities

Category	Percentage
Excellent	90–100
Good	76–89
Fair	60–75
Poor	0–59

(Source: Delar, 2022)

RESULTS AND DISCUSSION

Student Learning Outcomes

Students' cognitive learning outcomes after using Assemblr Edu AR: BioDigest were obtained by analyzing objective test scores, namely the initial test (pretest) and final test (posttest).

Table 3. Mean pretest and posttest scores

Class	Mean Pretest	Mean Posttest
Control	64.40	83.10
Experimental	73.43	89.30

As shown in Table 3, the mean pretest and posttest scores of the experimental class were higher than those of the control class. After obtaining the pretest and posttest results, further statistical analyses were conducted, including normality testing, homogeneity testing, an independent sample t-test, and N-gain analysis.

Normality Test

The normality test was conducted to determine whether the student learning outcome data were normally distributed. The analysis was performed using the Shapiro–Wilk test, and the results are presented in Table 4.

Table 4. Results of the normality test

Class	Sig. Control	Sig. Experimental	Description
Control	.082	.060	Normal
Experimental	.142	.089	Normal

Table 4 shows that the pretest and posttest data from both the control and experimental classes were normally distributed. Therefore, the data met the assumption required for further parametric statistical analysis using the Independent Sample t-test.

Homogeneity Test

The homogeneity test was conducted to determine whether the control and experimental classes had homogeneous variances. The results of the homogeneity test are presented in Table 5.

Table 5. Results of the homogeneity test

Data	Sig.	Description
Posttest	.705	Homogeneous

Based on Table 5, the data from both classes had homogeneous variances. Thus, parametric statistical analysis could be continued using the Independent Sample t-test.

Independent Sample t-test Analysis

After confirming that the data from both classes were normally distributed and homogeneous, a parametric statistical test was conducted using the Independent Sample t-test. The criterion for hypothesis testing was set at a significance level of 5% ($\alpha = 0.05$). A significant difference in learning outcomes was indicated when the probability significance value (Sig.) was less than 0.05. Conversely, when the Sig.

value was greater than 0.05, no significant difference in learning outcomes was indicated.

Table 6. Results of the independent sample t-test

Data	Sig.	Description
Posttest	.000	Significant difference

As presented in Table 6, there was a significant difference in learning outcomes between the control and experimental classes. This finding indicates that the use of the Assemblr Edu AR: BioDigest application had a positive effect on improving students' learning outcomes.

N-gain Test

The N-gain test was used to determine the effectiveness of the Assemblr Edu AR: BioDigest learning media in improving students' achievement.

Table 7. Results of the N-gain test

Class	N-gain	Category
Experimental	0.5944	Moderate

Based on Table 7, the N-gain score of the experimental class was 0.5944, which falls into the moderate category. This result indicates that the use of Assemblr Edu AR: BioDigest demonstrated a moderate level of effectiveness in supporting students' learning outcomes. The finding suggests that the learning media were effective in facilitating the learning process, although their effectiveness had not yet reached the high category.

The moderate level of effectiveness may have been influenced by several factors. First, students were still adapting to the use of Augmented Reality-based learning media; therefore, part of the instructional time was used to familiarize them with the application features. Second, differences in students' initial abilities and technological readiness, including limitations in device availability or internet connectivity, may have affected the optimal use of the media. Third, the relatively short duration of the intervention may have limited the impact of the media on improving learning outcomes. Therefore, more intensive, continuous, and well-supported implementation of the media may increase the possibility of achieving higher learning gains.

Students' Psychomotor Skills

The analysis of students' psychomotor skills in this study involved students from class XI.1 as the control class and students from class XI.2 as the experimental class. The comparison of students' psychomotor skill percentages in each aspect is presented in Table 8.

Table 8. Percentage of students' psychomotor skills

No.	Psychomotor Aspect	Control Class Percentage	Description	Experimental Class Percentage	Description
1	Perception	75.00	Fair	88.75	Good
2	Readiness	75.00	Fair	86.25	Good
3	Imitation	75.00	Fair	86.50	Good
4	Habitualization	74.50	Fair	87.50	Good
5	Proficiency	70.75	Fair	79.00	Good

No.	Psychomotor Aspect	Control Class Percentage	Description	Experimental Class Percentage	Description
6	Naturalization	62.65	Fair	75.63	Good
7	Originality	52.50	Poor	76.00	Good
	Mean	69.34	Fair	82.80	Good

Based on Table 8, the experimental class obtained higher psychomotor skill percentages than the control class across all aspects. The mean score of the experimental class was 82.80, categorized as good, while the control class achieved 69.34, categorized as fair. All psychomotor aspects in the experimental class were categorized as good, with the highest score in perception at 88.75. In contrast, the control class was mostly categorized as fair, while originality received the lowest score at 52.50 and was categorized as poor. These results indicate that the use of Assemblr Edu AR: BioDigest supported better psychomotor performance, particularly in helping students observe, imitate, practice, and develop skills more effectively.

Students' Affective Skills

The analysis of students' affective skills involved students from class XI.1 as the control class and students from class XI.2 as the experimental class. The comparison of students' affective skill percentages in each aspect is presented in Table 9.

Table 9. Percentage of students' affective skills

No.	Affective Aspect	Control Class Percentage	Description	Experimental Class Percentage	Description
1	Paying attention	75.00	Fair	86.00	Good
2	Responding	75.00	Fair	81.00	Good
3	Valuing	74.00	Fair	86.00	Good
4	Organizing	64.50	Fair	86.50	Good
5	Value characterization	51.25	Poor	81.25	Good
	Mean	67.95	Fair	84.15	Good

Based on Table 9, the experimental class achieved higher affective skill percentages than the control class in all aspects. The mean score of the experimental class was 84.15, categorized as good, while the control class obtained 67.95, categorized as fair. All affective aspects in the experimental class were categorized as good, with the highest score in organizing at 86.50. In contrast, the control class was mostly categorized as fair, while value characterization received the lowest score at 51.25 and was categorized as poor. These results indicate that the use of Assemblr Edu AR: BioDigest supported better affective engagement, particularly in improving students' attention, responses, self-regulation, and positive learning attitudes.

Based on the study conducted with Grade XI students at SMA Batik 2 Surakarta on the digestive system topic, differences were found between the experimental class (XI.2), which used Assemblr Edu AR: BioDigest, and the control class (XI.1), which used PowerPoint media. Assemblr Edu AR: BioDigest is an Augmented Reality-based learning application that enables students to observe learning objects in three-dimensional form, as shown in Figure 1. This is consistent with Iskandar et al. (2023), who reported that Assemblr Edu can present learning materials in 3D visual formats, allowing students to observe objects more realistically. In contrast, the control class used PowerPoint as the learning medium.

These differences were reflected in the effect of Assemblr Edu AR: BioDigest on students' cognitive learning outcomes, as well as their affective and psychomotor engagement during the learning process.



Figure 1. Assemblr Edu AR: BioDigest application

The effect on students' cognitive learning outcomes can be observed in Table 3. The table shows that students in the control class had relatively low initial understanding of the learning material, whereas students in the experimental class tended to have better initial understanding. The posttest results in both classes showed improvement; however, the increase in the experimental class was higher than that in the control class. The difference in posttest scores between the two classes indicates an absolute gain, suggesting that the AR-based intervention contributed to greater learning achievement than PowerPoint-based instruction. This improvement indicates not only an increase in students' scores but also a stronger and deeper understanding of the concepts being learned.

The difference in posttest results between the two classes shows that the use of Assemblr Edu AR: BioDigest produced higher learning outcomes than instruction using PowerPoint. This improvement can be explained by the learning mechanisms that occurred during the use of AR media. The three-dimensional visualization of objects in the application helped students observe the structure of digestive organs more realistically and in greater detail, making previously abstract concepts more concrete and easier to understand. When students develop stronger conceptual understanding, their ability to answer evaluation questions also improves, which ultimately contributes to better learning outcomes. This finding is consistent with the Cognitive Theory of Multimedia Learning proposed by Mayer, which explains that learning becomes more effective when information is presented through a combination of text, images, and animation because students process information through verbal and visual channels simultaneously.

In addition, the interactive features of AR media enabled students to learn actively through exploration, observation, and manipulation of virtual objects. This active engagement encouraged greater attention, curiosity, and learning motivation compared with passive learning through conventional presentation media. Learning experiences that involve direct interaction tend to strengthen memory retention, making the information learned easier to recall during the posttest. Thus, the effect of AR on learning outcomes was not merely due to the use of technology, but rather to the learning experience created by the technology, which was more visual, interactive, and meaningful. This is also in line with constructivist theory, which emphasizes that knowledge is actively constructed by students through interaction with the learning environment, as well as Dual Coding Theory, which states that information received through both verbal and visual codes is easier to understand and remember.

These findings are consistent with Tania et al. (2023) and Prasetya (2025), who reported that the use of technology-based media such as Assemblr Edu AR can improve student learning outcomes. In addition, AR media provide opportunities for students to imagine and construct mental representations of the material, thereby enhancing cognitive outcomes (Qorimah & Utama, 2022).

The N-gain score in the experimental class was 0.5944 and was categorized as moderate. This indicates that the use of Assemblr Edu AR: BioDigest had an effect on improving students' cognitive learning outcomes. The appropriate selection of learning media determines whether learning materials are effectively delivered, which in turn affects student learning outcomes (Nabilla et al., 2025). Nevertheless, the moderate category indicates that Assemblr Edu AR: BioDigest was effective, although it had not yet reached a high level of effectiveness. This may have been caused by several factors, including insufficient instructional time and unstable internet connectivity, which limited the optimal use of the media. Scientifically, the moderate category suggests that the intervention had a measurable impact, but further improvement is still needed in terms of duration of use, intensity of practice, and readiness of supporting facilities to achieve higher learning gains.

In the experimental class, which used Assemblr Edu AR: BioDigest, the digestive system material was presented through more realistic visualizations. These visualizations helped students understand the structure and function of organs more clearly, resulting in better learning outcomes in the experimental class than in the control class. The visualization provided by Assemblr Edu AR: BioDigest is shown in Figure 2.

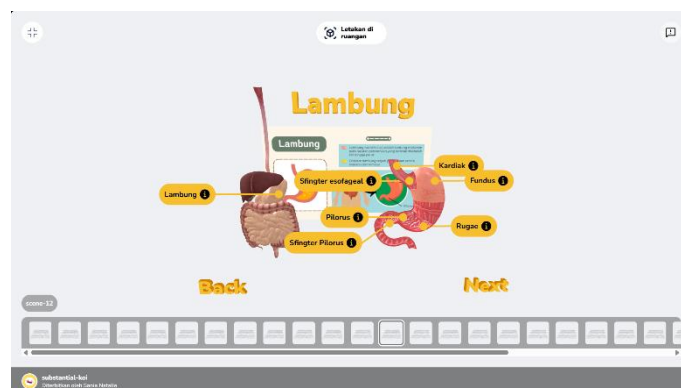


Figure 2. Visualization in the Assemblr Edu AR: BioDigest application

This finding is supported by Brilliant & Nurcahyanto (2025), who stated that the use of Augmented Reality media helps students visualize abstract materials or concepts more interactively, thereby improving conceptual understanding and learning outcomes. The appropriate selection of media can also improve learning outcomes and increase motivation to study a topic. Visual stimulation can further enhance students' learning interest (Nurhaliza et al., 2022).

In addition to improving cognitive learning outcomes, the use of Assemblr Edu AR: BioDigest also influenced students' affective and psychomotor engagement during the learning process. In the psychomotor domain, students in the class using Assemblr Edu AR: BioDigest showed active involvement during learning, whereas students in the class without the application demonstrated only moderate active involvement. This difference is shown in Figure 3, where each psychomotor aspect in the experimental class was higher than that in the control class. The score differences across indicators

indicate that AR media not only enhanced basic skills but also influenced more advanced skills such as creativity and adaptive action.

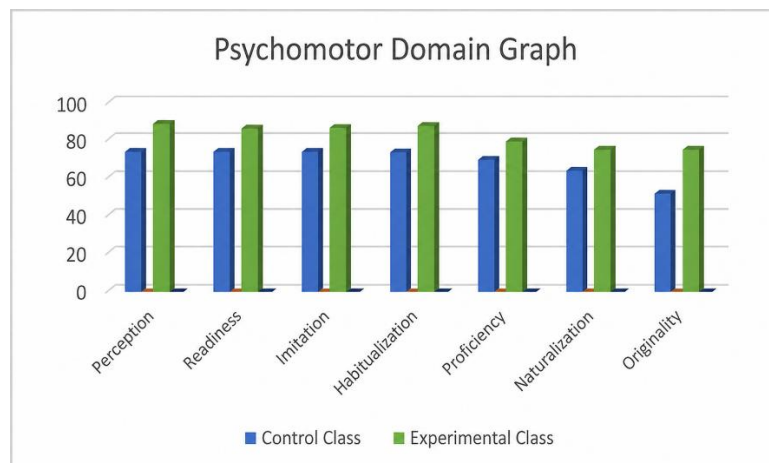


Figure 3. Psychomotor domain graph

Figure 3 shows that all psychomotor aspects in the experimental class had higher scores than those in the control class. This pattern indicates a consistent improvement across all skill indicators after the use of Assemblr Edu AR: BioDigest. In other words, Augmented Reality-based media did not affect only one specific aspect but had a broader influence on students' skill development throughout the learning process.

In general, the highest achievements in the experimental class were found in perception, readiness, imitation, and habitualization. This indicates that students were better able to receive learning stimuli, prepare themselves for learning activities, imitate procedural steps, and develop independent learning habits. The high scores in these basic aspects suggest that AR was effective in supporting students from the early to intermediate stages of skill mastery. Three-dimensional object visualization and interactive features made it easier for students to understand instructions, observe procedures, and practice them more accurately.

In the proficiency aspect, the experimental class still scored higher than the control class, although the score was not as high as in the previous aspects. This suggests that students had begun to achieve better skill mastery but still required repeated practice to reach optimal performance. Meanwhile, naturalization and especially originality were the lowest-scoring aspects in both classes. This pattern is understandable because the ability to act spontaneously, flexibly, and creatively represents a more complex level of skill than merely imitating or following procedures. In other words, students found it relatively easier to achieve basic skills than higher-order creative skills.

In the perception aspect, students in the experimental class were able to understand the learning material more quickly by observing objects in detail using Assemblr Edu AR: BioDigest, compared with students in the control class who used PowerPoint. The use of Augmented Reality-based media allowed students to experience learning that was more engaging, interactive, and easier to understand, thereby improving their perception of the material studied. This is consistent with Melliofatria (2024), who stated that Augmented Reality-based media provide students with access to freely explore learning materials, interact with virtual objects in real environments, and receive immediate feedback, making learning more meaningful.

The readiness aspect refers to students' physical and mental preparedness to participate in learning activities. In this aspect, the experimental class demonstrated

better readiness than the control class. In the imitation aspect, many students in the experimental class were able to imitate the skills taught by following the steps accurately. In contrast, several students in the control class still experienced difficulties in imitating the given steps. This finding is consistent with Mubai et al. (2020), who demonstrated that Augmented Reality technology can virtually display practicum tools and materials, as well as simulate material more realistically, making it easier for students to imitate the available steps.

The habitualization aspect reflects students' ability to perform skills routinely and automatically. Students in the experimental class were more skilled in conducting learning independently, whereas students in the control class showed lower skill performance. The proficiency aspect indicates the level of material mastery. Students in the experimental class demonstrated higher and more accurate mastery of the material than those in the control class. This is supported by Sari et al. (2024), who stated that the use of the Assemblr Edu application in the experimental class helped students better understand learning materials because the application provides clearer and more engaging representations of the content.

The final aspects are naturalization and originality, which indicate the ability to perform skills creatively. Students in the experimental class not only mastered technical skills but were also able to develop and adapt them to different situations. This occurred because students in the experimental class tended to be more capable of expressing their opinions and ideas, allowing their creativity to be better channeled. This is consistent with Sulistyowati & Aryani (2025), who reported that the use of the Assemblr Edu application, in this case BioTranspezia, can improve students' communication in expressing opinions and creative ideas.

In addition to the psychomotor domain, the implementation of Assemblr Edu AR: BioDigest also had a positive impact on students' affective domain during the learning process. The affective domain is related to students' attitudes, interest, motivation, and engagement in learning activities. Figure 4, which presents the affective domain graph, shows that every affective aspect in the control class was lower than in the experimental class. This pattern indicates that AR media not only improved students' skills but also encouraged enthusiasm, attention, and participation during learning. This is consistent with Sutama & Fajriani (2021), who stated that interactive media, such as videos and 3D images, make students more interested and increase their motivation to participate in learning.

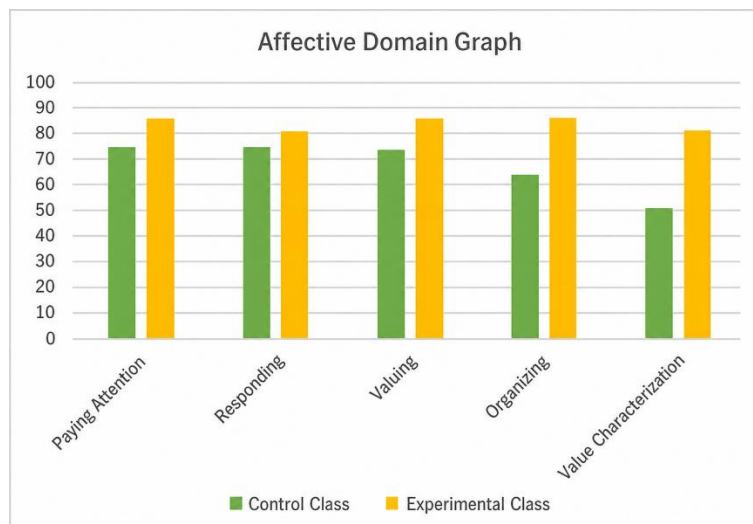


Figure 4. Affective domain graph

Figure 4 shows that all affective aspects in the experimental class had higher scores than those in the control class. This pattern indicates a consistent improvement in every indicator of attitude and learning engagement after the use of Assemblr Edu AR: BioDigest. Thus, the influence of AR media was not limited to one particular aspect but was distributed across the overall affective dimensions of students during the learning process.

In general, the highest achievements in the experimental class were found in organizing and valuing, followed by paying attention. This indicates that students were not only able to focus on the material but were also able to regulate themselves during learning and provide better evaluations or responses to the material studied. The high scores in these aspects suggest that AR media created a learning atmosphere that encouraged discipline, concentration, and cognitive-emotional engagement simultaneously.

Meanwhile, although the responding and value characterization aspects remained higher in the experimental class than in the control class, their achievements were relatively lower than those of the other indicators. This pattern can be interpreted as evidence that active response and the internalization of values as habits require a longer and more continuous learning process. Attitudes such as responsibility, cooperation, and the habit of expressing positive opinions generally do not develop instantly but through repeated learning experiences.

The first aspect of affective ability is paying attention. The results shown in the graph indicate that students in the experimental class paid greater attention to the learning material than those in the control class. One factor contributing to this result was the use of the Assemblr Edu application, which helped create an enjoyable learning atmosphere, making learning more meaningful and increasing students' enthusiasm. In addition, Setyowati et al. (2020) stated that interactive media have entertainment value and appeal for students, enabling them to focus more attention on the media.

In the responding aspect, observations showed that students in the experimental class were more active in responding and asking questions during learning, whereas students in the control class tended to be less active. This occurred because the use of Assemblr Edu helped channel students' creativity. According to Rahim et al. (2025), attractive and interactive media can stimulate students' curiosity, which encourages them to ask questions and become more active. The third aspect is valuing, which reflects students' ability to evaluate learning materials more critically and deeply. In the experimental class, this ability was more evident, whereas students in the control class appeared to have less mastery of this aspect.

The organizing aspect reflects students' ability to regulate and control themselves during the learning process. Students in the experimental class appeared more skilled and showed better mastery of this aspect than those in the control class. The final aspect is value characterization. Students in the experimental class demonstrated more positive attitudes, such as responsibility, cooperation, and respect for others' opinions. This is consistent with Labuhanbatu & Utara (2024), who found that interactive learning can shape students' positive attitudes. In the control class, these attitudes were still present but did not develop as optimally as in the experimental class.

Overall, the findings of this study indicate that the implementation of Assemblr Edu AR: BioDigest was effective in improving students' learning outcomes on the digestive system topic. This effectiveness was reflected not only in improved cognitive learning outcomes but also in students' engagement during the learning process. Students' affective and psychomotor engagement were interrelated in supporting

learning. The affective domain contributed to the formation of students' attitudes, interest, and learning motivation. Students who demonstrated enthusiasm, attention, and active participation tended to be more involved in each stage of learning.

Affective engagement supported the development of psychomotor skills, as students became directly involved in learning activities, such as using the application, observing digestive system models, and exploring the presented material. Through these activities, students gained more authentic and meaningful learning experiences. Pratistiningsih et al. (2024) stated that digital media innovations, including the use of Augmented Reality, are needed in education because they can improve students' practical skills, motivation, and critical thinking abilities.

The relationship between the affective and psychomotor domains contributed to the improvement of students' cognitive learning outcomes. Students with strong motivation and skills were better able to understand learning concepts, resulting in more optimal cognitive achievement. The use of Assemblr Edu AR: BioDigest as an Augmented Reality-based learning medium created a learning environment that was more interactive, engaging, and less monotonous. This encouraged students to participate more actively in the learning process, so learning was not limited to content delivery but also involved students' overall learning experiences. This is consistent with Suryani et al. (2024), who stated that the use of the Assemblr Edu AR application can create a learning atmosphere that is enjoyable, creative, and effective.

Therefore, the implementation of Assemblr Edu AR: BioDigest was not only effective in improving students' cognitive learning outcomes but also capable of promoting student engagement in the affective and psychomotor domains, enabling learning objectives to be achieved more optimally. The score differences in the affective domain indicate that a more engaging learning experience can foster positive emotional responses that contribute to students' readiness to learn.

CONCLUSION

The implementation of the Assemblr Edu AR: BioDigest application significantly improved students' learning outcomes in the digestive system topic. The Independent Samples t-test showed a significant difference between the experimental and control classes ($p < 0.05$), indicating that AR-based instruction was more effective than learning with PowerPoint media. The experimental class also achieved an N-Gain score of 0.5944, categorized as moderate, which confirms the effectiveness of the intervention. In addition to cognitive improvement, the use of Assemblr Edu AR: BioDigest supported better affective and psychomotor outcomes. Students in the experimental class showed stronger attention, participation, motivation, positive attitudes, media-use skills, procedural readiness, and creative expression. These improvements suggest that interactive three-dimensional AR visualization helped make abstract digestive system concepts more concrete, encouraged active exploration, and created a more meaningful learning experience. This study implies that Augmented Reality-based learning media can be used as an innovative alternative in biology instruction, particularly for abstract and complex topics. Its integration may support not only students' cognitive achievement but also their affective engagement and psychomotor development.

RECOMMENDATION

Based on the findings, teachers are encouraged to integrate AR-based learning media into biology instruction to help students understand abstract concepts more effectively. Learning activities should be designed to strengthen students' affective

development, particularly value characterization, by promoting interaction, discussion, and active participation. Students' psychomotor abilities, especially originality, should also be improved by providing more opportunities for exploration and creative idea expression. Future development of Assemblr Edu AR: BioDigest should include more interactive features tailored to students' characteristics so that learning outcomes can be further improved.

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