

Development of Augmented Reality in Wetlands Context on Global Warming Material to Enhance Students' Conceptual Understanding and Motivation

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Article Info	Abstract
Article history: Received: September 17, 2025 Accepted: November 12, 2025 Published: November 14, 2025 Keywords: Augmented reality Conceptual understanding Global warming Student motivation Wetland This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License © 2025 Berkala ilmiah Pendidikan Fisika	The development of a wetland-context Augmented Reality (AR) learning media for global warming was conducted to address low student understanding and motivation in environmental science. This study aims to assess the validity, practicality, and effectiveness of the AR media (GLOWET-AR) in enhancing conceptual understanding and learning motivation among high school students. Using a Research & Development (R&D) approach, a limited pilot test was carried out involving expert validation, pretest-posttest evaluation of concept understanding and motivation (with N-Gain metrics), and a user response questionnaire. Findings reveal that GLOWET-AR is valid, effective, and practical. Expert validation averaged 92.5% categorized as highly appropriate. Conceptual understanding improved with an average N-Gain of 0.71, categorized as high, while learning motivation also increased with an average N-Gain of 0.62, categorized as medium. Student responses to the media were highly positive, with an average response rate of 89%, categorized as very good. Implications include recommending authentic local contexts in AR media development for other subjects, alongside technical and pedagogical support for educators. Despite the positive outcomes, the limited scale of the pilot test implies that these effects may not be fully generalizable across diverse student populations.
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INTRODUCTION

Global warming is one of the most pressing environmental issues that requires serious attention, making its inclusion in the education curriculum essential, particularly in understanding its impacts on the environment, including wetland ecosystems. Wetlands play a crucial role in carbon sequestration and global carbon balance, maintaining ecosystem stability, and serving as habitats for diverse species (Dar & Dar, 2024; Mitsch & Gosselink, 2015; Tang et al., 2024). This is especially relevant for Banjarmasin, known as the “city of a thousand rivers,” where wetlands represent an ecosystem whose sustainability must be preserved.

As the future agents of change, students have a significant role in dealing with global warming, which threatens life on Earth (Syamsiyah & Novarinda, 2024). As the next generation, students contribute to improving the environment by promoting environmental awareness in schools and communities and practicing an eco-friendly lifestyle (such as

reducing the use of plastic, saving energy, and growing trees). Additionally, students can be involved in environmental activism initiatives such as advocating for green policies at school or participating in scientific research that finds solutions to the effects of climate change. With understanding and creative minds, students are able to take actions that will change the world for a better future.

The potential for students to be change agents in the challenge of global warming can only be achieved if they have a strong conceptual grasp of the issue. Nonetheless, students have limited awareness about the field of global warming ([Kurup et al., 2021](#); [Teixeira et al., 2024](#)). Previous research in Indonesia also pointed out that students' concept of global warming is low and limited ([Suryawirawati et al., 2018](#)), where one of the causes was due to their unmotivated attitude as a learner ([Agustin et al., 2021](#); [Eliza et al., 2022](#)). Initial observations of several teachers and students in high schools in Banjarmasin showed that the public does not understand well the material about global warming. Traditional teaching methods often suffer from a lack of motivation, requiring novel and effective learning media that can enhance both conceptual understanding and learners' motivation.

The current developments in technology require new learning media that creatively contribute to the development of concepts and enhance students' motivation. Augmented reality (AR) is one technology that has the potential to enhance learning ([Dunleavy & Dede, 2014](#)). AR allows them to see things as they really are, using 3D interactive animations ([Billinghurst et al., 2015](#)). Using AR to study global warming in the wetland environment enables students to achieve a stronger immersion and motivation in learning about environmental problems that are increasingly important due to the impact of climate change.

From a theoretical perspective, dual coding supports learning by combining visual and verbal information, which helps strengthen memory and deepen conceptual understanding ([Paivio, 1991](#); [Richard & Fiorella, 2021](#)). At the same time, AR interactivity allows students to engage directly with and manipulate 3D objects, fostering greater involvement and a stronger sense of control over their learning ([Akçayır & Akçayır, 2017](#)). Embodied learning also plays a key role, as it connects physical interaction with cognitive processing, making abstract physics concepts easier to grasp ([Johnson-Glenberg, 2018](#)). Recent meta-analyses suggest that AR can positively influence both learning outcomes and student motivation, although its impact largely depends on how it is designed and implemented within specific learning contexts ([Li et al., 2025](#); [Zuo et al., 2025](#)).

Consequently, this study is important as the basis for developing new AR learning media that address global warming topics in wetlands. This course will not only enhance students' holistic view of the effects of global warming but also motivate them to contribute to initiatives for environmental protection. Furthermore, AR learning media is expected to evolve in line with education technology and appeal to today's digital generation, who are born into a world of personal device ownership. This media development product is expected to become a new learning model that is applicable in any area as an inventory tool for the quality of environmental education in Indonesia.

Some previous studies constructed AR learning in science education ([Godoy Jr, 2021](#); [Shaghaghian et al., 2024](#)). Yet, studies focused on AR media in the context of wetlands and global warming are scarce. This research contributes novelty by combining AR and a global warming study in wetland-based learning for Banjarmasin students' characteristics. Banjarmasin, known as the "City of a thousand rivers," boasts extensive wetland systems, including river, swamp, and mangrove zone areas, which are crucial in mitigating climate change. As a city with lowland characteristics, the considerable amount of water and rivers in Banjarmasin are sensitive to global warming, which can cause a rise in sea level, a decrease in water quality, and loss of wetland biodiversity. Therefore, wetland-based global warming education is very suitable for students in this city because theoretical knowledge

combined with local environment explanations can enhance their ecological awareness and potential motivation to be involved in the conservation of wetlands.

METHODS

The research employed the Research and Development (R&D) method, utilizing the ADDIE model ([Sugiyono, 2008](#)), which consists of Analysis, Design, Development, Implementation, and Evaluation, to describe the validity, practicality, and effectiveness of the media in enhancing students' conceptual understanding and learning motivation. Data were collected through observations, interviews, conceptual understanding tests, and questionnaires.

The conceptual understanding test consisted of 30 multiple-choice items with a maximum score of 100, administered during both the pretest and posttest stages. Questionnaires or validation sheets were used to assess the appropriateness of the learning media before implementation in the classroom. Validation was conducted by two experts and one practitioner, each of whom evaluated the media based on three aspects: content validity, display, and usability.

The Learning Motivation Questionnaire, based on the ARCS model, encompasses four main aspects: Attention, Relevance, Confidence, and Satisfaction. This instrument comprised 20 items rated on a 4-point Likert scale. It was administered both before and after the learning activities using GLOWET-AR (Global Warming in the Context of Wetlands–Augmented Reality). Additionally, a user response questionnaire consisting of 15 items on a 4-point Likert scale was administered to students after they had used the learning media to evaluate their learning experiences. Data analysis for the conceptual understanding test was conducted using the N-Gain to measure students' improvement in understanding. Table 1 presents the N-Gain criteria ([Hake,1998](#)) used to measure students' improvement in understanding.

Table 1 N-Gain criteria

N-Gain	Criteria
$g \geq 0.7$	high
$0.7 > g \geq 0.3$	Medium
$g < 0.3$	low

Data from the expert validation sheet were analyzed using appropriate percentage calculations. Table 2 presents the interpretation of the appropriateness of the validated AR media ([Arikunto, 2006](#)).

Table 2 Interpretation of AR media appropriate

Percentage (%)	Interpretation
75-100	Highly Appropriate
50-74.99	Appropriate
25-49.99	Inappropriate
0-24.99	Highly Inappropriate

The improvement of learning motivation was also analyzed using the N-Gain, applying the same calculation method as in the conceptual understanding test. The criteria for measuring improvement in learning motivation are presented in Table 1. Data from the user response questionnaire were analyzed by calculating the percentage of students' responses, which were then categorized based on the criteria ranges presented in Table 3 ([Hapsari & Zulherman, 2021](#)).

Table 3 Interpretation of students' responses

Percentage (%)	Interpretation
76-100	Very Good
51-75	Good
26-50	Fair
0-25	Poor

RESULTS AND DISCUSSION

The learning media developed in this study is an Augmented Reality (AR)-based instructional tool contextualized within wetlands for the topic of global warming. The media consists of several components, including the initial layout, user guide, and learning materials.

Analysis

The analysis stage of this research was carried out to identify the initial needs of teachers and students regarding the physics learning process in schools. Preliminary observations and interviews with teachers and students at senior high schools in Banjarmasin indicated that students have not fully understood the concept of global warming. Interviews with teachers revealed that students experience difficulties in directly presenting concepts related to global warming in the classroom. This is due to the limited availability of teaching materials and appropriate learning media for this purpose. Furthermore, students stated that their learning mainly focuses on the teacher's delivery of the material. Conventional teaching methods tend to reduce students' motivation to learn, thus highlighting the need for innovative learning media that can enhance both conceptual understanding and learning motivation.

The content must also align with the learning outcomes of the *Merdeka Curriculum* for senior high schools, particularly the competencies that require students to identify the causes and impacts of climate change, as well as to engage in mitigation actions, ensuring that instructional synchronization can improve learning outcomes ([Amores-Valencia et al., 2022](#)). Based on this needs analysis, the AR media developed was designed to adjust its content, design, and interactivity to bridge the gap in students' conceptual understanding and to maximize their learning motivation.

Design

After analyzing the needs of teachers and students, the next step was to design the GLOWET-AR learning media by creating an initial storyboard. Figure 1 illustrates the storyboard, which would later be developed into AR during the development stage. At this stage, the instruments were also constructed to evaluate the appropriateness of GLOWET-AR, the conceptual understanding test, the learning motivation questionnaire, and the teacher and student response questionnaires. Each instrument was validated to ensure its appropriateness for use in the limited trial.

In the design phase, the storyboard and learning scenario for GLOWET-AR were designed to embed an authentic activity that enables students to experience simulations of climate change and wetland ecosystem issues, as well as reflect on mitigation-driven decisions. This line of thought is also supported by the literature, which suggests that integrating simulation and reflection in AR design enhances not only conceptual grasp but also student engagement ([Alkhabra et al., 2023](#)). The design of the interface/user experience (UI/UX) was also simple, responsive, and low-latency because prior work reveals that technical factors such as tracking, latency, and usability have a strong impact on the learning effectiveness in AR and students' motivation ([Li et al., 2025](#)).

SLIDE	CONTENT	FEATURE	SENTENCE
1	Start = Go to Slide 2 AR View = AR image of all barcodes Instructions = Use AR to go to slide 10		
2	Hyperlinks to each slide Home to slide 1 Material 1 to slide 3 Material 2 to slide 7 Material 3 to slide 9		
3	AR View: 3D illustration of Earth experiencing global warming from space. The process of global warming can be seen. 	- 3D Earth has a sign! Can be clicked to reveal the meaning of global warming - The thermometer emoticon has a! Sign which can be clicked to display the text According to National, etc. - Add a mangrove image to the bottom right corner, along with the text "Click me." When clicked, discussion question 1 will appear. - There is a sign! On each arrow, text will appear as in the picture	- Global warming is the long-term increase in the average temperature of the Earth's surface due to increasing concentrations of greenhouse gases (GHG) in the atmosphere. - According to the National Aeronautics and Space Administration (NASA), the Earth's surface temperature in 2022 increased by 0.89 °C compared to the annual average temperature during the period
	- The sun radiates light - The arrow from the sun moves - The Earth rotates - Add a thermometer emoticon near the earth (example thermometer image as shown in the slide)		1951-1980. This temperature is the fifth warmest on record and continues a long-term warming trend despite three consecutive years of La Nina in the tropical Pacific Ocean. - Discussion 1: What will the Earth's surface temperature be in 2025? - Each writing! Like the picture

Figure 1 GLOWET-AR storyboard

Development

Following the design phase, the GLOWET-AR storyboard was developed into an AR-based learning medium using additional applications. Figure 2 presents the outcome of the GLOWET-AR media after entering the development stage.



Figure 2 Interface GLOWET-AR

Three experts then validated this learning media to assess the appropriateness of the AR. The three validators evaluated GLOWET-AR based on content, appearance, and usability aspects. Table 4 presents the validation results from the three validators.

Table 4 Validation percentage

Aspect	Percentage (%)	Interpretation
Content	94.75	Highly Appropriate
Visual Design	89	Highly Appropriate
Usability	94.25	Highly Appropriate
Average	92.5	Highly Appropriate

Validation of Augmented Reality (AR)-based learning media obtained an average score of 3.70 (92.5%) from three validators, included in the “highly proper” category. This result suggests that the dimensions of content, visual design, and pedagogical appropriateness are very well addressed. The finding is in line with a meta-analysis that indicates that the average effect size of AR use for higher education in general contexts ($g \approx 0.896$) was large and more specific regarding teaching purposes and learner performance ([Li et al., 2025](#)).

The validators not only scored the validation instrument but also provided feedback and recommendations for enhancing GLOWET-AR. These recommendations involved the addition of an exit button and fixing a couple of editorial mistakes on media, as well as the rearrangement of buttons on the initial screen to improve usability. After GLOWET-AR was validated, it was modified based on the validators’ comments and will be tested in a pilot trial.

Implementation

The implementation stage involved a limited trial with a small group of 30 high school students. Prior to the trial, students were given a pretest on conceptual understanding and learning motivation. The pretest aimed to assess students’ initial knowledge of global warming and their motivation to learn before using the GLOWET-AR media. After engaging with GLOWET-AR, students completed a posttest consisting of the conceptual understanding test, the learning motivation questionnaire, and a user response questionnaire regarding their experience with GLOWET-AR. Table 5 presents the data on students’ conceptual understanding obtained from the pretest and posttest, analyzed using the N-Gain test.

Table 5 N-Gain for the student' conceptual understanding

Average Score		N-Gain
Pretest	Posttest	
29.19	79.27	0.71

Table 6 presents the highest and lowest scores from both the pretest and posttest.

Table 6 Highest and lowest scores

Highest Score		Lowest Score	
Pretest	Posttest	Pretest	Posttest
56.67	83.33	26.67	66.67

Based on the data in Table 5 and Table 6, there was an increase in the average score from 29.19 in the pretest to 79.27 in the posttest. To measure this improvement, an N-Gain calculation was conducted. The resulting N-Gain value was 0.71. Referring to Table 1, this N-Gain value falls into the *high* category. This indicates that the use of the GLOWET-AR learning media in the context of wetlands was effective in enhancing students’ conceptual understanding. Utilizing technology in learning will help students to understand physics concepts ([Lasiani et al., 2025](#)).

The achieved N-Gain score demonstrates that the treatment applied, namely learning with GLOWET-AR, successfully improved students' conceptual understanding of the topic of global warming. This success can be attributed to two main components: the utilization of the wetland context and the specific format of GLOWET-AR itself, as illustrated in Figure 3.



Figure 3 GLOWET-AR Visual

The wetland context, combined with the global warming material in GLOWET-AR, encourages students to connect local and global impacts, such as how local activities like wetland conservation contribute to global warming mitigation efforts. Climate Change Education (CCE) shows that from 2013 to 2022, academic discussions have largely focused on student awareness, curriculum, and learning factors such as motivation and instructional strategies. The need for local contextualization (for example, wetlands in tropical areas such as Kalimantan) has become a critical aspect in CCE to ensure that the material is not only theoretical but also sensitive to students' local conditions (Hadiapurwa et al., 2024). Table 7 presents the data on students' learning motivation obtained from the pretest and posttest, which were analyzed using the N-Gain test.

Table 7 N-Gain for students' learning motivation

Aspect	Average		N-Gain
	Pretest	Posttest	
Attention	2.56	3.5	0.65
Relevance	2.53	3.67	0.77
Confidence	2.6	3.37	0.54
Satisfaction	2.63	3.33	0.51
Average	2.58	3.46	0.62

Learning motivation, although it increased to the medium category (0.62), indicates that the affective aspect needs further support. The literature suggests that the components of relevance and confidence in GLOWET-AR should be strengthened and accompanied by follow-up activities to sustain motivation (Zuo et al., 2025).

Table 8 shows the percentage of students' responses after using the GLOWET-AR learning media.

Table 8 Percentage of students' responses

Student Response (%)	Interpretation
89	Very Good

Students' responses to the media during implementation indicated that they considered the AR media to be "very good," meaning that the media was perceived as helpful for understanding and engaging attention; this result reinforces that AR media is not only statistically effective but also well accepted by users (Alkhabra et al., 2023). The

implementation was also supported by teacher training and the provision of user guidelines, which many studies have identified as key factors for the successful use of AR in classrooms ([Li et al., 2025](#)).

Evaluation

At the evaluation stage, measurements were carried out on the appropriateness of the developed AR learning media. The evaluation process was based on assessments and suggestions from validators, concept understanding tests, motivation questionnaires, and student response questionnaires.

The evaluation stage demonstrated that AR media is highly appropriate, as validated by experts, and has been proven to improve conceptual understanding significantly. Aksit's study (2025) showed that systematically designed instruction in environmental courses can enhance both students' knowledge and their risk perception of climate change ([Aksit, 2025](#)).

However, the evaluation of motivation, which fell into the medium category, indicates room for improvement, particularly in psychological aspects such as student satisfaction, material relevance, and learning through real experiences and tangible actions outside the classroom. Affective motivation often develops more slowly than cognitive aspects and requires a greater dose of interaction and direct experience ([Törmänen et al., 2025](#)).

CONCLUSION

Based on the results, the development of augmented reality-based learning media in the wetland context for global warming material is valid, practical, and effective in improving students' conceptual understanding and motivation, as demonstrated in limited trials. The validity test obtained an average percentage from three experts of 92.5%, which falls into the "highly appropriate" category. The concept understanding test obtained an average N-Gain score of 0.71, which falls into the "high" category. Student motivation obtained an average N-Gain score of 0.62, which falls into the "medium" category. The student response questionnaire obtained an average percentage of 89%, which is categorized as "very good." Despite the positive results, this study has limitations, as it was conducted only in limited trials; therefore, the observed improvements cannot be fully generalized and do not yet represent the broader variety of student characteristics. However, these results should be interpreted as preliminary. Future research involving control groups, a larger number of participants, and follow-up or retention tests is needed to determine the effectiveness of the intervention confidently. This study recommends leveraging authentic local contexts in the development of AR learning media for other topics to enhance students' conceptual understanding and stimulate their learning motivation.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this article.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, L and IAS; methodology, L; formal analysis, IAS; writing preparation of the original draft, L and IAS. All authors have read, reviewed, and approved the final version of the manuscript prior to publication.

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