



Development of augmented reality-based flashcards with HOTS-level questions to improve learning outcomes of grade 11 students on the human excretory system

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Abstract. The available learning media that can visualize the conceptual material in the excretory system are still limited, while the 21st century demands students to have creative thinking, critical thinking, and problem-solving skills. In reality, students' critical thinking skills are still relatively low. Therefore, learning media are needed that can solve this problem. This study aims to describe the validity, practicality, and effectiveness of media on learning outcomes. This study is a research and development (R&D) project using the ADDIE model, which includes the stages of Analysis, Design, Development, Implementation, and Evaluation. The study was conducted at Panombeian Panei State High School 1 with the following participants: validators, biology teachers, and 11th-grade students. The research results indicate that this media resource meets the feasibility standards, with average scores of 88.19% from media experts and 86.13% from subject material experts, placing it in the "highly feasible" category. The results of the practicality test showed a teacher response rate of 92.5%, categorized as "highly practical," and a student response rate in the small-scale test of 80.2%, categorized as "practical," with the limited trial showing an average of 92.54%, categorized as "highly practical." The effectiveness test results showed that the average pretest score of 62,3 increased to 84,2 on the posttest. The N-gain results for the pretest and posttest averaged 0.58, which was classified as medium. Based on these results, the augmented reality-based flashcard medium using HOTS questions on the human excretory system is deemed valid, practical, and effective for use in the learning process. The implications of this study show that Augmented Reality-based flashcards can serve as an interactive learning media to support students' higher-order thinking skills (HOTS) in understanding the complex material on the excretory system. This media is recommended for use by teachers as an alternative learning resource. However, further research is recommended to evaluate the effectiveness of this media on a larger sample and in other biology topics.

Keywords: *Augmented reality, Flashcard, Higher-order thinking skills, Human excretory system*

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INTRODUCTION

In the 21st century, education also requires people to adapt to advancements in science and technology, so learning should be centered on students, and students should become more active rather than being passive learners. Based on this, to achieve educational goals, it is important to consider supporting components such as the curriculum, educators, and school facilities and infrastructure (Apriani & Sudrajat, 2025). Technological developments have made it easier for teachers and students to learn by using more creative and innovative models. The use of technology in the 21st century aims to hone skills and can increase learning motivation for students. Learning in the 21st century requires teachers to adapt strategies, models, and teaching methods to the characteristics of that generation (Banarsari et al., 2023).

A teacher must be creative and innovative, able to present interesting learning activities by utilizing technology so that learning goals can be achieved (Puspitarini, 2022). To achieve these learning goals, teachers must pay attention to the learning media to be used. Learning media serves as an important intermediary in the learning process to convey messages effectively from teachers to students. The use of learning media is the right effort to improve the quality and effectiveness of learning so that it can improve student learning outcomes

(Lubis et al., 2023). Learning media is needed in the learning process, especially in biology materials. Biology learning is often considered complex, so an innovative approach is needed to help students understand these abstract and complex concepts (Putri et al., 2024). One of the biological materials that uses many terms and is abstract is the excretory system, which causes students to have difficulty learning the material (Dwilian et al., 2025). The excretory system is often considered difficult by students because it involves understanding the body's organs, needing to memorize the names of organs, understanding the excretion process, and the complex stages of urine formation. This material requires a deep understanding, so the use of appropriate learning media is essential (Wulandari et al., 2025).

Based on observation at Senior High School 1 Panombeian Panei, it was found that learning activities were still not optimal in visualizing the process in biology material. This was because teachers still predominantly used learning media such as textbooks, PowerPoint, and torsos. The use of two-dimensional (2D) images in PowerPoint has limitations because they cannot depict the entire physiological process that occurs. Meanwhile, the torso model only displays the three-dimensional structure of the organs without the names of the parts or explanations of the organs' functions. This situation indicates that the teaching aids used are not yet fully capable of helping students understand the material comprehensively, so their understanding of the processes in the excretory system is not yet optimal.

The use of learning media is not yet optimal because of a lack of time, references, and motivation from teachers to improve learning media. When learning media isn't optimal, it has an impact on student learning outcomes (Fitriyanti et al., 2021). Based on an interview with one of the teachers at Senior High School 1 Panombeian Panei, the excretory system is one of the subjects that students find difficult to understand, as shown by the fact that many students still fail to achieve the minimum passing score of 75. The teacher said that students have difficulty understanding the subject because of the complicated processes that occur in the human excretory system. Based on the analysis of student needs, improvements need to be made to learning media. Learning media can be one of the solutions used by educators to improve students' understanding of the material (Wicaksono & Wiratama, 2024).

To support the development of these skills, teachers must do more than simply impart knowledge; they must prepare students to develop the skills they will need to meet the demands of the 21st century, specifically creative thinking, critical thinking, and problem-solving skills (Skulmowski & Xu, 2022). These skills are very important, especially in science education, which places a high value on critical thinking, as it closely aligns with the school science curriculum. Students must develop these skills to evaluate, discuss, and analyze the knowledge they encounter (Prayogi et al., 2025). In reality, students' critical thinking skills are still low, as evidenced by data from the Program for International Student Assessment (PISA), which indicates that science literacy in Indonesia is among the lowest in the world. Results from international studies such as the Program for International Student Assessment (PISA) consistently show that Indonesian students' science literacy scores remain low compared to the global average. Students have difficulty presenting information and creating accurate graphs, so they are at a basic proficiency level in interpreting and presenting the information provided. This indicates that Indonesian students' science literacy skills remain low (OECD, 2023). Students have difficulty interpreting information and presenting it accurately, for example when creating graphs, so their skills remain at a basic level. Higher-level science literacy in PISA requires higher-order thinking skills (HOTS), such as analyzing, evaluating, and drawing conclusions from data. Therefore, learning media that train students to answer HOTS-based questions are needed to improve their critical thinking skills and, in turn, their science literacy.

The results of interviews conducted at SMA Negeri 1 Panombeian Panei with biology teachers indicate that, during the learning assessment process, teachers also rarely give questions related to critical thinking skills. Based on a curriculum analysis that has also been

conducted, it was found that student learning outcomes require students to be able to perform learning activities that include the ability to analyze, evaluate, and even create, such as analyzing the interrelationships between organ systems in the body to respond to internal and external stimuli. These requirements indicate that the learning process in phase F is no longer oriented toward low-order thinking skills that are limited to memorizing and understanding concepts but has shifted toward developing higher-order thinking skills. The role of educators is to facilitate and develop students' higher-order thinking skills. Learning becomes more meaningful when students are encouraged to engage in higher-order thinking. Conceptual mastery is achieved when students are capable of higher-order thinking; they can analyze, evaluate, and apply concepts effectively. Therefore, it is necessary to assess students to ensure these educational goals are achieved (Fauziyah et al., 2023).

An alternative medium that can be used is flashcards. Flashcards are a type of card containing words, pictures, or numbers used by teachers and students in the classroom (Maulida & Rahmatan, 2025). The purpose of using flashcards is as a visual aid to make students more interested and enjoy the learning process, as well as to improve students' understanding of the material provided by the teacher. The use of flashcards in classroom learning activities has been proven to maximize conceptual understanding and learning activity in the classroom through visualization (images) that have an impact on students' cognitive learning outcomes (Sarnia et al., 2024). The advantage of this medium lies in the images presented along with their descriptions, which make them attractive. Flashcards have advantages in terms of usability and portability. This medium enables flexible use at various times and places, while also increasing student learning activities (Nurjanah et al., 2023).

Flashcards can be combined with visualization, namely Augmented Reality. The use of visualization-based media will make students more interested and help them easily understand abstract concepts. Augmented Reality (AR) is a technology that can project two-dimensional (2D) objects into three-dimensional (3D) objects, creating a more realistic and interactive experience. The use of interactive multimedia based on Augmented Reality will show objects that can be seen in real life and can be applied in biology learning. The combination of Flashcards and Augmented Reality aims to ensure that students not only memorize concepts but also understand the material on the excretory system by increasing student participation and understanding because it presents information visually and interactively (Siregar et al., 2025).

Based on the description above, there is a need for research on the development of instructional media to help improve students' conceptual understanding of the excretory system and enhance their 21st-century skills, particularly their creative thinking, critical thinking, and problem-solving skills. Accordingly, the researcher developed instructional materials in the form of Augmented Reality-based flashcards with HOTS questions on the human excretory system. This is also supported by research conducted by Alfina et al. (2026), which demonstrated that AR-based flashcards on the human organ systems can significantly improve students' critical thinking skills through high-order thinking tasks, as evidenced by an N-Gain Score of 0.74 (high category). With its ability to present interactive, real-time 3D visualizations of objects, AR-based media has proven capable of helping students analyze the relationships between organ systems more concretely, while also supporting higher-order thinking processes.

METHOD

Research design

The type of research used in this study is research and development (R&D). Research and development is a method used to research, design, produce, and test the validity of a product that has been produced (Sugiyono, 2023). The development model used in this study

is the ADDIE development model. The ADDIE model is a general learning model and is suitable for use in developmental research (Anafi et al., 2021). This development model includes five stages, namely Analysis, Design, Develop, Implement, and Evaluate. The analysis stage is to determine the initial needs in product development. At this stage, a needs analysis will be conducted, including curriculum analysis, student characteristics analysis, student needs analysis, and educator needs analysis. The design stage consists of several steps, namely: preparation of tools and materials, format selection, content organization, and the design of validation rubrics for subject matter experts, media experts, and test instrument experts. In the development stage, the researcher has completed the design of the Augmented Reality-based flashcard media. Next, during the development phase, a validation process by experts will be conducted. During the implementation stage, the researcher assessed the practicality of the educational media based on teachers' and students' responses. During the evaluation stage, the researcher evaluated the effectiveness of this educational product by administering a pre-test and a post-test to the students.

This research was carried out at SMA Negeri 1 Panombeian Panei. The subjects in this study were 11th-grade science students. The media trial was conducted on a small group consisting of 9 students. Meanwhile, the limited pilot test consisted of 21 students. In addition, the research subjects included expert faculty members consisting of 1 instrument expert, 1 content expert, 1 media expert, and 1 test instrument expert.

Research instrument and data collection technique

The research instrument is a measuring tool used to measure the phenomenon that is to be observed. The instrument used aims to evaluate the product being developed by providing a list of questions to experts or respondents. The questionnaires required in this study are: (1) validation of the assessment sheet by material experts, (2) validation of the assessment sheet by media experts, (3) a questionnaire sheet for biology teachers, (4) a questionnaire sheet for student responses, and (5) a test instrument (pretest-posttest).

The data collection methods used in this study were interviews, observations, questionnaires, and tests. Interviews, observations, and the distribution of student needs questionnaires were conducted to obtain preliminary information regarding students' needs and understanding of the excretory system material, the availability of learning media, and their needs for learning media. HOTS test questions were used to assess students' achievement of higher-order thinking skills, including analytical competencies (C4), evaluation (C5), and creativity (C6). The test consisted of 10 items.

Data analysis

The data obtained in this study consisted of quantitative and qualitative data. The data were obtained from the results of validation by subject matter experts, media experts, student and teacher responses, and the impact of media on improved learning outcomes. This study used three assessment parameters, namely validity, practicality, and effectiveness.

1. Data validitas media

Validity was determined through validation by media experts and subject matter experts. The assessment on the validation sheet used a Likert scale with a score range of 1 to 4. The validation results were calculated using the following equation (Mukaromah & Istianah, 2026).

$$\text{Percentage of Validity of Each Aspect (\%)} = \frac{\sum \text{score obtained for each aspect}}{\sum \text{maximum score for each aspect}} \times 100\%$$

The percentage of validity obtained will then be adjusted to the following categories in Table 1.

Table 1. Categories of media and material validity	
Percentage value (%)	Category
>84 - 100	Very valid
>69 - 84	Valid
>54 - 69	Fairly valid
>39 - 54	Less valid
0 - 39	Invalid

The practicality of augmented reality-based flashcards can be determined based on the results of the feedback questionnaires completed by students and the responses from teachers. The percentage of practicality obtained will then be adjusted to the following categories in Table 2.

Table 2. Practical test criteria	
Percentage (%)	Description
85 - 100	Very practical
65 - 85	Practical
45 - 64	Less practical
0 - 44	Impractical

(Source: Septiani & Okmarisa, 2023)

To test the effectiveness of media, it can be known through the results of pre-test and post-test students. Furthermore, pre-test and post-test data were analyzed using the N-gain formula to conclude how much the students' understanding increased

The following is the N-gain equation used:

$$N - gain = \frac{\text{Posttest score} - \text{Pretest score}}{\text{Maximum score} - \text{Pretest score}}$$

The results of the gain score calculation are then adjusted to the following categories in Table 3.

Table 3. N-Gain value categories	
N-gain value	Criterion
$g > 0.7$	Tall
$0.3 < g < 0.7$	Keep
$g < 0.3$	Low

(Source : Haka et al., 2025)

RESULTS AND DISCUSSION

Analysis

This process included an analysis of the curriculum, student characteristics, student needs, and teacher needs. A curriculum analysis was carried out to ensure that the instructional materials developed align with the curriculum implemented. Based on the analysis, the 11th-grade biology curriculum at Panombeian Panei utilizes the Merdeka Curriculum based on deep learning. In terms of content, the learning material aligns with the Learning Outcomes (LO) and students' cognitive development levels. As for the medium, its engaging visual presentation and ease of use enhance students' interest and active participation in the learning process.

Analysis of student characteristics was conducted to identify students' learning styles and the difficulties they encounter in learning biology, as a basis for designing instructional materials tailored to real-world conditions in the field. At this stage, students have a visual learning style. Analysis of student needs was conducted to identify students' needs for more attractive, visual, and interactive learning media, as well as to measure students' level of interest in using Augmented Reality-based flashcards. The results of the student needs analysis show that the majority of students said they need more attractive and visual learning materials

to complement conventional learning resources such as textbooks. Flashcards serve as a visual learning tool that combines images and text to enhance visual learning, helping students understand biological concepts and making abstract concepts more tangible so they can grasp material that cannot be observed directly. Therefore, augmented reality-based flashcards are an appropriate learning tool (Nabila et al., 2026).

The analysis of teacher needs aims to identify the challenges teachers experience in teaching biology and to assess the availability of existing teaching materials, which will serve as a basis for the development of new teaching materials. Based on the results of the teacher needs analysis conducted during the interviews, teachers face difficulties in teaching biology topics such as the excretory system because it involves physiological processes that cannot be observed directly. Teachers need teaching media capable of illustrating such conceptual material. Augmented reality-based flashcards are an ideal solution because they can boost students' motivation and enthusiasm. With this approach, the flashcards provide clear visual images, and augmented reality enhances the experience, making the content feel more three-dimensional and realistic (Tamboo et al., 2024).

Design

In this stage, the researcher used materials and tools to design the media, namely Canva, the Assemblr platform, Moduls, and textbooks. During the format creation stage, A5-sized paper (14.8 x 21 cm) was used, and the content sections of the media were designed, consisting of three subtopics: the structure and function of the organs of the excretory system, the mechanism of urine formation, disorders of the excretory system, and treatment technologies. The Augmented Reality-based flashcard design includes a cover page, instructions for use, learning objectives, and material on the human excretory system (Figure 1).

Development

This phase consists of two stages, namely: (1) material expert validation, (2) media expert validation.

Validation result by material expert

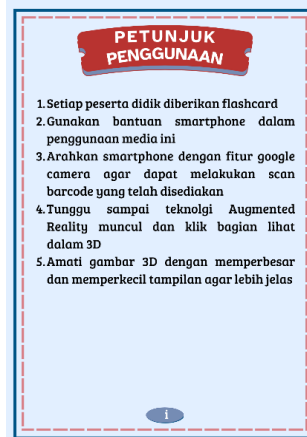
The subject-matter expert evaluation of the Augmented Reality-based flashcard media on the excretory system was conducted by a material expert. There are eight indicators to be evaluated: relevance of the content to learning objectives; relevance to student needs and accuracy of the content; stimulation of curiosity; presentation techniques; instructional delivery; comprehensiveness of the presentation; clarity of usage instructions and suitability for students; and use of language and symbols. The results of the subject matter expert's evaluation are presented in Table 4.

Table 4. Percentage of validation results from subject matter experts

Criteria evaluated	Total score	Maximum score	Average percentage (%)	Criteria
Relevance of the material to learning objectives	4	4	100	Very valid
Relevance to needs and accuracy of the material	7	8	87.5	Very valid
Stimulation of curiosity	4	4	100	Very valid
Presentation techniques	10	12	83.3	Very valid
Delivery of instruction	6	8	75	Valid
Completeness of presentation	3	4	75	Valid
Clarity of usage instructions and suitability for students	17	20	85	Very valid
Use of language and symbols	10	12	83.3	Very valid
Average	61	72	86.13	Very valid



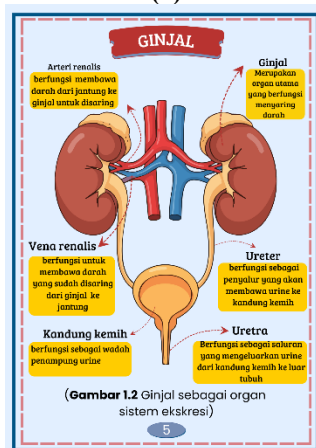
(a)



(b)



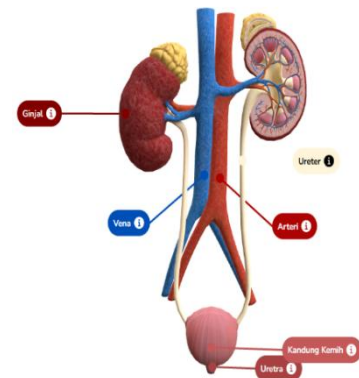
(c)



(d)



(e)



(f)

Figure 1. Flashcard sections a) main cover page; (b) Instructions for use; (c) subtopic 1; (d) The organ on flashcards; (e) Marker 3D; (f) Organ 3d in assemblr edu

Based on the results in Table 4, the material expert evaluation yielded a score of 86,13%, falling into the “ Very valid” category. In terms of the relevance of the material to the learning objectives, the learning outcomes and learning objectives presented in this instructional material are aligned. The objective is to help students gain a complete and comprehensive understanding of the human excretory system. Comprehensive instructional media also support the gradual development of students’ competencies. The systematic presentation makes it easier for students to understand the material used in this medium, facilitates comprehension, and enhances students’ critical thinking skills (Anapia et al., 2024).

In the presentation technique aspect, this indicates that the augmented reality-based flashcard medium for the excretory system material that was developed generally meets the acceptability criteria. When using flashcards during learning, the interactive and participatory nature of augmented reality-based flashcards will motivate students to learn independently and ensure that the presented material is not boring.

The aspects of clarity of usage instructions and suitability for students These aspects include clear usage instructions, the presentation of contextual and relevant problems, and the stimulation of critical, creative, and innovative thinking skills. This relates to students’ ease in using the media and connecting the material to real-life scenarios, thereby enabling them to enhance their critical thinking. The ease of using the media, combined with the presentation of contextual, everyday problems, has consistently been shown to improve students’ critical thinking skills (Maulida et al., 2025)

In terms of language and symbol usage, this aspect used in instructional media must be communicative so that the material can be well understood, and the appropriate use of language also helps students develop critical thinking skills because they are not hindered by difficult terms. This confirms that the linguistic aspect not only functions as a tool for conveying information but also plays a role in supporting students' deeper thinking processes (Viora et al., 2021).

Validation result by media expert

The validation of the augmented reality-based flashcards on the excretory system by a media expert was conducted by a media expert. There were six evaluation criteria used: practicality and visual appeal, marker sensitivity, balance between objects, typography of the flashcard content, simplicity, design, and benefits. The evaluation results were expressed as percentages by the researcher to align with the feasibility criteria. The results of the evaluation by the media expert are shown in Table 5.

Table 5. Results of the assessment by media experts

Criteria evaluated	Total score	Maximum score	Average percentage (%)	Criteria
Practicality and Attractive Design	14	16	87,5	Very valid
Marker Sensitivity	7	8	87,5	Very valid
Balance Between Objects	6	8	75	Valid
Flashcard Content Typography	11	12	91,66	Very valid
Simplicity	7	8	87,5	Very valid
Design and Benefits	12	12	100	Very valid
Average	57	64	88,19	Very valid

Based on the results in Table 5, the media expert evaluation yielded a score of 88.19%, falling into the “Very valid” category. In terms of marker sensitivity, this aspect covers how markers are applied; the results show that marker recognition is fast and responsive, and the objects remain stable, thereby supporting the ease and independence of using augmented reality-based flashcard media. Marker-based technology, with its ability to display 3D objects very quickly and stably when the marker is clearly visible, is a superior choice for exploratory and independent learning

In terms of object balance, this aspect encompasses a proportional composition between 3D elements and informational text, harmonious color coordination that supports learning focus, and a visual design that does not impose a cognitive burden on students as they process the learning material. Based on cognitive theory, visual elements and text that are well-structured and balanced will help students acquire information more efficiently and reduce unnecessary cognitive load (Rasyid, 2023).

Regarding the typography of the flashcard content, this aspect includes the use of a limited number of font types, proportional font sizes, and contrasting colors that facilitate reading the material. These results align with the principles of cognitive load theory, which emphasizes that the way learning materials are presented can influence the level of cognitive load on students; therefore, media designers must minimize this load so that students can focus on understanding the content.

In the Simplicity aspect, this aspect includes the user flow, as well as symbols or icons that are easy to understand and function well. This study has achieved the “highly acceptable” category, thereby supporting the potential to enhance students' motivation, engagement, and understanding of physiological concepts, particularly in the excretory system curriculum.

Implementation

After undergoing validation by experts and being deemed valid, the Augmented Reality-based flashcards on the human excretory system were distributed to biology teachers to obtain their evaluations of the developed teaching material. This teacher response evaluation was conducted by biology teachers in schools. The biology teachers used four evaluation criteria: visual presentation, ease of use, content relevance, and practicality and usefulness. The results of biology teacher responses are in Table 6.

Table 6. Results of biology teachers respon

Criteria evaluated	Total score	Maximum score	Flashcard category	
			Percentage (%)	Criteria
Media Presentation Aspects	18	20	90	Very practical
Ease of Use Aspects	9	10	90	Very practical
Content Relevance Aspects	9	10	90	Very practical
Practicality and Usefulness Aspects	10	10	100	Very practical
Average	46	50	92.5	Very practical

Based on the teachers' responses, the average rating was 95.2%, falling into the "very practical" category. The evaluated aspects included the media's visual presentation, ease of use, appropriateness of the content, and practicality and usefulness. The surrounding environment can serve as a learning resource for the contextual approach, a concept that enables teachers to connect the material to real-world conditions. Through this approach, students are guided to connect their knowledge with real-life experiences in their daily lives.

Student responses in small trials

This small-group pilot study was conducted with nine students from Class XI-1 at Panombeian Panei State High School No. 1, who were categorized as having low, moderate, and high ability based on their biology grades in the second semester. The students' responses in the small-group pilot study are shown in Table 7. The average results of the small-group trial were 80.2%, which falls into the "practical" category.

Table 7. Percentage of Student Responses in the small trials

Aspect	Flashcard assessment			Criteria
	Score	Maximum score	Percentage %	
Media Display	56	72	77	Practical
AR-Based Flashcard Presentation	149	180	82	Practical
Content	60	72	83	Practical
Ease of Use	88	108	81	Practical
Learning Motivation	86	108	79	Practical
Average	439	540	80.2	Practical

Student responses in limited trials

This limited-group trial was carried out with 21 students from Class XI-1, who were categorized as having low, medium, and high ability based on their biology grades in the second semester. The students' responses to the limited-group trial are shown in Table 8.

Table 8. Percentage of student responses in the limited trial

Aspect	Flashcard Assessment			Criteria
	Score	Maximum Score	Percentage %	
Media Display	138	144	95.8	Very practical
AR-Based Flashcard Presentation	332	360	92.2	Very practical
Content	133	144	92.3	Very practical
Ease of Use	192	216	88	Very practical
Learning Motivation	204	216	94.4	Very practical
Average	999	1080	92.54	Very practical

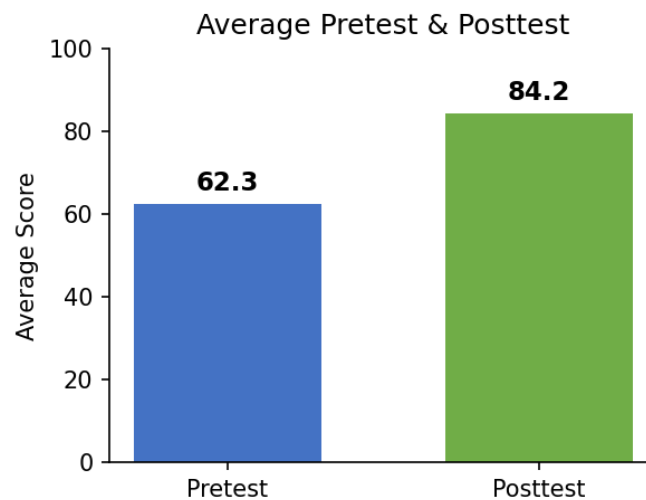
The results of the limited group testing were 92.54, which falls into the “very practical” category. Students offered several suggestions for improving some of the blurry barcodes caused by internet connection issues.

In line with the findings of Nabila et al. (2026), students’ responses to this augmented reality-based flashcard medium indicate that it successfully captured their interest. Students do indeed need teaching materials that are in line with the times and technology-based. AR flashcards offer a solution capable of facilitating a more active, effective, and creative learning process. This medium can help overcome the limitations of real objects that are difficult to bring into the classroom, thereby enabling biology instruction, particularly regarding the concept of biodiversity, to be conducted virtually and interactively.

Evaluation

Effectiveness of the media

The results of the study show an increase in students’ average scores from 62.3 on the pretest to 84.2 on the posttest (Figure 2). Figure 2 represents an increase of 21.9 points (35,15%). This indicates that the intervention had a positive effect on improving students’ abilities.

**Figure 2. Comparison of pretest and posttest scores**

N-gain test

In addition, an analysis was conducted using the N-Gain test, which aims to measure the effectiveness of instruction or interventions in improving student learning outcomes. Based on the overall N-Gain score calculated using pre-test and post-test scores, the average N-Gain score was found to be “0.58.” This falls into the moderate category. In conclusion, this teaching material can improve learning outcomes using HOTS questions to a moderate extent.

The C4 question involves analyzing the structure and function of the excretory organs, analyzing the factors that influence sweat and urine secretion, and analyzing the relationship between the filtration process and urine formation. The C5 question involves evaluating healthy lifestyle practices related to disorders of the excretory system, and the C6 question involves designing a healthy lifestyle plan related to disorders of the excretory system. In addition, presenting concepts in a more engaging and realistic way makes the learning environment more enjoyable. The use of AR in learning also helps students actively explore and analyze problems, which fosters the development of critical thinking. An interactive and engaging learning environment facilitated by AR can also boost students' motivation to learn. When students feel interested and actively engaged in the learning process, they tend to focus more on analyzing problems and finding solutions, resulting in the development of critical thinking skills (Ariyanti et al., 2026).

Analyzing the structure and function of the excretory organs, the factors that influence sweat and urine secretion, and the relationship between the filtration process and urine formation are abstract concepts that students cannot observe directly through conventional teaching methods. Augmented reality technology offers a solution by visualizing the structure of the excretory organs in an interactive three-dimensional format using physical cards (markers) as flashcards. With this media, students can observe the structure and anatomy of the organs in detail, examine the structure of the nephron, and trace the flow of blood through the filtration process until urine is gradually formed. This integration combines the power of interactive visualization from AR, which helps students understand the abstract structure and mechanisms of the excretory organs and make them concrete (Maulida et al., 2025).

The ability to evaluate healthy lifestyle practices (C5) is essentially developed in stages through two complementary media. AR flashcards first provide students with a visual understanding of how nephrons work to filter blood into urine, so they know what a normal filtration process looks like. Students then use this understanding as a benchmark when assessing daily habits, such as holding in urine, not drinking enough water, or eating too much salt, to determine whether these habits place a strain on the kidneys (Alfina et al., 2026).

The ability to design a healthy lifestyle (C6) requires students to develop concrete solutions, rather than simply judging whether a habit is good or bad. The visual understanding gained from AR flashcards regarding how nephrons work and the filtration process serves as the foundation for students to design physiologically sound recommendations, such as creating a water drinking schedule based on an understanding of glomerular workload, rather than simply reciting memorized general advice. Interactive 3D visualizations help students build more accurate mental representations than simply reading static text, thereby providing them with a deeper conceptual understanding of the structure and function of the body's organs. AR Problem Cards help present real-world problems, and consequently, students find it easier to connect the results of their analysis to possible solutions (Ariyanti et al., 2026).

Based on the overall N-Gain calculations from the pretest and posttest scores, an average N-Gain of 0.58 was obtained, which falls into the moderate category. These results indicate that AR-based flashcard instructional materials can improve student learning outcomes on HOTS questions, although the improvement has not yet reached the high category. This moderate category suggests that the developed instructional media has effectively helped students visually understand the concept of the excretory system; however, the transfer of this understanding to higher-order thinking skills, such as analyzing, evaluating, and designing, has not yet occurred optimally among all students. This is understandable, given that HOTS questions require multi-layered cognitive processes that cannot be fully developed through a single type of medium. Thus, other factors, such as students' learning habits and the intensity of practice, also influence the extent of improvement.

CONCLUSION

The results of research and development of educational media in the form of Augmented Reality-based flashcards with Higher-Order Thinking Skills (HOTS) questions to improve the learning outcomes of 11th-grade students regarding the human excretory system. The research results show that the instructional media developed using the ADDIE model received high validation scores from subject matter experts and media experts (86.13% and 88.19%, respectively), and that the practicality test yielded very positive results based on feedback from teachers and students (92.5% and 92.54%), thus deeming this media suitable for pilot testing.

The effectiveness of this material is also evidenced by data showing an increase in pre-test and post-test scores, from 62.3 to 84.2, indicating improved student learning outcomes. Furthermore, an N-gain score of 0.58 demonstrates improved learning outcomes and confirms that this material is quite effective in enhancing learning outcomes, particularly for Higher-Order Thinking Skills (HOTS) questions. The implications of this study show that Augmented Reality-based flashcards can serve as an interactive learning media to support students' higher-order thinking skills (HOTS) in understanding the complex material on the excretory system. Teachers can use this media as an alternative instructional tool that supports the learning process and strengthens students' HOTS, as well as a reference for developing similar augmented reality-based digital learning media on other Biology materials. For future research, it is recommended to involve at least two validators, such as media and material experts, to ensure more objective and reliable validation results.

REFERENCES

- Alfina, A., Zulkifli, L., Sukarso, A., Jamaluddin, J., & Irawan Zain, I. Z. (2026). Development of Augmented Reality-Based Flashcard Learning Materials to Enhance Students' Critical Thinking Skills in the Human Body Systems Curriculum. *NUSRA: Jurnal Penelitian dan Ilmu Pendidikan*, 7(2), 568–581. <https://doi.org/10.55681/nusra.v7i2.6246>
- Anafi, K., Wiryokusumo, I., & Leksono, P. (2021). Pengembangan Media Pembelajaran Model ADDIE Menggunakan Software Unity 3D. *Jurnal Education and Development*, 9, 433–438. <https://journal.ipts.ac.id/index.php/ED/article/view/3206>
- Anapia, S., Husain, I. H., Mardin, H., Mamu, H. D., & Akbar, M. N. (2024). Pengembangan Modul Pembelajaran Berbasis Augmented Reality pada Materi Sel untuk Meningkatkan Kemampuan Berpikir Kritis Peserta Didik SMA Negeri 1 Tibawa. *ORYZA (Jurnal Pendidikan Biologi)*, 13(2), 263–274. <https://doi.org/10.33627/oz.v13i2.2751>
- Apriani, I. N., & Sudrajat, A. K. (2025). Kesulitan Belajar Siswa pada Pembelajaran Biologi Materi Ekosistem Berdasarkan Penggunaan Strategi Pembelajaran. *Jurnal Edukasi Biologi*, 11(2), 205–219. <https://doi.org/10.21831/edubio.v11i2.24273>
- Ariyanti, A. S., Juliyanto, E., & Rahayu, R. (2026). Augmented reality problem cards in problem-based learning support science critical thinking. *Academia Open*, 11(1), Article 14350. <https://doi.org/10.21070/acopen.11.2026.14350>
- Banarsari, A., Rizki Nurfadilah, D., & Zainul Akmal, A. (2023). Pemanfaatan Teknologi Pendidikan Pada Abad 21. *Seminar Nasional Inovasi Pendidikan ke-6 (SNIP 2022)*, 459–464. <https://doi.org/10.20961/shes.v6i1.71152>
- Dwilian, R. A., Yuhanna, W. L., & Kiswardianta, R. B. (2025). Implementasi pendekatan STEM untuk meningkatkan kemampuan berpikir kritis peserta didik pada materi sistem ekskresi. *Jurnal Edukasi dan Sains Biologi*, 7(1), 1–11. <https://doi.org/10.37301/esabi.v7i1.93>
- Fauziyah, A., Hala, Y., & Aziz, A. A. (2023). Uji kevalidan instrumen tes berorientasi Higher Order Thinking Skills (hots) pada materi sistem ekskresi kelas XI SMA/MA. *Jurnal Biogenerasi*, 8(1), 329–333. <https://doi.org/10.30605/biogenerasi.v8i1.2125>

- Fitriyanti, M., Maasawet, E. T., & Boleng, D. T. (2021). Analisis Permasalahan Guru Terkait Media Pembelajaran Biologi Berbasis Aplikasi Mobile Learning Menggunakan Teknik Mnemonik Verbal. *Jurnal Pendidikan*, 9(2), 67–72. <https://doi.org/10.36232/pendidikan.v9i2.1148>
- Haka, N. B., Asih, N., Oktafiani, R., & Masya, H. (2025). Pengembangan media pembelajaran augmented reality berbasis Android untuk meningkatkan pemahaman konsep siswa SMA. *Didaktika Biologi: Jurnal Penelitian Pendidikan Biologi*, 9(1), 63–74. <https://doi.org/10.32502/didaktikabiologi.v9i1.241>
- Lubis, L. H., Febriani, B., Fitra Yana, R., Azhar, A., & Darajat, M. (2023). The Use of Learning Media and its Effect on Improving the Quality of Student Learning Outcomes. *International Journal Of Education, Social Studies, And Management (IJESSM)*, 3(2), 7–14. <https://doi.org/10.52121/ijessm.v3i2.148>
- Maulida, M. & Rahmatan, H. (2025). Development of Augmented Reality-Based Flashcard Media on Ecosystem Material. *12(2)*, 168–177. <https://ejurnalunsam.id/index.php/jempa/article/view/13122>
- Maulida, N. A., Irianti, R., & Widiyastuti, D. A. (2025). Pengembangan media flashcard augmented reality keragaman tumbuhan paku terrestrial berbasis PBL untuk meningkatkan kemampuan berpikir kritis siswa SMA. *Biodik: Jurnal Ilmiah Pendidikan Biologi*, 11(4), 176–185. <https://doi.org/10.22437/biodik.v11i04.49639>
- Mukaromah, I. N., & Istianah, F. (2026). Pengembangan Media Flashcard Berbasis Augmented Reality (AR) untuk Meningkatkan Hasil Belajar Siswa Materi Sistem Tata Surya Sekolah Dasar Negeri 1 Jampes. *Jurnal Penelitian Pendidikan Guru Sekolah Dasar*, 14(4), 841–855. <https://ejournal.unesa.ac.id/index.php/jurnal-penelitian-pgsd/article/view/77677>
- Nabila, R. S., Irianti, R., & Utami, N. H. (2026). Pengembangan Media Flashcard Berbasis Augmented Reality Keragaman Jamur Makroskopis Divisi Ascomycota di Tahura Sultan Adam Mandiangin sebagai Penunjang Pembelajaran Biologi di SMA. *Biocaster: Jurnal Kajian Biologi*, 6(3), 1241–1254. <https://doi.org/10.36312/biocaster.v6i3.1326>
- Nurjanah, T. A., Sumiyati, Y., & Saripudin. (2023). Penggunaan Media *Flashcard* dalam Pembelajaran Bahasa Indonesia untuk Meningkatkan Pemahaman Siswa. *Literat - Jurnal Pendidikan Bahasa Dan Sastra Indonesia*, 2(1), 18–24. <https://ejournal.unsap.ac.id/index.php/literat/article/view/688>
- OECD. (2023). *PISA 2022 Results (Volume I)*. OECD Publishing. <https://doi.org/10.1787/53f23881-en>
- Prayogi, S., Verawati, N. N. S. P., Bilad, M. R., Samsuri, T., Hunaepi, Asy'ari, M., Yusup, M. Y., Azmi, I., & Ernita, N. (2025). Emphasizing reflective processes in scientific inquiry and its impact on preservice science teachers' critical thinking skills. *Social Sciences & Humanities Open*, 12, 101895. <https://doi.org/https://doi.org/10.1016/j.ssaho.2025.101895>
- Puspitarini, D. (2022). Blended Learning sebagai Model Pembelajaran Abad 21. *Ideguru: Jurnal Karya Ilmiah Guru*, 7(1), 1–6. <https://doi.org/10.51169/ideguru.v7i1.307>
- Putri, I. I., Rahmat, A., Riandi, R., & Riza, L. S. (2024). Utilizing Learning Media In Biology: A Step Towards Interactive Media Development. *Journal of Natural Science and Integration*, 7(2), 292–302. <https://doi.org/10.24014/jnsi.v7i2.29493>
- Rasyid, M. (2023). Pengaruh Media Pembelajaran E-Atlas dengan Motivasi Belajar Siswa SMA. *Jurnal Edukasi Biologi*, 9(2), 128–135. <https://doi.org/10.21831/edubio.v9i2.19277>
- Sarnia, S., Japa, L., & Artayasa, I. P. (2024). Pengaruh Media Pembelajaran Kartu Bergambar (Flash Card) Terhadap Hasil Belajar Biologi Siswa Kelas X IPA MA Dakwah Islamiyah

- Putri Kediri Lombok Barat. *Jurnal Pendidikan, Sains, Geologi, Dan Geofisika (GeoScienceEd Journal)*, 5(1), 86–90. <https://doi.org/10.29303/goescienceed.v5i1.296>
- Septiani, B. D. & Okmarisa, H. (2023). Pengembangan media pembelajaran menggunakan Construct 2 dengan pendekatan scaffolding pada materi laju reaksi. *Journal of Research and Education Chemistry*, 5(1), 12–23. [https://doi.org/10.25299/jrec.2023.vol5\(1\).12548](https://doi.org/10.25299/jrec.2023.vol5(1).12548)
- Siregar, D. A., Siregar, N., Nasution, S. R. W., & Nasution, H. N. (2025). Development of augmented reality-based flashcard learning media for teaching leaf types. *JPBIO (Jurnal Pendidikan Biologi)*, 10(2), 418–429. <https://doi.org/10.31932/jpbio.v10i2.5434>
- Skulmowski, A., & Xu, K.M. (2022). Understanding Cognitive Load in Digital and Online Learning: a New Perspective on Extraneous Cognitive Load. *Educ Psychol Rev*, 34, 171–196. <https://doi.org/10.1007/s10648-021-09624-7>
- Sugiyono. (2023). *Metode Penelitian Kuantitatif, Kualitatif, dan R&D*. Alfabeta.
- Tamboo, C. I., Mardin, H., Husain, I., Ibrahim, M., & Usman, N. F. (2024). Pengembangan media pembelajaran flashcard berbasis augmented reality pada materi sel di kelas XI SMA Negeri 1 Tibawa. *ORYZA: Jurnal Pendidikan Biologi*, 13(2), 240–253. <https://doi.org/10.33627/oz.v13i2.2750>
- Viora, D., Wahyuningsi, E., Surya, Y. F., & Marta, R. (2021). Penggunaan Media Pembelajaran dalam Pengajaran Bahasa Indonesia. *Jurnal Pendidikan Rokania*, 6(2), 262–272. <https://doi.org/10.37728/jpr.v6i2.432>
- Wicaksono, S. A., & Wiratama, R. (2024). Pemanfaatan Media Digital Interaktif dalam Pembelajaran Biologi untuk Meningkatkan Motivasi Siswa. *Jurnal Cakrawala Pendidikan dan Biologi*, 1(3). <https://doi.org/10.61132/jucapenbi.v1i3.183>
- Wulandari, M., Sukamto, D. S., & Putri, H. R. (2025). Penerapan Model Pembelajaran Role Playing pada Materi Sistem Ekskresi Menggunakan Media Gambar untuk Meningkatkan Hasil Belajar Siswa Kelas XI IPA MA At-Taqwa Suren. *Jurnal Ilmiah Profesi Pendidikan*, 10(3), 2483–2488. <https://doi.org/10.29303/jipp.v10i3.3510>