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Development of Augmented Reality-Based Digital Learning Media on Plant and Animal Cell Topics to Enhance the Analytical Skills of Eighth Grade Junior High School Students

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Article Information:
Received August 18, 2025
Revised October 17, 2025
Accepted November 13, 2025

Keywords:
Analytical Skills; Augmented Reality; Digital Learning Media, Science Education

Abstract

Background: Technological advances inside the industrial revolution 4.0 era have encouraged the educational world to offer interactive and contextual learning, mainly in growing better-order wondering abilities inclusive of analysis. The topic of plant and animal cells in science lessons is abstract and often difficult for students to grasp when taught conventionally.
Aims: The aim of this study was to develop using plant and animal cell material to enhance the analytical skills of eighth-grade junior high school students.
Methods: The stages of media development encompass analysis, design, development, implementation, and assessment. The media was created using Unity and Vuforia software with marker-based tracking techniques and validated by media and subject matter experts.
Results: Validation by material specialists and media specialists confirmed validity levels of 96.59% and 96.25%, respectively. Readability (98.12%) and practicality (95%) tests also showed excellent scores.
Conclusion: With these results from this study, it could be concluded that the AR-based learning media developed is appropriate for use in science learning because it can present abstract material more interactively and efficaciously in schooling students' analytical talents.

A. Introduction

The fast rapid improvement of facts and communication technology has forced educators to continue innovating, especially in creating learning that aligns with the needs of the 21st century. Analytical competencies are essential high-level reasoning skills for students (Daryanes et al., 2023). In science education, this skill is particularly vital because students frequently encounter complicated and abstract principles, such as those related to the structure and function of plant and animal cells (Johann et al., 2020). Anderson and Karthwohl state that analytical skills include the skills of differentiating, organizing, and connecting, all of which support students in understanding the relationships between parts within a system as a whole (Laksono & Ad'hiya, 2018).

Meaningful science learning should be student-centered, allowing students to actively construct knowledge through observation, exploration, and analysis (Laid & Adlaon, 2025). A student-centered learning approach is believed to enhance the exceptional of studying as it allows students to construct their information (Maulidya et al., 2021). However, the results of previous study show that many students find it difficult to understand abstract material, such as cell structure, due to the limitations of the learning media

How to Cite : Hidayatulloh, M. R., Mulyati, Y., & Yuanvanelli, Y. D. (2025). Development of Augmented Reality-Based Digital Learning Media on Plant and Animal Cell Topics to Enhance the Analytical Skills of Eighth Grade Junior High School Students. *FINGER: Jurnal Ilmiah Teknologi Pendidikan*, *4*(3), 173–185. https://doi.org/10.58723/finger.v4i3.500
ISSN : 2830-6813
Published by : CV Media Inti Teknologi

used. This situation impacts students' analytical abilities regarding concepts that should be related to everyday life (Setiyani et al., 2020).

One potential solution to this problem is using Augmented Reality (AR) technology in learning (Candido & Cattaneo, 2025). AR technology combines virtual elements with the real world in an interactive way, allowing students to interact directly with digital objects in a realistic context (Zapata et al., 2024;Garzón, 2021). Additionally, smartphones, which are widely used by students today, offer significant opportunities to implement learning technologies like AR in a more practical and accessible manner (Sukma et al., 2023). This allows students to improve their understanding and memory of the material being studied (Latif et al., 2023; Marti et al., 2020).

Several studys have demonstrated the possitive effect of AR on scholar motivation and understanding in science education (Erbas & Demirer, 2019). AR enables the presentation of key concepts in a visual and multidimensional manner, making complex information easier to understand and remember (Baba et al., 2022; Wu et al., 2023). However, research specifically focused on developing and evaluating the effectiveness of AR in science education at the junior high school level, particularly on the topics of plant and animal cells, remains limited (Xu et al., 2022). However, this material has a high level of abstraction and is difficult to understand when presented solely through conventional methods (Laswi & Bungawati, 2024). Unlike previous AR studies, this study emphasizes the development of analytical capabilities as a part of better-order thinking skills (HOTS) through the design of interactive 3D capabilities and multi-level analytical quizzes. The learning media developed is especially intended for junior high school students, using the ADDIE development model tailored to the cognitive characteristics of middle school students.

The results of the student needs survey showed that 81.92% of students really needed AR-based learning media, and 91.67% of them stated that they agreed with the importance of developing such media, especially on the material on cell structure and function (Masri et al., 2023). Conventional learning is often unable to meet students needs in developing analytical thinking skills optimally, even though this skill is very important for understanding information systematically and in depth (Wu et al., 2023; Kwangmuang et al., 2024).

The use of engaging and interactive learning media can increase students' interest in studying and facilitate the procedure of expertise the material (Kartini et al., 2020; Koç & Kanadlı, 2025). Educational media serve as a tool for teachers to bring information, aiming to seize students' interest and lead them to more interested in the material being studied (Faqih, 2020). Therefore, there is a need to develop a digital educational media based on AR, specifically designed for plant and animal cell material. This media not only clarifies abstract concepts but also has the potential to actively and meaningfully train and enhance students' analytical skills.

Based on the above description, this study aims to develop AR–based digital learning media for plant and animal cell material to enhance the analytical skills of eighth-grade junior high school students. This observe is predicted to make a contribution to improving the quality of science learning through innovative media appropriate to the material's characteristics and the needs of students in the digital age.

B. Research Methods

This study used the ADDIE (Analysis, Design, Development, Implementation, Evaluation) development model to produce AR-based learning media as shown in figure 1. This model was chosen because of its systematic structure and the allowing evaluation at each stage to improve the validity and effectiveness of the resulting product (Safitri et al., 2022).

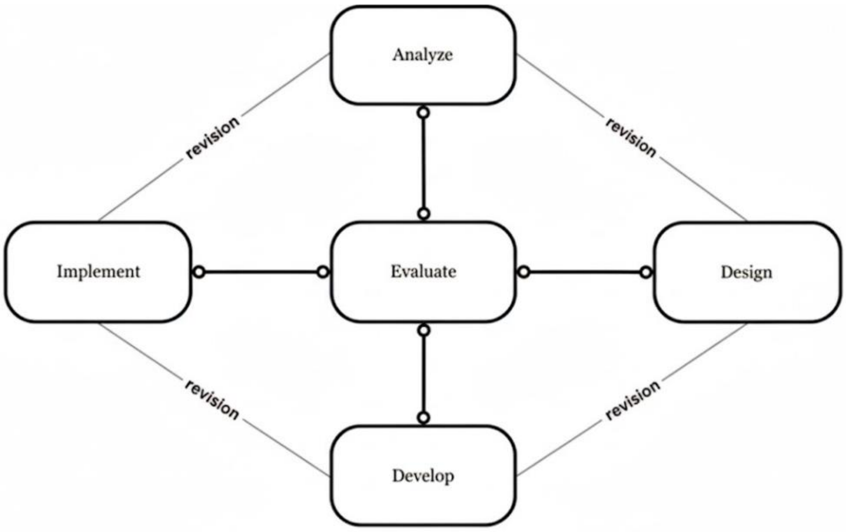

Figure 1. ADDIE Development Model

In the analysis phase, a literature review and observations of eighth-grade science lessons were conducted to identify media needs that could enhance students' understanding and analytical skills. Following the analysis phase, the design phase encompassed content organization, navigation flow design, and the integration of AR elements into an intuitive and user-friendly interface, adhering to Branch's (2009) learning design principles.

In the development phase, Unity and Vuforia were used with marker-based tracking techniques. The media prototype was validated by subject matter and media professionals to evaluate the appropriateness of the content material, presentation, and technical factors, then revised based on the experts' feedback.

Next, the implementation phase involved readability and practicality tests conducted by four junior excessive school technology instructors to make certain ease of use and know-how. in the end, the assessment phase involved formative and summative methods to assess the effectiveness and efficiency of the media as a foundation for improving and enhancing the fine of the studying media. Therefore, data analysis was conducted using descriptive quantitative methods to assess the validity, readability, and practicality of the advanced media. This approach aligns with the objectives of the initial phase of the Research and Development (R&D) process within the early degrees, namely to ensure the feasibility of learning media before being tested extensively in the field.

Inferential statistical tests, such as t-tests or ANOVA, have not been applied because this study does not involve group comparisons or measurements of changes in student studying outcomes earlier than and after treatment. The use of inferential statistics is only relevant at the field trial stage in further research, when the media is implemented directly to measure a significant improvement in students' analytical skills. Thus, descriptive analysis is considered most appropriate to describe the feasibility of the media at this stage of development.

This study used questionnaires as instruments to obtain quantitative data. The data were then analyzed descriptively and quantitatively to measure the validity and practicality of the developed learning media. The studies units used included interview sheets for teachers as supporting data, validation sheets with the aid of professionals, media professional validation, and practicality test sheets filled out by junior high school science instructors. teachers were selected as initial respondents because they act as primary evaluators before classroom implementation

Furthermore, the facts analysis method, within the form of responses and opinions provided by media expert validators and material experts, was analyzed using Excel as a tool to calculate the consequences of the facts analysis. Meanwhile, quantitative data were obtained from the assessment results in numerical form.

Table 1. Likert Scale Scoring

Score	Category
4	Strongly agree
3	Agree
2	Disagree
1	Strongly disagree

Assessment of the validity and practicality of learning media uses a Likert scale, where validators check the provided categories, namely (4) strongly agree, (3) agree, (2) disagree, and (1) strongly disagree. To calculate of media validity, the following formula is used:

$$P = \frac{f}{N} \times 100\% \quad (1)$$

Explanation:
f : Score obtained
N : Maximum score
P : Percentage score

The resulting percentage is interpreted using the criteria listed media in Table 2.

Table 2. Criteria for the Validity and Practicality of Learning Media

Percentage	Criteria
80% - 100	Highly Valid/Practical
60% - 80	Valid/Practical
40% - 60	Fairly Valid/Practical
20% - 40	Not Valid/Practical
0% - 20	Very Invalid/Impractical

C. Results and Discussion

1. Results

ARCell Explorer is an AR-based application that was developed in this study and evaluated for its feasibility. It is designed to improve students' analytical skills in plant and animal cells, particularly those in Grade VIII. The development of this application followed the stages of the development model applied in this study.

1.1 Analysis Stage

The initial needs analysis included interviews with teachers at one of the public junior high schools in Malang and a literature review. The results of interviews with four science teachers showed that science education at the school had implemented the independent curriculum, but learning still faced challenges, especially in improving students' analytical skills. Some students showed low engagement, were unresponsive, and had difficulty understanding abstract concepts. Additionally, the material on animal and plant cells is considered highly abstract, making it difficult for students to visualize and comprehend. Therefore, this digital learning medium based on AR was developed to address these challenges through an interactive and practical approach. The needs analysis results were used as a reference for formulating alternative solutions and recommending the content of the instructional materials to be developed, so that they could benefit both teachers and students (Septiani & Wardhani, 2022). The results of the analysis stage influenced the design stage that was to be implemented.

1.2 Design Stage

Research at this stage involved the initial design of ARCell Explorer, which consists of various main components. At this stage, a framework or content flow for the media is developed, covering the opening section, presentation of material, integration of AR and 3D technology, development of practice questions, and evaluation. Additionally, an attractive and functional user interface (UI) is designed to ensure the media is easy to use and capable of capturing students' attention. This UI design considers layout, color, icons, and navigation to support the effectiveness of learning.

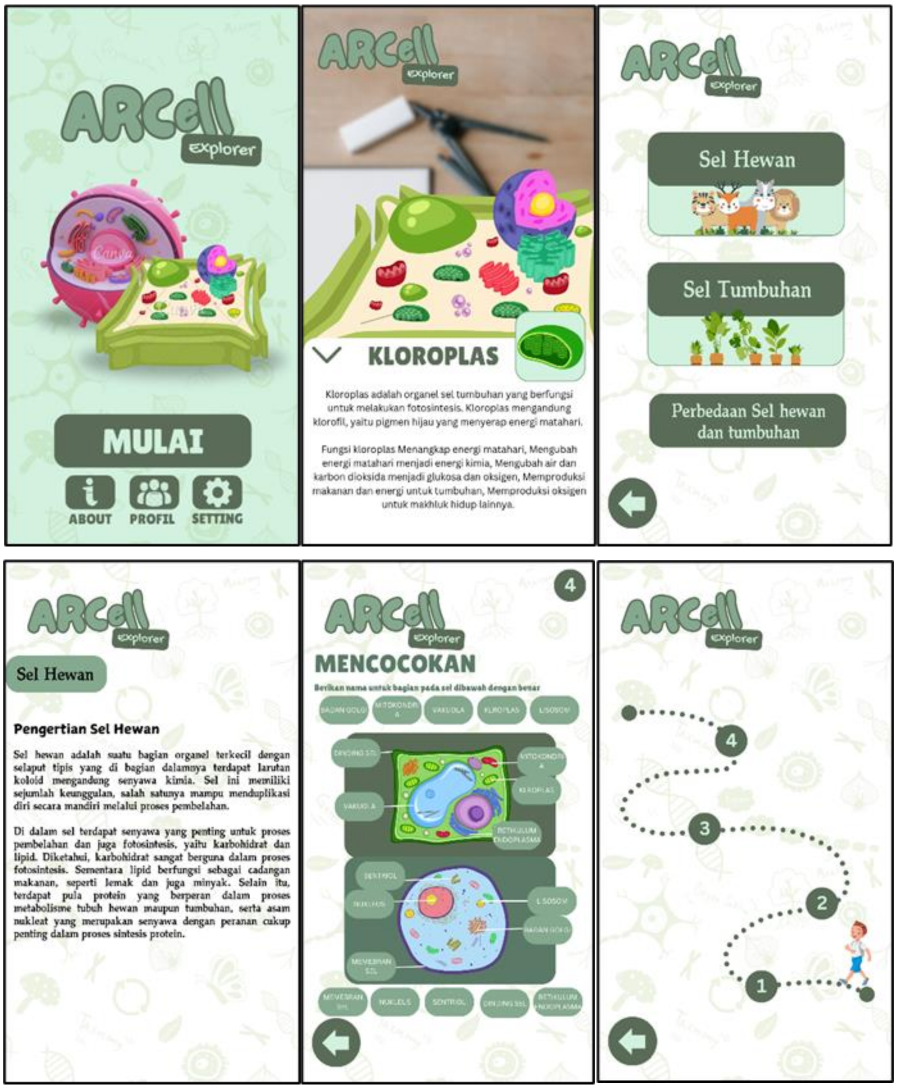

Figure 2. Initial Design of the ARCell Explorer Interface

Figure 2 shows the UI design developed for this learning media, including the home screen, instructions for use, material pages for further learning, 3D models based on AR, and several quizzes to assess students' abilities.

1.3 Development Stage

According to Made et al. (2021), the development stage focuses on producing learning materials based on the design structure. At this stage, researchers transform the initial design into a tangible learning media product in the form of an application, namely an application that is ready to be used by students (Rofifah et al., 2021). The improvement section is the core phase of the instructional design process in the ADDIE model. All design plans from the design phase begin to be realized into learning media products that can be used in this phase (Spatioti et al., 2022). Branch (2009) emphasizes that development must consider content suitability, visual design, technical functionality, and user readiness (Shakeel et al., 2023). Resources are collected in the early stages of media development, including learning materials, development software, and supporting hardware. In the technical aspect, the main software used is Unity and Vuforia, while Blender and Tinkercad are used for creating three-dimensional 3D objects. The development process of the media interface in Unity is shown in Figure 3. The 3D models developed include animal and plant cells designed proportionally and realistically so that students can visually understand the shape and function of each organelle. Vuforia is used to create markers and is included in Unity as a detector for markers that have been created.

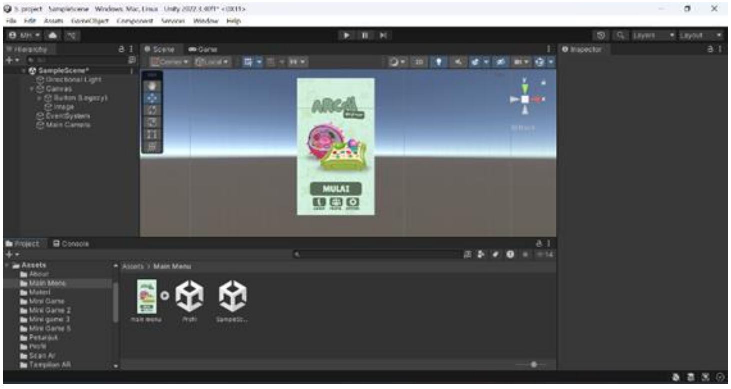

Figure 3. ARCell Explorer Interface Development in Unity Software

Each 3D model is then linked to a two-dimensional image (marker) printed as a trigger for the AR display. Once the model and marker have been created, the user interface (UI) is developed in Unity with an interactive and user-friendly design, as shown in Figure 4.

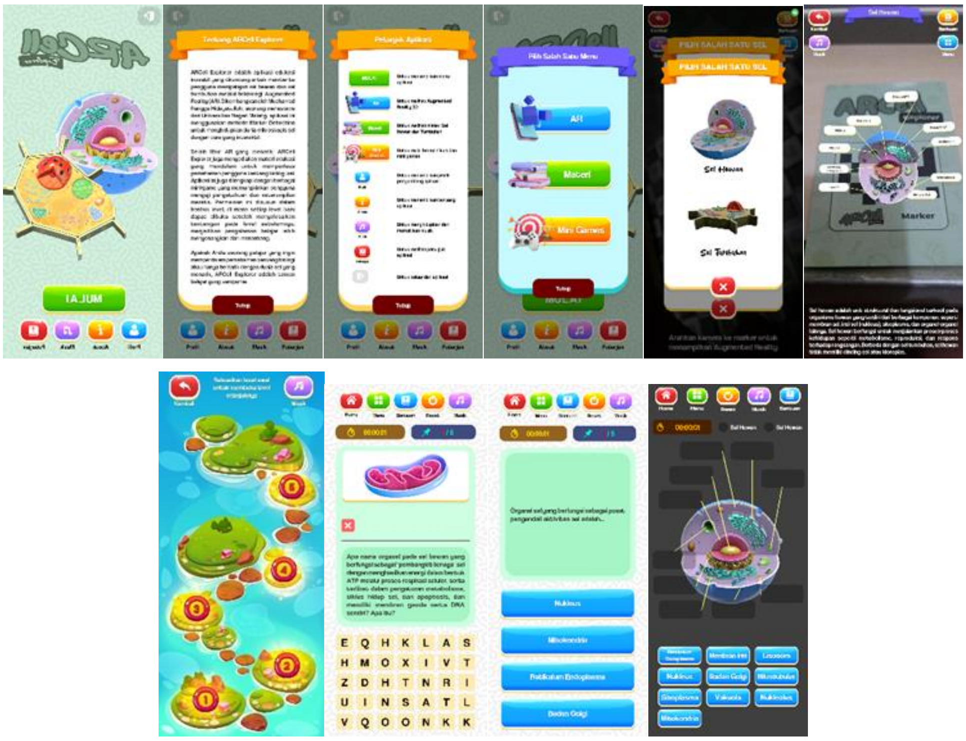

Figure 4. ARCell Explorer Interface View

The UI is designed to include a material menu, AR simulation, practice questions, evaluation, and usage instructions. Next, the marker and 3D object are integrated into Unity using the Vuforia plugin. The predefined markers are linked to 3D models, so when the device's camera scans the marker, the 3D object appears automatically with interactive features, such as rotation, zoom, and label addition. Supporting components for this educational media include a website, as shown in Figure 5, which aims to make the application easily and practically accessible via the web and is also integrated with the marker cards provided.

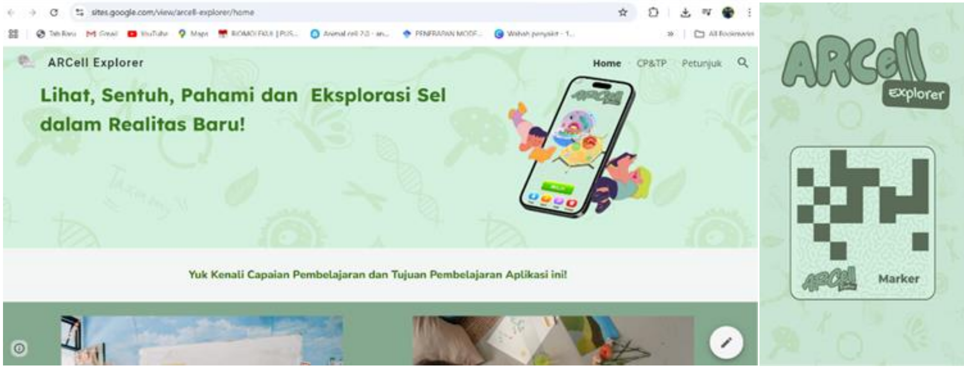

Figure 5. ARCell Explorer Web View and Marker Cards

This process is carried out interactively to ensure that all media elements function properly, are stable, and appeal to users. This approach results in learning media that not only present material in an informative manner but also provide an interactive learning experience through AR technology.

After the learning media is completed, it is validated by subject matter experts and media experts to determine the media's suitability and obtain suggestions for improvement. This aims to improve the quality of the learning media with the results of validation by media experts in Table 3.

Table 3. Media Expert Validation Results

No	Validator	*f* (Score)	*N* (Max Score)	P (Percentage)	Description
1	Lecturer	43	44	97.73%	Highly Valid
2	Lecturer	37	44	84.09%	
3	Science Teacher	43	44	97.73%	
4	Science Teacher	44	44	100.00%	
5	Science Teacher	44	44	100.00%	
6	Science Teacher	44	44	100.00%	
Overall Average		**42.5**	**44**	**96.59%**	**Highly Valid**

The validation results based on six media experts' assessment of the ARCell Explorer learning media developed yielded an average score of 96.59%. According to the criteria outlined by Sa'adah (2022), this score falls into the "Highly Valid" category. These results indicate that the media meets the criteria for suitability, particularly in terms of visual appeal, ease of use, interactivity, and consistency in interface design. The experts also commended the simple yet engaging interface design, which effectively utilizes colors, icons, and layout elements aligned with the characteristics of junior high school students.

In addition, this media has advantages in terms of interactivity, especially through the AR feature that allows users to display three-dimensional models of cell organelles in real time using the device's camera. This is supported by the fact that visualization with the help of AR can increase student participation and interest in abstract science material (Firmansyah & Azhar., 2024).

Beyond the media's suitability, the content or material packaged within the educational media has also been validated by six subject matter experts, lecturers, and science teachers. The subject matter expert validation results in Table 3 show that ARCell Explorer received an average score of 96.25%, which falls into the "Highly Feasible" category. These results demonstrate that the content presented in the educational media meets the criteria of scientific accuracy, material completeness, and alignment with the learning outcomes specified in the eighth-grade junior high school curriculum.

Table 4. Results of Expert Validation of Materials

No	Validator	*f* (Score)	*N* (Max Score)	P (Percentage)	Description
1	Lecturer	40	40	100.00%	Highly Valid
2	Lecturer	34	40	100.00%	
3	Science Teacher	37	40	85.00%	
4	Science Teacher	40	40	92.50%	
5	Science Teacher	40	40	100.00%	

No	Validator	*f* (Score)	*N* (Max Score)	P (Percentage)	Description
6	Science Teacher	40	40	100.00%	
Overall Average		**38.5**	**40**	**96.25%**	**Highly Valid**

The material's presentation was assessed as appropriate for junior high school students, characterized through the usage of communicative language and 3D visualizations that helped clarify abstract concepts. The material was structured and logical, beginning with an introduction to cells because the primary units of lifestyles, the differences between plant and animal cells, and an explanation of organelles and their functions. This finding aligns with research results. those findings are in keeping with previous research results. This indicates that AR-based media is able to develop high-level thinking skills (HOTS), including analytical skills, through visual presentation and immersive learning experiences (Anapia et al. 2024).

1.4 Implementation Stage

The implementation stage is part of the development process. Its aim is to assess the quantity to which the developed learning media can be understood (in terms of readability) and utilized (in terms of practicality) by users, namely science teachers. This testing is carried out after media and subject matter experts have validated the media.

A. Learning Media Readability Test

Readability tests were conducted to determine the extent to which the content of the learning media could be understood by teachers as initial users before being implemented for students. A 4-point Likert scale was used in the questionnaire covering several aspects, including language clarity, presentation structure, and visual comprehensibility. This test was administered to four science teachers at the junior high school level, with the readability test results presented in Table 3.

The readability test results in Table 5 indicate that the learning media achieved an average percentage of 98.12%, which falls into the "Very Good" category. This achievement indicates that the developed media has a fairly high level of readability and is easily understood by teachers and students. The main factors supporting this readability are communicative language, the systematic presentation of material, easy-to-read text, and appropriate images for junior high school students.

Table 5. Readability Test Results

No	Validator	*f* (Score)	*N* (Max Score)	P (Percentage)	Description
1	Science Teacher 1	38	40	95.00%	Highly Valid
2	Science Teacher 2	40	40	100.00%	
3	Science Teacher 3	40	40	100.00%	
4	Science Teacher 4	39	40	97.50%	
Overall Average		**39.25**	**40**	**98.12%**	**Highly Valid**

B. Practicality Test of Learning Media

The results of this test were used to determine whether ARCell Explorer could be an effective and efficient medium for use. The instruments used in this test included ease of use, clarity of instructions, integration into learning, and time of use. Science teachers filled out the practicality questionnaire after trying the medium directly, with the results presented in Table 6.

Table 6. Practicality Test Results

No	Validator	*f* (Score)	*N* (Max Score)	P (Percentage)	Description
1	Science Teacher 1	35	40	87.50%	Highly Valid
2	Science Teacher 2	40	40	100.00%	
3	Science Teacher 3	39	40	97.50%	
4	Science Teacher 4	38	40	95.00%	
Overall Average		**38.00**	**40**	**95.00%**	**Highly Valid**

Based on the practicality test results in Table 6, the learning medium achieved an average score of 95%, categorized as "Very Practical." Teachers assessed that this media is easy to operate without special training and is equipped with clear usage instructions. Additionally, this media can be utilized in the learning process both in groups and individually, supporting the achievement of learning objectives and goals. Furthermore, the media is also efficient because it is easy to use anywhere and can be used for self-learning by students.

1.5 Evaluation Stage

The evaluation stage can be considered the final step in the development process of a learning medium. Its aim is to assess the product's suitability in terms of content, media quality, readability, and practicality of use in learning activities, as presented in Table 7. The evaluation process was carried out through validation by experts and input from science teachers as the medium's initial users.

Table 7. Summary of Results

No	Assessment Component	Percentage	Description
1	Subject Matter Expert Validation	96.59%	Highly Valid
2	Media Expert Validation	96.25%	Highly Valid
3	Readability Test	98.12%	Excellent
4	Practicality Test	95.00%	Highly Practical

Based on the validation results from subject matter experts and media experts, and the readability and practicality test results by validators and science teachers, this AR-based learning media has met the feasibility standards regarding content, visual design, ease of use, and comprehension. Based on this, ARCell Explorer is a suitable tool in science education to enhance students' analytical skills on plant and animal cell topics in 8th-grade junior high school.

The evaluation was conducted in line with the development of this AR media, and comments and suggestions were collected to make this media better and more useful in its application. The materials and questions in the learning media are frequently updated to meet the objectives and needs of students in relation to their analytical skills. The validation results show that the material is structured in a logical and accurate manner and is appropriate for the students' level of understanding. The questions provided can train students' analytical skills in learning, especially in the material on animal and plant cells. This is also supported by attractive and user-friendly visuals and design, as evidenced by the high results of the readability and practicality tests.

However, improvements are still needed in several areas for future refinement. Some teachers and users suggest that this media be equipped with an automatic evaluation feature or direct feedback after students complete the questions, to make the learning process more interactive. Additionally, there are still some technical challenges with the camera, sometimes making it difficult to focus. Although AR is relatively straightforward, improvements are needed to enhance the application's stability on certain devices to optimize the user experience.

2. Discussion

The outcomes of the study show that the developed ARCell Explorer has a very high level of validity from subject matter experts (96.25%) and media experts (96.59%), as well as obtaining a readability score of 98.12% and practicality of 95%. Those outcomes suggest that the AR-based digital learning media produced has met the eligibility criteria in terms of content, design, and simplicity of use. In general, these findings confirm the results of previous studies (Anapia et al., 2024; Erbas & Demirer, 2019; Firmansyah & Azhar, 2024), which also found that using AR can increase students' motivation and knowledge of abstract scientific ideas. however, this study provides an additional contribution by showing that AR now not most effective improves conceptual understanding however additionally performs a significant function in training students analytical skills on the junior high school level through visual and interactive exploration activities.

Unlike the studies by Marti et al. (2020), which highlight the effects of AR on increasing learning interest and memory retention, this study emphasizes the aspect of analytical skills—a higher-order thinking skill (HOTS) that is rarely studied in depth in the context of AR. In this case, the ARCell Explorer medium allows students to identify, differentiate, and organize the structure and function of cell organelles through realistic three-dimensional visualization. Students' active involvement in observing and manipulating virtual cell objects supports the principle *of experiential learning* as expressed by Mansour et al. (2025),where experience-based learning can strengthen analytical and problem-solving skills.

In addition, the results of this study also show consistency with the findings of Xu et al. (2022), which state that the effectiveness of AR in science learning depends on the active involvement of users and the quality of content integration in the learning context. In this study, the multi-level quiz feature in ARCell Explorer serves as a form of formative assessment that encourages students to conduct in-depth analysis of cell organelle functions in real-life contexts. Thus, the results of this study not only confirm the effectiveness of AR as found in previous literature but also expand upon it by demonstrating the role of AR in developing systematic analytical thinking processes in junior high school students.

However, in its application in the classroom environment, there are still a number of challenges that need to be taken into account. First, the availability of devices that support AR technology is not yet evenly distributed in every school. Some students may have limited access to smartphones with camera specifications that are adequate to run the application optimally. Second, teacher readiness is a crucial factor. Teachers need to have sufficient digital literacy to operate and integrate ARCell Explorer into learning activities. As stated by Laid & Adlaon (2025),the effectiveness of technology-based learning is highly dependent on the readiness of educators to manage and facilitate the digital-based learning process. Third, students' level of digital literacy also affects the effectiveness of the media. Although the current generation is generally familiar with technology, the use of AR for educational purposes requires guidance so that students can make the most of the media for scientific analysis, not just visual exploration.

These challenges show that the success of AR media implementation is not only determined by the quality of the learning media, but also by the readiness of the educational ecosystem that supports it. Therefore, teacher training, improvement of school technology infrastructure, and digital literacy assistance for students need to be the focus of further policy and research. With these steps, media such as ARCell Explorer can be implemented more widely and effectively to improve students' analytical skills in science learning.

2.1 Implications

The findings of this observe show that AR-primarily based digital studying media have a very high level of validity, practicality, and readability, making them appropriate and powerful to be used in science studying, especially at the topics of plant and animal cells. These results reinforce the argument in the research background that many students find it difficult to understand abstract concepts such as cell structure due to the limitations of available learning media. Therefore, the improvement of AR-based media not only serves as an opportunity to enhance students visual understanding and memory but also directly addresses the needs of 21st-century studying, which emphasizes active participation and the improvement of better-order thinking skills (HOTS), including analytical abilities.

2.2 Research Contribution

This research has made a significant contribution to the development of innovative learning media by utilizing AR technology that is easily accessible via smartphones. The main contribution lies in the development of educational media that is capable of presenting abstract material in a three-dimensional and interactive manner, thereby making it easier for students to understand and analyze the concepts of cell structure and function. Additionally, this research enriches the literature on AR implementation in science education at the junior high school level, particularly through the systematic and practical application of the ADDIE development model.

2.3 Limitations

Although the study's results show success in developing AR media, this study still has several limitations. First, the implementation test was only conducted on a limited basis with teachers as the initial users, so it does not fully describe the direct impact through quantitative student performance data on improving students' analytical skills quantitatively. Second, the media developed only covers plant and animal cell material, so it does not cover other science subjects requiring interactive visual media. Additionally, the accessibility of the media still depends on specific devices that support AR and an internet connection to access the integrated web platform.

2.4 Suggestions

Given the existing limitations, it is recommended that further research be conducted on direct media trials with students in real learning situations to directly measure the impact on analytical skills in more tangible ways. Additionally, future development could expand the scope to include other science subjects that also require abstract visualization and enhance media compatibility across various devices. Developing interactive features like real-time quiz feedback and integration with a Learning Management System (LMS) could also be the next innovation to support a more personalized and adaptive learning process.

D. Conclusion

Augmented Reality (AR) on plant and animal cell material to improve the analytical abilities of eighth-grade junior high school students. The development was carried out using the ADDIE model, which includes the stages of analysis, design, development, Implementation, and evaluation. The validation results by experts stated that this learning media may be very appropriate to be used. Subject matter expert validation achieved a mean score of 96.25%, and media expert validation scored 96.59%, falling into the "notably legitimate" category. readability tests conducted with teachers yielded a mean score of 98.12%, indicating that the media is especially understandable. Additionally, the practicality test scored 95.00%, indicating that the media is surprisingly sensible for learning.

The developed media is capable of transforming abstract concepts into engaging and easy-to-understand three-dimensional visual learning experiences. This contributes significantly to improving students' analytical skills, as they can observe, differentiate, and connect the functions of cell organelles more clearly. Furthermore, this study shows that the integration of AR technology in science education can be a strategic innovation to strengthen higher-order thinking skills in junior high school. However, improvements to features such as automatic evaluation and technical stability are still needed to ensure that the media provides an optimal learning experience.

Overall, this development proves that AR-based media has the potential to be an effective solution in providing science learning that is more meaningful, interactive, and relevant to the demands of 21st-century education.

E. Acknowledgment

This research was funded through a research grant provided by Universitas Negeri Malang under Contract No. 24.2.761/UN32.14.1/LT/2025, based on the Rector's Decree No. 21.2.51/UN32/KP/2025 dated February 21, 2025. We would also like to express our gratitude to Mrs. Sita Yuliawati, a science teacher at SMP Negeri 20 Malang, for the opportunity, assistance, and cooperation during the field research

F. Author Contribution Statement

YM served as the main supervisor who provided conceptual guidance in the implementation of the research. MRH was responsible for developing ARCell Explorer, its contents, and conducting the research, as well as collecting and analyzing field data. YDY contributed to the preparation and refinement of the manuscript. Meanwhile, SY supported the implementation of the research at the school and provided input regarding the implementation of the learning media in a real environment.

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