Dawuh Guru
Jurnal Pendidikan MI/SD

e-ISSN: 2775-5789, ISSN: 2962-746X
Vol. 6 No. 2 Agustus Tahun 2026
DOI: https://doi.org/10.35878/guru.v6i2.2371

Development of "DELBARA" Teaching Materials to Improve Students' Critical Thinking Skills in Elementary Schools

Satrio Mustiko Wijayanto[1], Yuni Ratnasari[2], Khamdun[3]
[1 2 3]Universitas Muria Kudus,
[1]satriomustiko@gmail.com,
[2]yuni.ratnasari@umk.ac.id,[3]khamdun@umk.ac.id

OPEN ACCESS

Dikirim : 11 Juli 2026
Diterima : 23 Juli 2026
Terbit : 31 Agustus 2026
Koresponden:
satriomustiko@gmail.com
Cara sitasi: Wijayanto,S.M., Ratnasari, Y., Khamdun. (2026). Development of "DELBARA" Teaching Materials to Improve Students' Critical Thinking Skills in Elementary Schools. *Dawuh Guru: Jurnal Pendidikan MI/SD, 6(2). 219- 234.* https://doi.org/10.35878/guru.v6i2.2371

Abstract

The low critical-thinking ability of elementary school students and the limitations of teaching materials in visualizing the concept of photosynthesis pose challenges to learning science. This study aims to analyze the development needs, determine the feasibility, and test the effectiveness of DELBARA (Deep Learning Based on Augmented Reality) teaching materials on photosynthetic materials to improve the critical thinking skills of Grade IV elementary school students in Jepara Regency. The research uses the Research and Development (R&D) method with the ADDIE model, which includes the Analysis, Design, Development, Implementation, and Evaluation stages. Data were collected through observation, interviews, questionnaires, tests, and documentation, then analyzed descriptively and using the Normalized Gain (N-Gain) test. The results of the study show that teachers need interactive, innovative teaching materials that can visualize abstract concepts. DELBARA's teaching materials are deemed feasible following validation by material and media experts, who assessed the content, presentation, language, graphics, and Augmented Reality integration. The product implementation showed an increase in critical thinking skills, with a pretest average of 71.22 rising to 86.00 on the posttest and an N-Gain of 0.513, placing it in the medium category.

Keywords : DELBARA teaching materials, critical thinking, elementary schools

A. Introduction

The advancement of science and technology has brought significant changes in education, especially in the development of learning resources and strategies(Mursid et al., 2023,Arzeman et al., 2026). 21st-century learning is no longer oriented solely toward the mastery of knowledge but also toward the development of higher-order thinking skills, including critical thinking(Mursid et al., 2023). The ability to think critically is an important competency because it enables students to analyze

information, evaluate alternative problem-solving approaches, formulate evidence-based arguments, and make logical decisions. Therefore, learning in elementary schools needs to be designed to encourage students to actively build knowledge through meaningful activities.

In this research, the term Deep Learning in DELBARA refers to the deep learning approach promoted by the Ministry of Education, Culture, Research, and Technology (Kemendikbud), rather than deep learning as a computational or artificial intelligence technique. The approach was operationalized through learning activities designed to encourage students to learn meaningfully, mindfully, and joyfully, while actively constructing an understanding of the photosynthesis process and applying it to real-life contexts. However, various studies show that students' critical thinking skills in Indonesia still need improvement. The results of the for International Student Assessment (PISA) 2022 show that InProgrammedonesian students' science literacy remains below the average among OECD member countries. This condition indicates that most students still have difficulty in applying scientific concepts to analyze phenomena, solve problems, and make decisions based on scientific evidence. These findings show the need for learning innovations that not only focus on mastering concepts but also on developing critical thinking skills from the elementary school level.

These problems are also found in the learning of the Natural and Social Sciences (Baihaqi et al., 2025), especially in the study of photosynthetic materials. Photosynthesis is one of the topics that has abstract characteristics because the process occurring cannot be directly observed by students. As a result, students often have difficulty understanding the relationship among sunlight, water, carbon dioxide, chlorophyll, glucose, and oxygen in biological processes. Learning that is still dominated by textbooks, verbal explanations, and two-dimensional images leads students to memorize concepts rather than understand the underlying mechanisms. This condition has an impact on students' low ability to interpret information, analyze relationships between concepts, evaluate phenomena, and draw logical conclusions(Manasikana et al., 2025).

The results of the needs analysis, carried out through learning observations, interviews with Grade IV teachers, and the dissemination of needs analysis questionnaires, show that teachers need more innovative, interactive teaching materials that align with the characteristics of elementary school students. The teacher stated that the teaching materials used so far have not been able to visualize the concept of photosynthesis concretely and have not provided learning activities that specifically train critical thinking skills. On the other hand, students show interest in learning that uses digital technology because it is considered more engaging, easier to understand, and more likely to increase motivation to learn. The findings show a gap between learning needs and available teaching materials, necessitating the development of materials that address these needs.

One alternative is to develop teaching materials that integrate Deep Learning approaches with Augmented Reality (AR) technology. The Deep Learning approach emphasizes the learning process that encourages students to build a deep conceptual understanding through observing, exploring, analyzing, discussing, problem-solving, and reflecting(Wei, 2023,Song et al., 2022). Meanwhile, Augmented Reality technology can combine three-dimensional virtual objects with real environments, allowing abstract concepts to be visualized more concretely and interactively. The integration of these two approaches is expected to create a more meaningful learning experience and support the development of students' critical thinking skills.

Several previous studies have reported that the use of Augmented Reality can improve students' motivation to learn, conceptual understanding, and learning outcomes. Similarly, research on the application of the Deep Learning approach shows that learning oriented towards exploration, reflection, and problem-solving can increase student involvement in the learning process. However, most of these studies still examine the two approaches separately. Research integrating Deep Learning and Augmented Reality into science learning materials, especially for photosynthesis in elementary schools, with a focus on improving critical thinking skills, remains relatively limited. In addition, research that begins with a comprehensive needs analysis, proceeds to product development using the ADDIE model, and tests its feasibility and effectiveness in the context of learning in elementary schools has also not been widely conducted.

Based on these conditions, this study developed DELBARA (Deep Learning Based on Augmented Reality) teaching materials as a learning innovation for photosynthesis. The product is designed to integrate Deep Learning-based activities with three-dimensional object visualization via Augmented Reality, enabling learners to have a more active, contextual, and meaningful learning experience. The development of teaching materials is carried out using the ADDIE model, which includes the stages of Analysis, Design, Development, Implementation, and Evaluation. This study aims to: (1) analyze the need for the development of DELBARA teaching materials on photosynthesis materials to improve the critical thinking skills of grade IV elementary school students; (2) to determine the level of feasibility of DELBARA teaching materials based on the assessment of material experts and media experts; and (3) to know the effectiveness of DELBARA's teaching materials in improving the critical thinking skills of grade IV elementary school students in Jepara Regency.

The novelty of this research lies in the development of DELBARA teaching materials that integrate the Deep Learning approach with Augmented Reality technology into a single learning product specifically designed for elementary school photosynthesis materials. Unlike previous research, which generally either develops Augmented Reality-based media or applies Deep Learning approaches separately, this study combines both approaches into teaching materials that include meaningful

learning activities, three-dimensional visualization, critical-thinking exercises, and learning reflection. In addition, this research not only produces learning products but also provides empirical evidence regarding user needs, product feasibility based on expert validation, and the effectiveness of teaching materials through improving critical thinking skills.

B. Methods

This research employed a Research and Development (R&D) approach using the ADDIE development model, consisting of Analysis, Design, Development, Implementation, and Evaluation. The research was conducted during the even semester of the 2025/2026 Academic Year at Watuaji State Elementary School 1, Jepara Regency. The product developed was DELBARA (Deep Learning Based on Augmented Reality) teaching materials on photosynthesis for Grade IV students.

1. Preliminary Study and Analysis

Before product development, a preliminary study was conducted through classroom observation, interviews with the Grade IV teacher, and a teacher needs-analysis questionnaire. The study examined the learning process, existing teaching materials, student participation, difficulties in learning photosynthesis, and the need for interactive and technology-based materials. The findings showed that existing materials were mainly text-based with two-dimensional images and provided limited activities to develop students' critical-thinking skills. The analysis also considered Grade IV students' characteristics, learning objectives, and Independent Curriculum requirements. These findings guided the selection of content, learning activities, visualizations, and Augmented Reality features incorporated into DELBARA.

2. Design

At the Design stage, the researcher translated the needs identified during the preliminary study into the initial design of the DELBARA teaching materials. The researcher organized the photosynthesis content according to the learning objectives and determined the sequence of learning activities. The teaching materials were designed to contain explanations of photosynthesis, illustrations, learning activities, critical-thinking questions, Augmented Reality-based visualizations, and evaluation activities.

The researcher also designed the critical-thinking assessment instruments used in the product trial. The pretest and posttest items were developed according to five indicators of critical thinking: interpretation, analysis, evaluation, inference, and explanation.

3. Development and Expert Validation

At the Development stage, the DELBARA prototype was developed by integrating photosynthesis content, illustrations, learning activities, critical-thinking exercises, and Augmented Reality components. The product was validated by material and media experts using a four-point Likert scale. The

material expert assessed content suitability, accuracy, depth, language, and critical-thinking integration, while the media expert evaluated visual design, readability, navigation, AR integration, and usability. The validation results showed average scores of 3.53 from the material expert and 3.76 from the media expert, both categorized as very valid. Revisions were made based on the validators' feedback before implementation.

4. Implementation

After the product had been validated and revised, the researcher conducted a product trial involving nine Grade IV students. The students were selected using purposive sampling based on the consideration that they had studied the prerequisite material, had characteristics relevant to the research objectives, and had obtained permission from the school to participate in the trial.

The implementation was conducted on April 22–24, 2026, in Grade IV of SDN 2 Watuaji. Before the learning activities using DELBARA, students completed the pretest to measure their initial critical-thinking ability. The researcher then implemented learning activities using the DELBARA teaching materials. During the implementation, students were involved in activities contained in the teaching materials, including observing phenomena, exploring information, discussing, analyzing, and drawing conclusions. The Augmented Reality features were used to visualize the photosynthesis process through three-dimensional objects. After completing the learning activities, students completed the posttest using questions based on the same critical-thinking indicators measured in the pretest. The pretest and posttest scores were then compared to determine changes in students' critical-thinking ability following the implementation of DELBARA.

5. Data Collection

Data collection were collected through observation, interviews, questionnaires, tests, and documentation. Qualitative data were obtained from observations, interviews, documentation, and validators' comments, and were analyzed by organizing the information into learning conditions, student characteristics, existing teaching materials, learning difficulties, and teacher needs. Findings from observations, interviews, and questionnaires were compared to identify recurring problems and determine the requirements of the DELBARA teaching materials. Validators' suggestions were also analyzed based on content, presentation, language, graphics, navigation, and Augmented Reality integration and were used as a basis for product revision.

Quantitative data consisted of teacher needs-analysis questionnaire scores, expert validation scores, and students' pretest and posttest scores. Expert validation was analyzed descriptively using the formula Mean = $\Sigma X/N$, resulting in average scores of 3.53 from the material expert and 3.76 from the media expert, both categorized as very valid. The effectiveness of DELBARA was analyzed

using the **N-Gain** formula. The average pretest score was 71.22, while the posttest score was 86.00, with an average N-Gain of 0.513, categorized as medium. Thus, quantitative analysis was used to determine the feasibility of the DELBARA teaching materials and the improvement of students' critical-thinking skills.

C. Results And Discussion

1. DELBARA Development with ADDIE

The main research process followed the ADDIE development model, which consisted of five systematic stages: Analysis, Design, Development, Implementation, and Evaluation. In the Analysis stage, learning needs, student characteristics, curriculum demands, and problems related to the teaching of photosynthesis were identified through observations, teacher interviews, needs-analysis questionnaires, and analysis of existing teaching materials. The Design stage focused on developing the structure and content of DELBARA, including the integration of Deep Learning activities, critical-thinking exercises, and Augmented Reality-based visualizations. In the Development stage, the initial product was produced and subsequently validated by material and media experts to assess its content, presentation, language, graphics, and AR integration. The Implementation stage involved testing DELBARA with nine fourth-grade students through learning activities and pretest-posttest assessments. Finally, the Evaluation stage was conducted by analyzing expert validation results, implementation findings, student learning outcomes, and N-Gain scores to determine the feasibility and effectiveness of the developed teaching materials. Through these interconnected stages, the ADDIE model provided a systematic foundation for producing DELBARA as a learning product that responds to identified needs and supports the improvement of students' critical-thinking skills

The results of the study show that the results of the needs analysis show that teachers and students need teaching materials that are more interactive, innovative, and able to visualize abstract photosynthesis concepts and encourage the development of critical thinking skills. The "DELBARA" teaching materials developed are declared feasible for use based on the validation results of material experts and media experts who show that the product has met the feasibility aspects of content, presentation, language, graphics, and the use of Augmented Reality technology.

2. Research Result

Based on the results of interviews with several teachers, it can be seen that photosynthetic materials have conceptual characteristics and involve various biological processes that cannot be directly observed by students. The concepts of light energy absorption, the role of chlorophyll, the conversion of carbon dioxide and water into glucose, and the release of oxygen are abstract processes that require visualization so that they are easy to understand by elementary school-age students. If learning only relies on verbal explanations or two-dimensional images contained in textbooks, students tend to have difficulty in building a complete conceptual

understanding. These difficulties have an impact on students' low ability to analyze cause-and-effect relationships, explain scientific phenomena, and solve problems related to daily life.

The results of the interview were also corroborated by the results of observations made that could be known related to several things in IPAS learning. The results of the observation show that the learning process is still dominated by the delivery of material directly through the lecture method combined with simple questions and answers. Teachers have tried to provide examples that are close to students' lives, but learning activities are still oriented towards the delivery of information so that students' opportunities to explore and discover concepts independently are not optimal.

During the learning process, the teacher uses the package book as the main learning resource. The media used is generally in the form of pictures contained in books or simple presentation shows. Although the image helps explain the concept, the available visualizations are not yet able to dynamically depict the process of photosynthesis. As a result, students have difficulty understanding the relationship between sunlight, chlorophyll, carbon dioxide, water, and glucose formation as a single biological process.

During the learning activities, most students show interest in learning at the beginning of the lesson, but their attention begins to decline when the teacher enters into explanations of abstract concepts. Only a few students actively ask questions, while most others wait more for the teacher's explanation. When the teacher gives a question that demands a reason or explanation, most students are only able to give a short answer without a logical argument.

Observations also show that learning activities still emphasize the aspect of remembering information more than the ability to analyze or evaluate a phenomenon. For example, students are able to name the ingredients needed in photosynthesis, but have difficulty when asked to explain why light-deficient plants experience less than optimal growth or attribute the photosynthesis process to environmental balance. These findings show that learning has not fully provided a learning experience that encourages the development of critical thinking skills. In fact, one of the learning goals of IPAS is to build students' ability to understand natural phenomena through the process of scientific thinking.

In addition to the characteristics of the material, the results of the identification of learning conditions in several elementary schools in Jepara Regency show that the use of innovative learning media is still relatively limited. Most teachers have used digital devices for learning administration, but not many have integrated technology as a medium that is able to facilitate interactive learning activities. In fact, most schools already have supporting facilities in the form of internet networks, projectors, and smartphone devices that can be used as technology-based learning media. This condition shows that there is an opportunity to develop digital teaching materials that

are more interesting, contextual, and able to improve the quality of students' learning experience.

Analysis of the characteristics of grade IV students shows that they are at a concrete operational stage. At this stage of development, students are more likely to understand concepts when they are presented through objects that can be observed, visualized, and connected to real experiences. Therefore, teaching materials that only present static text and images have not fully met their learning needs. Students need media that is able to present real visual representations so that abstract concepts can be learned through more meaningful learning experiences. In addition, elementary school students in the digital era have a high interest in interactive learning media that combines visual, animation, audio, and exploratory elements.

In terms of curriculum, IPAS learning in the Independent Curriculum emphasizes the importance of student-centered learning through investigation, exploration, collaboration, reflection, and problem-solving activities(Rahayu, 2025). The curriculum also directs teachers to build critical thinking competencies as part of the Student Profile. Therefore, the teaching materials developed not only function as a source of information, but also as a means that can encourage students to make observations, ask questions, analyze data, formulate arguments based on evidence, and draw logical conclusions.

Based on the results of the interview, the teacher said that photosynthesis material is one of the materials that is quite difficult for students to understand because the process cannot be observed directly. So far, teachers have explained the material using pictures in package books, learning videos from the internet, or PowerPoint presentations. However, the media is considered not to be able to provide a comprehensive visualization of the stages of photosynthesis.

Teachers also revealed that students tend to be more interested if learning involves interactive digital media. When teachers use simple videos or animations, students' attention is increased compared to when learning only using textbooks. However, the use of digital media is still limited because there are no teaching materials that are integrated with learning activities according to the characteristics of the Independent Curriculum (Widana et al., 2023).

In addition, the teacher said that learning still faces challenges in developing students' critical thinking skills (Ho et al., 2023,Ayustyaningtias et al., 2025). Most students are able to answer memorized questions, but have difficulty when asked to give reasons, compare conditions, infer observations, or solve problems related to daily life. Teachers hope that there will be teaching materials that not only present material, but also contain investigative activities, sparker questions, interactive simulations, and exercises that are able to develop students' critical thinking skills. Teachers also want teaching materials that are easy to use, accessible via smartphones, and appropriate to the characteristics of elementary school students.

Based on the results of the questionnaire that has been filled out by the science teachers of grade IV, it can be seen that the results of the questionnaire show that most teachers state that photosynthesis materials include materials that are quite difficult for students to understand, the available teaching materials are still dominated by two-dimensional texts and images, students need more interactive learning media, learning needs to be directed at improving critical thinking skills, Teachers need teaching materials that integrate digital technology with learning activities (Mahfudz & Sukarno, 2023,Suyantiningsih et al., 2023).

Meanwhile, the results of the analysis of the teaching materials that have been used so far can be seen that the results of the analysis show that the photosynthesis material in the Independent Curriculum requires students not only to understand basic concepts, but also to be able to explain the relationship between plant needs and the photosynthesis process, connect the concept with daily life, and show an attitude of concern for the environment. However, the teaching materials used in schools still present more factual information than learning activities that train critical thinking skills. Evaluation questions are also still dominated by questions at the level of remembering and understanding so that they have not fully measured students' ability to analyze, evaluate, and reason. Based on the results of the needs analysis, it is necessary to develop Augmented Reality-based deep learning teaching materials or given the acronym "DELBARA".

After the prototype of the teaching material is completed, an expert validation process is carried out to determine the feasibility of the product before it is implemented to students. Validation is carried out by material experts and media experts using pre-prepared assessment instruments. The material expert evaluates the suitability of the content with learning outcomes, the correctness of the concept, the depth of the material, the systematics of the presentation, the language, and the integration of learning activities with the indicators of critical thinking ability. Meanwhile, media experts assessed aspects of appearance, graphic design, readability, illustration quality, ease of navigation, integration of Augmented Reality technology, and ease of use of teaching materials in the learning process. The display of the "DELBARA" teaching materials can be seen in the following figure 1:

Figure 1 Display of "DELBARA"

Based on picture 1, it can be seen that the appearance of "DELBARA" has an attractive cover with a choice of attractive drawings, colors and animations, so that it can arouse students in reading the teaching materials. An attractive color choice that adapts to the characteristics of grade IV students. The illustrations made also illustrate the material concretely. The "DELBARA" teaching materials are also equipped with guides that make it easier to use teaching materials. The guidelines for the use of teaching materials can be seen in figure 2 below:

Figure 2 Guide to the Use of Teaching Materials

Based on Figure 2, it can be seen that the book usage guide provides information on the use of DELBARA. This guide contains things that teachers should do as well as things that students should do. Through this guide, it will certainly provide a clear picture of the learning process carried out in the classroom. Based on the results of the validation calculation of subject matter experts, it can be seen that the total score reaches a value of 106. The total score of the subject matter expert assessment is 3.53. In the assessment score, the

validity category is included as very valid. The calculation can be found that teaching materials are very suitable for use with a few revisions. The results of the calculation of media expert validation can be found with a total score of 113. The total score of the media expert assessment is 3.76. In the assessment score, the assessment category is very valid, so the teaching material is worth using with a slight revision.

Based on the results of these calculations, it can be concluded that based on the results of the assessment of material experts and media experts, the teaching materials "DELBARA" (Deep Learning Based on Augmented Reality) on photosynthesis materials are declared suitable for use in science learning in grade IV of elementary school. This feasibility is the basis that the product has met the academic, pedagogical, and technical requirements to be implemented at the field trial stage. In addition to providing convenience for teachers in delivering material, "DELBARA" also has the potential to create a more meaningful learning experience for students through interactive visualizations, learning activities that require reasoning, and exercises that systematically develop critical thinking skills as one of the main competencies of 21st century learning.

As for the results of the research related to the effectiveness of "DELBARA" teaching materials, it can be seen that the results of the implementation show that the use of "DELBARA" teaching materials has a positive impact on improving students' critical thinking skills. The implementation of the "DELBARA" teaching materials will be carried out on April 22-24, 2026 in grade IV of SDN 1 Watuaji. After participating in learning using these teaching materials, students show significant changes in the way they understand the concept of photosynthesis and in solving problems related to the material. If before learning most students are only able to remember facts or answer simple questions, after using "DELBARA" students begin to be able to articulate reasons logically, connect various concepts learned, analyze cause-and-effect relationships, and draw conclusions based on evidence obtained during the learning process.

The improvement of critical thinking skills is inseparable from the characteristics of the "DELBARA" teaching materials which are designed based on the Deep Learning approach. This approach places students as the main subjects in the learning process so that they gain the opportunity to build knowledge through active, reflective, and meaningful learning experiences(Suradika et al., 2023). The learning activities contained in "DELBARA" not only direct students to read the material, but also invite them to observe phenomena, identify problems, ask questions, explore, discuss, analyze information, and draw conclusions based on observations. Through this series of activities, students are trained to use high-level thinking skills in understanding the concept of photosynthesis in more depth.

Another advantage that contributes to the effectiveness of "DELBARA" is the integration of Augmented Reality (AR) technology in the presentation of materials(Ishartono et al., 2023,Wawan et al., 2023). Photosynthetic material is an abstract concept because it involves biological processes that cannot be directly observed by students. Through AR technology, the process is visualized in the form of three-dimensional objects that can be observed from various points of view using digital devices. This visualization helps students understand the relationship between sunlight, carbon dioxide, water, chlorophyll, and photosynthesis results in a more concrete way. Thus, students not only memorize the stages of photosynthesis, but also understand the scientific reasons behind each process that occurs.

During the implementation of learning, the observation results showed an improvement in the quality of student learning activities. Students seemed more enthusiastic about participating in learning, actively asking questions, discussing with their group mates, and daring to express their opinions when asked to explain the results of their observations. Interaction between teachers and students as well as between students also takes place more dynamically than conventional learning. This situation shows that the use of "DELBARA" is able to create a more participatory learning environment and provide space for students to develop the ability to think independently and collaboratively.

The effectiveness of "DELBARA" is also reflected in the ability of students to solve problems designed to measure critical thinking indicators. After participating in the lessons, students show increased ability to identify problems related to photosynthesis, analyze the relationship between factors that affect the photosynthesis process, provide arguments based on scientific concepts, evaluate various alternative answers, and draw conclusions supported by evidence. These changes show that learning is no longer oriented to memorizing concepts, but rather to the ability to use knowledge to explain phenomena encountered in daily life.

In addition to improving critical thinking skills, the use of "DELBARA" also has an impact on students' motivation and learning engagement. The integration of interesting illustrations, exploratory activities, and Augmented Reality-based visualizations makes learning more enjoyable and able to retain students' attention during the learning process(Wahyudiati, 2023,Cabrera-Solano et al., 2023). Students not only play the role of receivers of information, but become active learners who explore concepts through interactive learning experiences(Daniel et al., 2021). This condition has an impact on increasing curiosity, the courage to express opinions, and students' confidence in completing various learning tasks(Organ et al., 2022,Pujianti et al., 2021).

The teacher's response to the use of "DELBARA" teaching materials also showed positive results. The teacher assessed that this teaching material was able

to help explain concepts that were previously difficult for students to understand because they were visualized more realistically(Uden et al., 2023,Johari, 2018). Teachers also reported that the learning process became more structured because each stage was designed according to the principles of Deep Learning, including orientation, exploration, elaboration, reflection, and evaluation. DELBARA not only facilitates the delivery of learning materials but also provides an alternative learning resource that integrates digital technology with a pedagogical approach appropriate to the characteristics of elementary school students.

The effectiveness of DELBARA was evaluated by comparing students' pretest and posttest scores, as presented in Table 1. All nine students showed an increase in their scores after using the teaching materials. The average pretest score increased from 71.22 to 86.00, with an average N-Gain of 0.513, which falls into the medium category ($0.30 \leq g < 0.70$). This finding indicates that DELBARA was moderately effective in improving the critical-thinking skills of Grade IV students in learning photosynthesis. The improvement was reflected in students' ability to understand concepts, analyze information, and solve problems related to photosynthesis. The moderate level of improvement may have been influenced by differences in students' initial abilities, previous learning experiences, digital literacy, and the limited implementation period of the product.

D. Conclution

The results show that DELBARA (*Deep Learning Based on Augmented Reality*) was developed based on the actual needs of elementary science learning. Validation by material and media experts confirmed that DELBARA is feasible in terms of content, presentation, language, graphics, and technology. Its implementation also improved students' critical thinking skills, with the average score increasing from 71.22 on the pretest to 86.00 on the posttest and an N-Gain of 0.513 (medium category). Thus, DELBARA is a feasible and innovative teaching material that supports more active, interactive, and meaningful learning while strengthening conceptual understanding and critical thinking skills in fourth-grade students on photosynthesis.

Based on these findings, teachers are recommended to use DELBARA as a complementary teaching material and to integrate AR activities with reflective questions and discussions so that students do not only observe visualizations but also analyze, explain, and evaluate scientific phenomena. Future researchers are encouraged to conduct wider trials involving more schools and students, extend the implementation period, and explore the effectiveness of DELBARA on other science topics and learning competencies. Continuous reflection and evaluation are also important to improve the accessibility, usability, and quality of the AR-based learning experience.

References

Arzeman, A., Haines, J., Pritchard, C., Rutherford, S., & Francis, N. (2026).

Navigating new norms: a systematic review of factors for the development of effective digital tools in higher education. *FEBS Open Bio*, *16*(3). https://doi.org/10.1002/2211-5463.70151

Ayustyaningtias, R., Alinurdin, E., & Wahyudin, A. (2025). Improving Students' Critical Thinking Through Blended Learning Media Learning Game Word Wall. *ASEAN Journal of Educational Research and Technology*.

Baihaqi, M. I., Martanti, F., & Farda, U. J. (2025). *The Effectiveness of the Use of Three-Dimensional Media in IPAS on Student Learning Outcomes at Madrasah Ibtidaiyah*. *4*(2), 209–218.

Cabrera-Solano, P., Ochoa-Cueva, C., & Castillo-Cuesta, L. (2023). Implementing the Engage, Study, Activate Approach Using Technological Tools in Higher Education. *International Journal of Learning, Teaching and Educational Research*, *22*(1), 268–282. https://doi.org/10.26803/ijlter.22.1.15

Daniel, L., Doyle, T., & Kaesehagen, C. (2021). Supporting parents to co-produce differentiated learning opportunities in mathematics. *Education 3-13*, *0*(0), 1–15. https://doi.org/10.1080/03004279.2021.1878253

Ho, Y. R., Chen, B. Y., & Li, C. M. (2023). Thinking more wisely: using the Socratic method to develop critical thinking skills amongst healthcare students. *BMC Medical Education*, *23*(1), 1–16. https://doi.org/10.1186/s12909-023-04134-2

Ishartono, N., Halili, S. H., & Razak, R. A. (2023). A review of flipped learning in innovative math education. *International Journal of Evaluation and Research in Education*, *12*(4), 2194–2206. https://doi.org/10.11591/ijere.v12i4.25842

Johari, S. (2018). Teori Pembelajaran. In *Psikologi Pendidikan* (Vol. 1).

Mahfudz, M., & Sukarno, S. (2023). The effect of ex-add learning techniques on critical thinking skills and pedagogic competence of Islamic education students. *Journal of Education and Learning*, *17*(2), 221–228. https://doi.org/10.11591/edulearn.v17i2.20782

Manasikana, A., Rahayu, E., & Hidayati, L. (2025). Pengaruh Penerapan Project-Based Learning (PjBL) terhadap Kreativitas Peserta Didik pada Mata Pelajaran Projek Ipas. *Jshp*, *9*(1), 2580–5398.

Mursid, R., Muslim, & Farihah. (2023). Collaboration-Based Development Model E-Learning on Course Learning Achievements Working Skills. *International Journal of Instruction*, *16*(2), 307–318. https://doi.org/10.29333/iji.2023.16218a

Organ, J., O'Neill, S., & Shanahan, B. W. (2022). Development of Social Technology Entrepreneurial Ventures: A challenge project-based learning approach. *IFAC-PapersOnLine*, *55*(39), 181–186. https://doi.org/10.1016/j.ifacol.2022.12.050

Pujianti, P., Kardoyo, K., & Utanto, Y. (2021). *Biology Learning Management Contain Using Character Education With T-PACK Through Project Based Learning (PBL) Model*. *10*(2), 289–298.

Rahayu, D. (2025). *Jurnal Pendidikan Matematika*. *13*(1), 9–25.

Song, X., Yang, X., Wang, Q., Su, Y., & Hong, J. (2022). The relationship between teacher's gender and deep learning strategy: The mediating role of deep learning motivation. *Psychology in the Schools*, *59*(11), 2251–2266. https://doi.org/10.1002/pits.22694

Suradika, A., Dewi, H. I., & Nasution, M. I. (2023). Project-Based Learning and Problem-Based Learning Models in Critical and Creative Students. *Jurnal Pendidikan IPA Indonesia*, *12*(1), 153–167. https://doi.org/10.15294/jpii.v12i1.39713

Suyantiningsih, Badawi, Sumarno, Prihatmojo, A., Suprapto, I., & Munisah, E. (2023). Blended Project-Based Learning (BPjBL) on Students' Achievement: A Meta-Analysis Study. *International Journal of Instruction*, *16*(3), 1113–1126. https://doi.org/10.29333/iji.2023.16359a

Uden, L., Sulaiman, F., Ching, G. S., & Rosales, J. J. (2023). Integrated science, technology, engineering, and mathematics project-based learning for physics learning from neuroscience perspectives. *Frontiers in Psychology*, *14*. https://doi.org/10.3389/fpsyg.2023.1136246

Wahyudiati, D. (2023). Enhancing Students' Communication and STEM Reasoning Abilities Based on Gender Through Application of IT-based Chemistry Teaching Materials. *International Journal of Learning, Teaching and Educational Research*, *22*(5), 160–179. https://doi.org/10.26803/ijlter.22.5.8

Wawan, W., Retnawati, H., & Setyaningrum, W. (2023). An Integrative Learning Model to Improve Problem-Solving and Creative Thinking Abilities, Collaboration, and Motivation. *Islamic Guidance and Counseling Journal*, *6*(2). https://doi.org/10.25217/0020236402400

Wei, L. (2023). *Deep Learning in the Context of Big Data: The Theoretical Basis of Undergraduate Education Reform* (pp. 376–384). https://doi.org/10.1007/978-3-031-23950-2_40

Widana, I. W., Sumandya, I. W., & Citrawan, I. W. (2023). The special education teachers ' ability to develop an integrated learning evaluation of Pancasila student profiles based on local wisdom for special needs students in Indonesia. *Kasetsart Journal of Social Sciences*, *44*(2), 527–536.