ARES (Augmented Reality-Ethnoscience): development of digital learning media to improve critical thinking ability in elementary school students

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Article info	Abstract
	The 21st century presents various global challenges that require the development of students' critical thinking skills; however, the lack of contextual digital media to support ecosystem observation has contributed to low levels of students' critical thinking ability. This study aims to develop and examine the effectiveness of ARES, an Augmented Reality digital learning media integrated with the ethnoscience of *Perelek Runtah*, in improving students' critical thinking skills. The research employed the ADDIE development model (Analyze, Design, Develop, Implement, and Evaluate) using validation sheets, critical thinking tests, and questionnaires, with a sample of 24 fifth-grade elementary school students. The media trial was conducted using a quasi-experimental one-group pretest–posttest design across four learning sessions. Expert validation results obtained a score of 88% (very feasible), while the average posttest score (56.0) was higher than the pretest score (29.9). A paired-sample t-test showed a significant difference between pretest and posttest scores (p = 0.000 < 0.05), and the N-Gain value of 0.37 indicated a medium improvement. Student response results showed an average score of 82.91% (Highly Practical). Therefore, it can be concluded that ARES is effective in improving students' critical thinking skills and is recommended for use in elementary school science learning.

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1. Introduction

The development of science and technology in the twenty-first century has generated a range of consequences that give rise to new challenges significantly different from those of previous eras (Dwi et al., 2022).The twenty-first century emphasizes mastery of the 4C skills—Critical Thinking, Communication, Collaboration, and Creativity—as essential competencies for students to succeed and thrive. These skills play a crucial role in preparing students to work collaboratively, solve complex problems, foster tolerance toward differences among peers, and enhance critical and creative thinking abilities in addressing real-life challenges (Widiantie, 2025). The integration of twenty-first-century skills is no longer merely an option but a necessity in modern education, as these skills empower students to effectively navigate digital transformation and develop innovative solutions within an ever-evolving global landscape (Yunita & Mandasari, 2025; Kobandaha et al., 2025). One increasingly urgent global issue is the pollution of aquatic ecosystems by plastic waste.

Low public awareness of waste management has resulted in waste accumulation on land, disposal of garbage into roadside drainage systems, and direct dumping of waste into rivers (Tunggul et al., 2021). In Indonesia, approximately 66 million tons of plastic waste are generated annually, with an estimated 8 million tons entering the oceans (Alamsyah & Fadli, 2023). Over time, plastic waste in aquatic environments degrades into smaller fragments of varying sizes; the smallest particles resulting from this degradation are known as microplastics (Asrul, 2022). Microplastics release toxic compounds such as heavy metals and persistent organic pollutants (POPs), which, when ingested by living organisms, can cause organ dysfunction, including digestive disorders, reduced growth rates, inhibition of enzyme production, decreased steroid hormone levels, and reproductive disorders (Apriyanthi, 2023). These issues are important to teach students as future generations so that they develop environmental awareness and contribute to ecosystem conservation. At the elementary school level, ecosystem concepts are taught within the Grade V Natural Science curriculum.

Natural Science is a subject that examines natural phenomena based on observable facts (Wardani et al., 2022). Science learning at the elementary school level plays a vital role in building foundational understanding of the natural environment, the phenomena occurring within it, and basic scientific concepts (Maharani & Mahmudah, 2024). In science instruction, students are introduced to various concepts related to nature. However, science education often faces challenges; one of these is that not all scientific concepts can be presented concretely due to the abstract nature of certain topics (Diana et al., 2024; Evitasari & Aulia, 2022). Science learning in the Natural and Social Sciences (IPAS) subject is still frequently dominated by teacher-centered and textbook-oriented approaches (Damayanti et al., 2025). This condition makes abstract scientific concepts difficult for students to understand because they cannot be directly observed, resulting in low levels of conceptual understanding and limited scientific skills (Diana et al., 2024; Indriani, 2024). In fact, scientific competence is crucial for addressing twenty-first-century challenges such as plastic pollution in the environment.

Observations conducted at SDN Vidya Qasana revealed that fifth-grade students were only able to answer science questions at a basic level, while most higher-order thinking questions remained unanswered. This is evidenced by students' daily assessment results on ecosystem material, which showed an average score of 68.5, below the school's Minimum Learning Achievement Criteria of 75. According to the classroom teacher, students experience difficulties in identifying the characteristics of living organisms to analyze their modes of reproduction and types of food. Furthermore, students were only able to provide basic explanations regarding the long-term impacts of plastic use in daily life. These findings indicate that students require more

innovative learning approaches that focus on the development of critical thinking skills. One contributing factor to the difficulty in developing critical thinking skills is the continued dominance of conventional teaching practices, which rely heavily on textbooks and two-dimensional instructional media. In contrast, ecosystem topics require realistic visualization to allow students to directly observe learning objects, thereby enabling observation and analysis processes that support the development of critical thinking skills. Based on these challenges and students' learning needs, it is essential to develop instructional media capable of visualizing learning objects in three-dimensional forms.

ARES (Augmented Reality Ethnoscience) is a learning medium based on Augmented Reality (AR) technology integrated with ethnoscience, implemented in the form of an Android application. ARES enables realistic visualization of animals and plastic waste pollution through the application of AR technology. Augmented Reality is a technology that integrates virtual elements into the real-world environment and serves as a catalyst for transforming educational experiences toward student-centered learning approaches (Shonima & Sowmya, 2024). The use of AR in the learning process has been proven to enhance students' motivation and conceptual understanding through direct interaction with learning objects (Tse, 2024). ARES not only provides AR-based objects for observation but also includes reading content grounded in the ethnoscientific practice of *Perelek Runtah* from the Sundanese community in West Java. This integration of ethnoscience aims to promote learning through an approach that reflects authentic environmental contexts relevant to students' daily lives, thereby facilitating deeper conceptual understanding. The integration of ethnoscience has been shown to be effective in improving students' critical thinking skills through the presentation of contextually meaningful content (Sarkingobir & Bello, 2024).

Based on these issues, the purpose of this study is to develop and examine the effectiveness of an ethnoscience-integrated Augmented Reality digital learning media based on *Perelek Runtah* in enhancing students' critical thinking skills. This study integrates Perelek Runtah's ethnoscience into Augmented Reality–based digital learning media, an approach that has not been explored in previous research, and examines its impact on enhancing elementary school students' critical thinking skills in science learning.

2. Literature review
2.1 Augmented reality

Augmented Reality (AR) is a technology that projects two-dimensional and three-dimensional virtual objects into the real-world environment in real time (Sari et al., 2023). Students often experience difficulties in understanding abstract concepts embedded in learning materials (Melindawati, 2021). One topic in science education that requires strong conceptual and analytical understanding is ecosystems (Awaluddin, 2025). Ecosystem content emphasizes a deep understanding of interactions between biotic and abiotic components in maintaining environmental balance. Therefore, verbal explanations alone are insufficient, and instruction must be supported by observational activities and visualizations that realistically depict interactions among components (Pakpahan et al., 2024; Awaluddin, 2025). Students continue to face challenges in understanding the roles of various animals and plants within food chains (Dewi et al., 2024). Three-dimensional visualization helps represent abstract concepts realistically, thereby enhancing students' understanding (Nurasia & Gustiani, 2021). This approach aligns with Jean Piaget's theory of cognitive development, which emphasizes that learning processes for elementary school students should involve concrete objects.

Augmented Reality technology offers several advantages, including: (1) effectiveness in implementation, (2) flexibility for use across various media formats, (3) ease of operation, (4) relatively low production costs, and (5) more active interaction compared to other types of instructional media (Widyasari & Ismawati, 2020). The advantages and characteristics of AR are well aligned with ethnoscience, which is contextual in nature and capable of facilitating learning experiences that are authentic and relevant to students' local environments (Nurroniah et al., 2023; Fathuloh et al., 2025). Accordingly, the development of critical thinking skills in elementary education should be viewed as a synthesis of experiential learning design, meaningful social interaction, and the contextual use of technology. Through this integration, students are not only able to understand concepts theoretically but are also capable of applying them in real-life situations. The use of ethnoscience-based e-modules is effective in enhancing students' critical thinking skills (Manggul & Pratiwi, 2025). Similarly, AR-based instructional media have been shown to positively influence elementary school students' learning outcomes (Amalia et al., 2024).

2.2 Ethnoscience

Ethnoscience is an approach or field of study that focuses on culture, encompassing language, jargon, codes, behaviors, myths, symbols, and systems of thought within a particular community, which are used to interpret scientific knowledge in order to develop curricula that are relevant to students (Muyassaroh & Sunaryati, 2021). At present, the delivery of instructional content tends to be oriented toward purely scientific knowledge and relies primarily on students' cognitive development, without reintegrating local cultural wisdom into the educational system (Puspasari et al., 2020). In fact, learning activities that incorporate local wisdom can support students' understanding of subject matter through realistic and contextual learning experiences (Handayani et al., 2023). One cultural practice that can be integrated into the learning process is *Perelek Runtah*.

Perelek Runtah derives from the Sundanese words *perelek*, meaning "to collect," and *runtah*, meaning "waste," and thus literally refers to the practice of collecting waste. *Perelek Runtah* represents a form of local wisdom within the Sundanese community aimed at environmental preservation through the collection of organic and inorganic waste for recycling. This practice is a modification of an older local tradition known as *Perelek Beas*, a community activity in which residents collect rice to be donated to individuals who are ill or experiencing hardship (Karyaningsih et al., 2025).

The local wisdom embodied in *Perelek Runtah* is highly relevant to the Grade V elementary science ecosystem topic, which emphasizes environmental issues and the conservation of living organisms. Through this cultural practice, students can engage in basic clarification regarding types of waste, provide evidence of the impacts of waste pollution on the environment using data obtained from AR-based 3D objects, conduct further clarification of how pollution ultimately affects humans, and plan strategies and tactics for waste management. Accordingly, students' critical thinking skills can be effectively developed through the integration of Augmented Reality technology and ethnoscience.

2.3 Critical thinking skills

Critical thinking is an essential competence in twenty-first-century education, as it involves processes of problem solving, informed decision-making, and the development of a deep understanding of various issues (Halim, 2022; Robbani, 2025). According to Ennis (1986), critical thinking consists of five main components: Elementary Clarification, Basic Support, Inference,

Advanced Clarification, and Strategies and Tactics. Critical thinking encompasses not only cognitive aspects but also dispositional dimensions, which refer to the tendency to question assumptions and evaluate arguments rationally (Pratiwi et al., 2024).

The development of critical thinking skills in science learning at the elementary school level is particularly important to foster from an early age, as science education aims not only at conceptual mastery but also at cultivating a scientific mindset (Kirk et al., 2023). Students' critical thinking skills in science education are closely related to their ability to analyze information, evaluate evidence, and connect scientific concepts with everyday life phenomena (Wati & Sari, 2023). Science instruction that emphasizes rote memorization tends to render students passive; therefore, the development of critical thinking requires instructional strategies that promote intellectual engagement and independent scientific exploration (Adawiyah et al., 2025).

A learning model considered suitable for developing students' critical thinking skills is the guided inquiry learning model, which emphasizes discovery-based learning with teacher guidance throughout the instructional process (Widiya & Radia, 2023). Through guided inquiry, students can engage in practical activities using 3D Augmented Reality visualization features to construct new knowledge, as well as analyze environmental pollution and local wisdom in community-based mitigation efforts. The selection of appropriate learning models and instructional media plays a crucial role in enhancing students' critical thinking skills (Mukarima et al., 2024). Therefore, ARES is designed with 3D visualization features and the integration of local wisdom content to ensure contextualized learning and to support students in achieving critical thinking indicators.

3. Method

This study is classified as Research and Development (R&D) employing the ADDIE model, which consists of the stages of analysis, design, development, implementation, and evaluation. The ADDIE model is used to develop educational products and learning resources, including instructional media, to facilitate student-centered, innovative, and authentic learning processes (Branch, 2009).
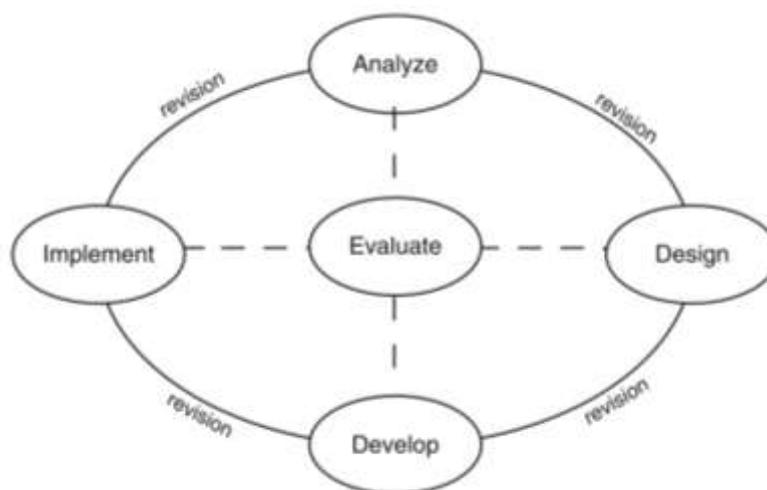

Figure 1. The ADDIE model concept

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This study was conducted at SDN Vidya Qasana during the odd semester of the 2025/2026 academic year. The population of the study consisted of a fifth-grade class comprising 24 students. The sampling technique employed was purposive sampling, as the class was selected based on teacher recommendations due to students' low performance on daily assessments in science subjects. The method used to examine the effectiveness of the instructional media on students' critical thinking skills was a quasi-experimental approach with a one-group pretest–posttest design.

Data collection in this study involved two types of instruments: test and non-test. The test instrument developed to measure students' critical thinking skills was a multiple-choice test. The items were constructed based on the cognitive domains of C4–C6 in Bloom's Taxonomy and aligned with critical thinking indicators. Non-test data were collected through interviews, validation sheets, and questionnaires.

The test development process involved validity and reliability testing. Validity testing consisted of two types: content validity and empirical validity. Content validity was evaluated by expert validators and yielded a score of 88.60, which falls within the range of 80 ≤ V ≤ 100 and is categorized as *very valid*. The empirical validity test indicated that five items were invalid; therefore, the initial set of 20 items was reduced to 15 valid test items for use in the study. Subsequently, a reliability test was conducted using the valid items to determine the consistency of the instrument. The reliability analysis produced a Cronbach's alpha coefficient of 0.836, indicating that the instrument was reliable.

The pretest was administered during the first meeting, prior to the treatment, while the posttest was administered during the fourth meeting, after the treatment. The data analysis techniques included validation analysis, feasibility testing, effectiveness testing, and practicality testing. The analysis of students' critical thinking skills was based on the indicators proposed by Ennis (1986). Validity results were obtained from expert validators in the fields of media, language, and content. Expert validation scores were calculated and compared using the formulas and feasibility criteria tables as presented below.

$$Valpro = \frac{srt}{smt} \times 100$$

Where: Valpro = Product Validation, Srt = score achieved, Smt = highest possible score.

Table 1. Product feasibility criteria

Score	Feasibility interpretation
80 ≤ V ≤ 100	Very Feasible
60 ≤ V < 80	Feasible
40 ≤ V < 60	Quite Feasible
20 ≤ V < 40	Less Feasible
0 ≤ V < 20	Very Little Feasible

The effectiveness of the instructional media was evaluated through an analysis of objective test results, which included a paired-sample *t*-test and an N-Gain test. The data used in this analysis were students' pretest and posttest scores. The formula used to calculate the N-Gain is presented as follows.

$$\text{N-Gain} = \frac{Postest\ Score - Pretest\ Score}{Max\ Score - Pretest\ Score}$$

Table 2. N-Gain score category

Score	Category
> 0.70	High
0.30 – 0.70	Medium
< 0.30	Less

Source: Hake (1998)

Student questionnaire assessment was also conducted to measure the practicality of the instructional media. The data used for the analysis were obtained from questionnaire response sheets. The collected data were calculated using the formula presented below.

$$P = \frac{F}{N} \times 100$$

Where: P = students' response percentage, F = score obtained, N = maximum score.

Table 3. Classification of students' responses

Student's Responses (%)	Category
81 – 100	Highly Practical
61 – 80	Practical
41 – 60	Medium Practical
21 – 40	Less Practical
0 – 20	Impractical

4. Results and discussion

4.1 Analyze

In the initial stage, the researchers conducted interviews and observations to identify problems occurring in the learning process. Subsequently, a needs analysis related to instructional media was carried out through the distribution of questionnaires to teachers and students. The results of the teacher questionnaire indicated that teachers primarily used PowerPoint presentations, whiteboards, and textbooks as instructional media. Teachers expressed the need for learning media that could facilitate students in conducting observational activities related to learning objects. Meanwhile, students' learning difficulties included challenges in identifying and classifying types of food chains and animal reproduction, as well as a tendency to become easily bored due to monotonous learning activities. The next step involved assessing students' critical thinking skills through a pretest to determine their initial ability levels.

Table 4. Students' Initial critical thinking skills

Indicators	Score	Interpretation
Elementary clarification	26.3	Moderate
Basic support	37.4	Moderate
Inference	27.7	Moderate
Advance clarification	24.9	Low
Strategies and Tactics	33.3	Moderate
Average	**29.92**	**Moderate**

Based on the results of the needs analysis, students' critical thinking skills as measured by the pretest showed an average score of 29.92. According to Ennis (1986), a score of 29.92 falls within the *moderate* level of critical thinking ability. Therefore, the development of Augmented Reality–based learning media is required to present realistically learning objects, thereby

engaging students in observational activities and supporting interactive, student-centered learning.

4.2 Design

During the design stage, the researchers created Augmented Reality (AR) animal object models that reflect real ecosystem conditions using Blender 3D. The modeled animals represent components of terrestrial, marine, and freshwater ecosystems, including several species endemic to Indonesia. In addition, 3D objects illustrating water pollution caused by plastic waste were incorporated to enable students to observe its impact on ecosystems directly.
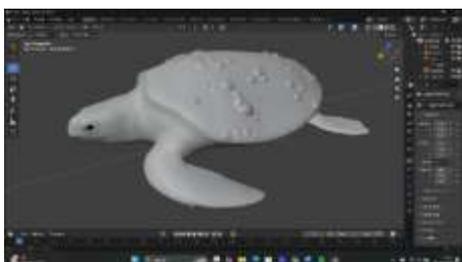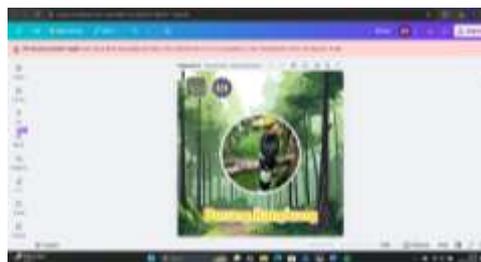

Figure 2. AR object design in blender 3D

Figure 3. Marker design in canva

At this stage, the researchers also designed the application graphics and the required interface buttons using Canva. The 3D objects modeled in Blender 3D were then animated so that the animal objects could move, making them more engaging and realistic. After the marker design was completed, the files were downloaded in JPG format to be uploaded to the Vuforia Engine.

4.3 Develop

The initial stage of the development process involved importing the designed assets into the Unity Editor. Marker assets were also uploaded to the Vuforia Engine to obtain the AR camera license key. After integrating the assets to build the application, programming was carried out to enhance the user experience, including usage flow, page navigation, and the provision of application features.
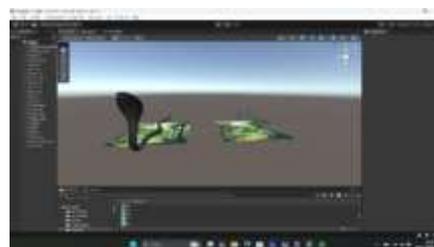

Figure 4. Main menu

Figure 5. AR menu page

Figure 6. Learning materials menu page

Figure 7. Learning outcomes menu

Figure 8. Quiz menu page

After the project development process was completed and the application was converted into an Android application, the application was installed and tested to identify any potential errors. If no errors were detected, the application proceeded to the expert validation stage. Expert validation was conducted by media, content, and language validators, consisting of a media expert lecturer, a language expert lecturer, and a classroom teacher as the content expert. The results of the expert validation were calculated using the product validation formula and are presented in the following table.

Table 5. Expert validation calculation results

Validators	Feasibility Percentage	Category
Media Expert	87%	Very Feasible
Content Expert	86%	Very Feasible
Language Expert	91%	Very Feasible
Average	**88%**	**Very Feasible**

Based on the table, the media expert validation obtained a score of 87%, the content expert validation obtained 86%, and the language expert validation obtained 91%. When averaged, the total validation percentage was 88%. Referring to the feasibility criteria table, this score falls within the *very feasible* category. Several aspects of the ARES media required revision following the expert validation stage, including: (1) the animal images on the markers were too small, resulting in frequent scanning errors; (2) the media background colors and illustrations lacked sufficient contrast with the interface buttons; (3) the ethnoscience content needed to be positioned at the beginning of the slides; (4) the instructional materials were not sufficiently specific; and (5) some vocabulary items contained ambiguous or double meanings.

4.4 Implement

During the implementation stage, the researchers utilized the developed and validated instructional media in the IPAS learning process on the topic of ecosystems for fifth-grade elementary school students. The implementation employed a guided inquiry learning model with the following syntax: (1) exploring phenomena and facts, (2) focusing attention, (3) planning observational activities, (4) carrying out implementation activities, (5) analyzing the obtained data, (6) constructing new knowledge, and (7) presenting observation results (Llewelyn, 2013). The learning activities were conducted in four sessions, beginning with a pretest and concluding with a posttest.

The test results were then used to conduct an effectiveness analysis to determine whether the ARES media was effective for use in the learning process. The effectiveness test consisted of

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a normality test and a paired-sample *t*-test. These analyses were performed using SPSS version 25, and the results are presented in the table below.

Table 6. Effectivity test

No	Effectivity Test	Indicator	Significance (Sig.)	Interpretation
1	Normality test	Pretest	0.349	Normally distributed
		Posttest	0.440	Normally distributed
2	Paired Sample t-test	Equal Variance Assumed	0.000	There is a difference in the average of the experiment and control group samples.

Based on Table 7, the normality test yielded significance values of 0.349 and 0.440, indicating that $p > 0.05$. These results demonstrate that the data were normally distributed and therefore met the assumptions for conducting parametric statistical analysis, specifically the paired-sample *t*-test. The results of the paired-sample *t*-test showed a two-tailed significance value of 0.000, indicating that $p < 0.05$, which confirms a statistically significant difference between students' pretest and posttest scores. Based on these effectiveness test results, it can be concluded that the ARES instructional media was effective in producing a significant improvement from pretest to posttest.

Furthermore, the analysis was extended using the N-Gain test to determine the level of effectiveness of the ARES media in science learning. Students' critical thinking skills were evaluated using test items constructed based on the cognitive levels C4–C6 and critical thinking indicators. Test score analysis was conducted for each indicator using N-Gain to identify the presence and classification of improvement. The results of the critical thinking skills analysis are presented in the table below.

Table 7. Students' final critical thinking skills

Indicators	Pretest	Posttest	N-Gain	Interpretation
Elementary clarification	26.3	49.9	0.32	Medium
Basic support	37.4	62.4	0.39	Medium
Inference	27.7	51.3	0.32	Medium
Advance clarification	24.9	56.9	0.42	Medium
Strategies and Tactics	33.3	59.6	0.39	Medium
Average	**29.9**	**56.0**	**0.37**	**Medium**

The results of the analysis of students' critical thinking skills presented in the table indicate that the average pretest and posttest scores for the critical thinking indicators were 29.9 and 56.0, respectively. According to Ennis (1986), the average pretest score of 29.9 falls within the *moderate* level of critical thinking ability, whereas the average posttest score of 56.0 is categorized as a *high* level. The average N-Gain score was 0.37, which, compared with the N-Gain classification criteria, is categorized as *medium*. Based on these results, it can be concluded that the ARES learning media has a medium level of effectiveness in improving students' critical thinking skills. These findings are consistent with the study by Shindi et al. (2025), which reported that a STEAM-based e-learning module demonstrated an effectiveness level of 0.61, also classified as *medium*, in enhancing elementary school students' critical thinking skills. Similarly, research by Nina et al. (2023) showed that the development of augmented reality–based flashcard media was effective in improving students' critical thinking skills on the topic of force

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in the fourth-grade science curriculum. Moreover, Augmented Reality and ethnoscience-based learning processes have been shown to enhance students' literacy and scientific skills (Sani et al., 2023; Dewi & Bahri, 2025).

The practicality test was conducted using data obtained from student response questionnaires. The questionnaire consisted of 20 items distributed across five aspects: media appearance, ease of use, learning content, ethnoscience integration, and learning motivation and interest. The results of the student questionnaire analysis are presented in the table below.

Table 8. Student response questionnaire

Aspect	Percentage (%)	Category
Media display	78.13	Practical
Ease of use	80.21	Practical
Learning content	83.33	Highly Practical
Ethnoscience integration	85.42	Highly Practical
Motivation and learning interest	87.50	Highly Practical
Average	**82.91**	**Highly Practical**

Based on the table, the media display aspect obtained a percentage of 78.13%, and the ease-of-use aspect achieved 80.21%; both are categorized as *practical*. Meanwhile, the learning content aspect obtained 83.33%, the ethnoscience integration aspect achieved 85.42%, and the motivation and learning interest aspect reached 87.50%; all three are classified as *very practical*. When the percentages of the five aspects were averaged, the overall score was 82.91%, which falls within the *Highly Practical* category. These findings are consistent with the study conducted by Seviana et al. (2022), which reported that the development of Augmented Reality–based instructional media achieved a practicality percentage of 86.66%, categorized as *Highly Practical*.

4.5 Evaluation

Evaluation is an activity conducted to assess the outcomes of product development, both before and after its implementation (Branch, 2010). Evaluation consists of two types: formative evaluation and summative evaluation. Formative evaluation is carried out during the design and development stages to ensure that the product aligns with the intended objectives. In contrast, summative evaluation is conducted after the product has been implemented to determine its level of effectiveness and practicality (Sofian et al., 2025).

Based on the analysis results, students' critical thinking skills after the intervention were categorized at a *high* level, with a *medium* degree of improvement. One factor contributing to this moderate degree of improvement was the limited duration of the intervention. In addition, the improvement in critical thinking skills could not be compared with the use of other learning media, as this study did not include a control group. The practicality assessment based on student response questionnaires indicated that the aspects of media appearance and ease of use were categorized as *Highly Practical*.

The use of Augmented Reality–based learning media integrated with the ethnoscience concept of *Perelek Runtah* remains relatively uncommon in elementary school learning. Technology-based learning media are rarely implemented due to teachers' limited competencies and knowledge, as well as insufficient technological training, resulting in learning processes that continue to rely on textbooks and remain monotonous (Falny et al., 2025). Conventional textbook-based instruction has been shown to negatively affect students' learning interest and academic outcomes (Bhismantara et al., 2024). Learning activities supported by the ARES media

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facilitate students' observation of animal objects to classify living organisms based on their roles in ecosystems, types of reproduction, and food categories, as well as to understand the environmental impact of plastic waste pollution and recognize local wisdom practices. Augmented Reality–based learning applications also enable students to observe vertebrate animals, particularly reptiles more easily (Pratama et al., 2022). Furthermore, ethnoscience-based learning supports teachers in teaching science through local wisdom, allowing students to apply scientific knowledge to solve problems within their surrounding environment (Flash & Flash, 2024).

5. Conclusion and implications

This study demonstrates that ARES, a digital Augmented Reality learning media integrated with ethnoscience, is effective in enhancing the critical thinking skills of fifth-grade elementary school students. Expert validation of the media, content, and language by specialists yielded an average percentage of 88%, indicating that the ARES media is very feasible for use in elementary science education. The results of student testing showed that the average posttest scores were higher than the pretest scores. Effectiveness analysis using a paired-sample *t*-test indicated that the ARES media significantly improved students' critical thinking skills from pretest to posttest. The N-Gain analysis revealed an average score of 0.37, suggesting that the use of ARES has a *medium* effect on enhancing students' critical thinking skills. Practicality assessment through student response questionnaires showed a percentage of 82.91%, indicating that the ARES media is highly practical for use in science learning on ecosystem topics.

The limitations of this study include a limited number of learning sessions and the absence of a comparison group or control class. Therefore, for future research, it is recommended to increase the number of learning sessions to evaluate the media further and to include a control class for comparison. The researchers also recommend that teachers implement ARES in science learning, particularly for ecosystem topics, to ensure that learning activities involve direct observation of material objects and are oriented toward relevant local wisdom within the surrounding environment.

Credit authorship contribution statement
Zidni Alfian Barif: Conceptualization, Investigation, Methodology, Data curation, Writing original draft. **Apnorlince Paulus:** Methodology, Validation, Project Administration. **Raihatul Jannah:** Designing tables and figures, Interpreting data, Formal analysis. **Alwiana Hamidah Nugroho:** Resources, Conceptualization, Writing original draft. **Nabila Ariiqah:** Conceptualization, Interpreting data, Proofreading.

Declaration of competing interest
The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work, results, or interpretation reported in this article.

Data Availability Statement
The data supporting the findings of this study are not publicly available as they contain information that could identify research participants. However, the data are available from the corresponding author upon reasonable request and with permission from the relevant authorities.

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Ethical Declaration

The study obtained permission from the Yogyakarta Education Office and the elementary school. All participants provided informed consent prior to their involvement in the study, including consent for note-taking and the use of their responses and observational data for research purposes. Participation was voluntary, and participants could withdraw at any time without any consequences. To protect confidentiality, no personally identifiable information was collected; all data were anonymized at the time of collection, stored securely, and access was restricted to the research team.

Declaration of AI statement

The authors acknowledge the use of ChatGPT (GPT-5.2, OpenAI) solely to assist with language refinement, grammar checking, and improving the readability of the manuscript. All conceptualization, study design, data collection, analysis, interpretation, and conclusions were carried out by the authors, who take full responsibility for the content of this manuscript.

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