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Development of Augmented Reality Learning Media Based on the Subak System to Improve Elementary Science Learning

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Abstract: This study aims to develop and examine the effectiveness of Subak system–integrated Augmented Reality (AR) media as a form of Balinese local wisdom in elementary science learning. The research employed a Research and Development (R&D) method using the ADDIE model and involved 44 third-grade students of SD Negeri 18 Denpasar as trial participants. The AR media was designed to visualize the water cycle through three-dimensional representations linked to Subak elements, including dams, irrigation channels, and rice fields. The effectiveness of the developed AR media was evaluated using a one-group pretest–posttest design. Students completed a cognitive achievement test on water cycle concepts before and after the implementation of the AR media. Learning improvement was analyzed using normalized gain (N-gain) scores and a paired-sample t-test to determine the statistical significance of the observed gains. The results indicate that the developed AR media demonstrates a very high level of validity and is effective in improving students' science learning outcomes. Beyond cognitive gains, the media enhances contextual learning, fosters environmental awareness, and strengthens students' appreciation of local wisdom. These findings confirm that integrating AR technology with the Subak system provides a meaningful and innovative approach to elementary science learning, aligning with the demands of digital-era education.

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Introduction

Science learning in elementary schools aims not only to develop students' cognitive understanding of scientific concepts but also to foster contextual awareness and connections with their environmental and cultural surroundings. Contemporary curricula emphasize contextual, collaborative, and problem-oriented learning that encourages students to actively construct knowledge rather than merely memorize information (Daryanto, 2022; Irfansyah, 2023). However, science instruction in many elementary classrooms still relies heavily on teacher-centered approaches and static two-dimensional learning media, which are often insufficient for explaining abstract and dynamic processes such as the water cycle. The dominance of text-based explanations and limited visualization reduces students' opportunities to observe and explore scientific phenomena, leading to low conceptual understanding and limited engagement in science learning (Erbas, 2019; Agustini, 2023). Context-based learning grounded in local wisdom has been shown to enhance students' understanding and learning motivation by connecting scientific concepts with real-life experiences (Arnita, 2021; Pradnyana, 2020). In the Balinese context, the Subak system represents a traditional water management practice closely related to the water cycle concept.

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However, its integration into science learning remains limited. Meanwhile, Augmented Reality (AR) technology offers strong potential to visualize complex processes interactively, yet most AR-based learning media still lack integration with local cultural contexts.

Science education in elementary schools aims not only to develop students' cognitive mastery of scientific concepts but also to cultivate contextual understanding, character formation, and awareness of their local environment and culture. The demands of 21st-century education require learning that integrates science, technology, and local wisdom so that abstract concepts become meaningful and relevant to students' daily experiences. Contemporary curricula emphasize contextual, collaborative, and problem-oriented learning, encouraging students to actively construct knowledge rather than merely memorize information (Daryanto, 2022; Irfansyah, 2023). Studies show that context-based learning grounded in local wisdom improves conceptual understanding, motivation, and the meaningfulness of science learning while strengthening environmental awareness from an early age (Arnita, 2021; Pradnyana, 2020). In Bali, the Subak system represents a traditional water management practice closely related to the water cycle concept. However, science learning in many elementary schools still relies on teacher-centered approaches and static two-dimensional media, limiting students' exploration and conceptual understanding (Erbas, 2019; Agustini, 2023). Therefore, integrating Subak into interactive learning media becomes a strategic step toward more meaningful and contextual science education.

The development of digital technology in education has opened up new opportunities to improve the quality of science learning in elementary schools, one of which is through the use of Augmented Reality (AR) technology. In general, AR allows three-dimensional virtual objects to be interactively integrated into the real environment, so that abstract concepts in science can be visualized more concretely and easily understood by students. Various studies show that AR can provide a more immersive learning experience, increase student attention, and encourage active engagement in the learning process (Hurst, 2021; Muhammad, 2021). Recent empirical findings reveal that the use of AR has a significant positive impact on improving students' learning focus, conceptual understanding, and long-term retention in science learning, especially in procedural and dynamic materials (Alkhabra, 2023). This shows that AR has great potential as an innovative learning medium that can address the limitations of conventional media. However, upon further examination, most research and development of AR media in primary education is still strongly oriented towards cognitive aspects alone, such as improving learning outcomes and conceptual understanding. The integration of affective dimensions, character values, and local cultural contexts has not been a major focus in AR development(Miguel, 2025; Ramtohul, 2024). In fact, science learning in elementary schools aims not only to build scientific knowledge but also to instill local wisdom values relevant to students' lives. The lack of integration of local cultural values in AR media has the potential to make learning ahistorical and detached from the socio-cultural context of students. This condition indicates an important research gap, namely the need to develop AR that is not only cognitively effective but also capable of systematically accommodating local cultural values so that science learning becomes more contextual, meaningful and rooted in the environment and identity of elementary school students (Wahyu, 2020; Wilder et al., 2024).

Previous studies show that Augmented Reality (AR) technology has strong potential as a culture-based educational medium, particularly for introducing and preserving the Subak system as a world cultural heritage. Several AR developments have focused on presenting Subak's structures, tools, and irrigation practices through interactive three-dimensional

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visualization, making complex cultural concepts easier to understand (Lyazzat, 2024; Ketut, 2021). However, these studies primarily emphasize cultural introduction, tourism promotion, and public awareness rather than supporting formal science learning in elementary schools. The connection between Subak visualization and science curriculum objectives, especially the water cycle concept, remains limited. In addition, previous studies rarely evaluate students' conceptual understanding or learning outcomes, indicating the need for AR-based Subak media specifically designed for elementary science learning.

The uniqueness of this study lies in integrating Augmented Reality (AR) technology with the Subak system as local wisdom to improve elementary students' science learning outcomes, particularly on the water cycle topic. Unlike many AR developments that mainly focus on visualizing abstract concepts, this study positions Subak as a real and meaningful learning context closely related to students' daily lives in Bali. The traditional Subak irrigation system, which reflects ecological and cultural values, is used to visualize processes such as evaporation, condensation, precipitation, and water flow within an authentic environmental setting. Through interactive three-dimensional visualization, students can observe and explore scientific processes in a contextual way, strengthening conceptual understanding while increasing engagement and appreciation for local environmental sustainability.

Research Method

The research method used in this study was Research and Development (R&D) with the ADDIE model approach (Analysis, Design, Development, Implementation and Evaluation), which was chosen because it has a systematic, structured and relevant workflow for the development of technology-based learning media (Indrawan, 2022). This study involved 44 third grade students at SD Negeri 18 Denpasar as test subjects, who were selected because they were at the concrete operational stage of cognitive development, thus requiring visual and contextual media to understand science concepts, especially the water cycle material. In the Analysis stage, the researcher conducted a needs analysis through a review of the elementary school science curriculum, observation of the learning process and analysis of student characteristics and learning problems, which showed that the water cycle material was still difficult to understand because it was abstract and delivered in a conventional manner. The Design stage focused on designing learning strategies and Augmented Reality (AR) media that integrated the Subak system as a context of local wisdom, including the preparation of storyboards, user interaction flows, marker designs and mapping of the water cycle concept with Subak elements such as dams, irrigation channels and rice fields. The Development stage included developing an AR application using Unity and Vuforia software, creating three-dimensional objects, animating the water cycle process and integrating learning narratives. The developed product was then validated by science subject matter experts, learning media experts and AR technology experts using Likert scale-based instruments and analyzed using Aiken's V index. The Implementation stage was carried out through limited trials on 44 third grade students at SD Negeri 18 Denpasar to determine the practicality, student responses and initial impact on learning outcomes. Furthermore, the Evaluation stage employed a One-Group Pretest–Posttest Design to measure the improvement of students' cognitive achievement after using the Subak-integrated AR media. In this stage, students completed a pretest before the learning intervention and a posttest after using the AR media. The difference between the two scores was used to identify the improvement in students' understanding of the water cycle concept, while student response

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questionnaires were administered to evaluate the attractiveness and ease of use of the media. The quantitative data were analyzed using descriptive statistics and learning gain analysis. This approach is in line with the view that development research is a scientific process of designing, producing and testing learning products to ensure they are suitable and effective for use in real contexts.

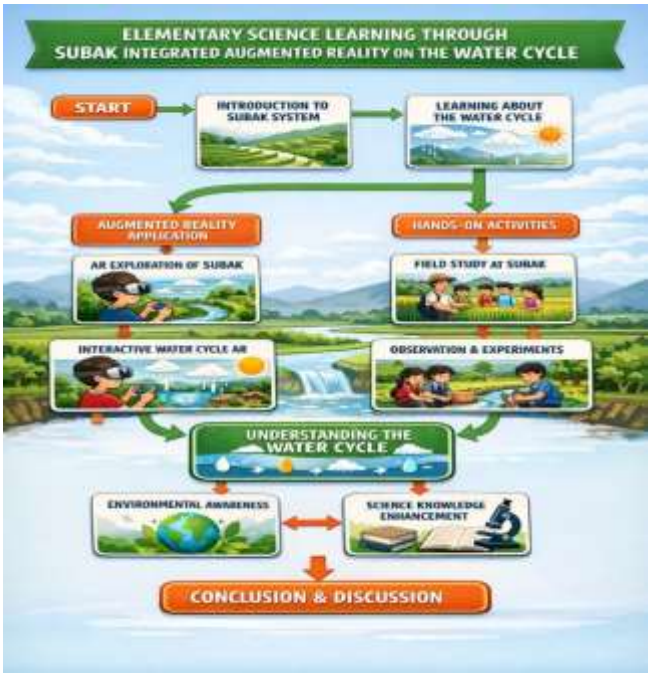

Figure 1. Flowchart of the Integrated Subak Water Cycle Augmented Reality Menu

Figure 1 illustrates the operational flow of the Subak-integrated Augmented Reality (AR) media for water cycle learning. The process begins with application initialization, where the system activates the camera to detect markers and display three-dimensional objects. Students then select the interaction mode and follow tutorial guidance before entering the AR interaction stage. At this stage, students explore the water cycle processes through visual and audio responses within the Subak irrigation context. The session concludes with evaluation and completion stages.

Data collection in this study employed two main techniques: expert validation and student response questionnaires. Expert validation was conducted to ensure that the Subak-integrated Augmented Reality (AR) media met standards of content accuracy, instructional design, and technical feasibility before classroom implementation. The validation process involved subject matter experts, learning media experts, and AR technology experts who evaluated the relevance of the material, the clarity of the interface and interactivity, and the stability and usability of the application. The instruments were developed using Likert-scale questionnaires covering aspects of content validity, construct validity, and conceptual validity. In addition, student questionnaires were used to measure responses related to practicality, attractiveness, and learning experiences after using the AR media.

The effectiveness of the developed Augmented Reality (AR) media was analyzed using a One-Group Pretest Posttest Design to measure the improvement in students' cognitive learning outcomes after the learning intervention. Students completed a pretest before using the AR media and a posttest after the learning activities were implemented. The difference between pretest and posttest scores was analyzed using a Paired Sample t-test to determine whether the improvement was statistically significant. Prior to hypothesis testing, a normality

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test was conducted to ensure that the data met the assumptions for parametric analysis. In addition, the level of improvement in learning outcomes was measured using the Normalized Gain (N-gain) score.

Results and Discussion

Results

The results of the development and implementation of Subak-integrated Augmented Reality (AR) media indicate that three-dimensional visualization provides a more concrete and meaningful representation of science learning for elementary school students. The AR media was designed to bridge the abstract concept of the water cycle by presenting it through interactive and contextual learning experiences. In this media, the Subak irrigation system is visualized coherently, enabling students to observe the sequential processes of evaporation, condensation, precipitation, and infiltration. These processes are directly linked to elements of the Subak system, such as dams, irrigation channels, and rice fields, allowing students to understand the relationship between scientific processes and real-world water management practices. The visual design uses bright colors, realistic object proportions, and smooth animations to increase students' attention and engagement. An intuitive and child-friendly interface allows students to interact easily with AR objects, while interactive labels and audio narration support conceptual understanding and reduce cognitive load in learning abstract science concepts. These findings support previous studies showing that AR technology can enhance conceptual understanding, engagement, and retention in science learning by providing immersive visualization of complex processes (Erbas & Demirer, 2019; Muhammad et al., 2021; Alkhabra et al., 2023). Furthermore, integrating local wisdom such as the Subak system into AR-based learning media strengthens contextual learning and connects scientific knowledge with students' cultural and environmental experiences, thereby making science learning more meaningful and relevant (Pradnyana & Setiawan, 2020; Wahyu, 2020).

Figure 2. Menu Display of the Subak Water Cycle AR Application

Figure 2 shows the initial interface of the Water Cycle and Balinese Subak-themed Augmented Reality (AR) learning media, which is specifically designed for elementary school students. In general, this visual display emphasizes a child friendly, contextual, and locally based learning environment, with a backdrop of Subak rice fields, mountains, rivers, and natural elements such as the sun and rain that reflect the water cycle process. The illustration of children learning together reinforces the message that learning is collaborative, fun, and student-centered. Specifically, in the center of the screen is a main button in the shape of a play icon that serves as the entrance to the interactive AR experience. Below it is a Download Marker and Guide menu, which shows that this media is systematically designed and easy to operate by both students and teachers. The presence of simple but communicative navigation elements shows that the interface design not only emphasizes aesthetics but also

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pays attention to ease of use and the readiness of students to start technology-based learning and local wisdom.

Figure 3. Guide to Using AR Integrated Water Cycle Subak

Figure 3 presents interactive guidelines for using the Subak Bali Integrated Water Cycle Augmented Reality (AR) media designed for elementary students. The interface provides simple step-by-step instructions, including accessing the AR menu, scanning the marker, and displaying interactive 3D objects. Supported by a Balinese landscape background and child-friendly visuals, the guide helps students easily understand the usage process while encouraging independent and engaging technology-based learning experiences.

Figure 4. Display in the Water Cycle Augmented Reality (AR) application

Figure 4 presents the Augmented Reality (AR) Water Cycle media integrated with the Subak system, where water cycle processes are visualized in three dimensions on a marker surface. The AR objects illustrate components such as the sun, clouds, rain, rivers, and landscapes representing evaporation, condensation, precipitation, and runoff. Contextualized through the Subak environment, this visualization helps students connect abstract scientific concepts with familiar local systems, while interactive features support deeper exploration and understanding.

Figure 5. Display in the Integrated Water Cycle Subak Augmented Reality (AR) application

Figure 5 presents an interactive Augmented Reality (AR) display integrating the Subak system into water cycle learning for elementary students. The three-dimensional visualization shows rice fields, irrigation channels, and water flow from the source to agricultural land. AR objects appear on markers, allowing observation from multiple angles.

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Interactive features such as audio and zoom support exploration, helping students connect scientific water cycle concepts with local environmental and cultural practices.

The feasibility of the Subak Integrated Water Cycle Augmented Reality (AR) media was obtained through a validation process by experts using Aiken's V index as the content validity coefficient. This validation involved several validators consisting of elementary school science subject matter experts, learning media experts, and AR technology experts. The validators assessed the suitability of the water cycle content with the curriculum, the accuracy of the Subak system integration as a learning context, the clarity of three-dimensional visualization, and the ease of use of the media by students. Aiken (1985) states that the Aiken's V index is used to measure the level of agreement among experts on the validity of an item or product being developed. Therefore, the use of this index provides a strong quantitative basis for assessing the feasibility of AR media from a scientific and pedagogical perspective.

Table 1. Expert Test Validity Criteria

Average Score	Validity Level
$0.8 < V \leq 1.0$	Very Valid
$0.4 < V \leq 0.8$	Sufficiently Valid
$0 < V \leq 0.4$	Invalid

The results of data validity grouping show that there are clear criteria for determining the suitability of the instruments or products developed. In general, validity assessment is based on the average score obtained from the evaluation results, thus providing an objective picture of data quality. Data with a validity score in the range of 0.80 to 1.00 is categorized as highly valid, indicating that the data has a very high level of suitability and is suitable for use without requiring revision. Furthermore, data with a validity score of more than 0.40 to 0.80 is categorized as valid, which means that the data has met the eligibility criteria, but limited improvements can still be made for refinement. Meanwhile, data with a validity score in the range of 0.00 to 0.40 is declared invalid, so it is not recommended for use in further analysis. This grouping provides a systematic basis for decision-making regarding the use of validated data.

Table 2. Assessment of Media Validators of Augmented Reality (AR) Integrated Water Cycle Subak

Validator	Aiken's V	Category
Validator 1	0.97	Very Valid
Validator 2	1	Very Valid
Average	0.995	Very Valid

The results presented in Table 2 indicate that the Subak-integrated water cycle Augmented Reality (AR) media achieved a very high level of validity based on expert evaluation. Validator 1 provided an Aiken’s V score of 0.97, while Validator 2 gave a score of 1.00, both categorized as very valid. These results indicate strong agreement among experts regarding the suitability of the content, the accuracy of the integration of the Subak system, and the clarity of the AR visualization. Overall, the average Aiken’s V score obtained was 0.985, which confirms that the developed AR media has a very high level of validity and is appropriate for use in elementary science learning.

Table 3. Aiken's V Index on Each Aspect

Aspect	Aiken's V	Category
Content	1.000	Very Valid
Presentation	0.962	Very Valid
Characteristics	1.000	Very Valid

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Aspect	Aiken's V	Category
Average	0.987	Very Valid

The results presented in Table 3 indicate that the Subak-integrated Augmented Reality (AR) media demonstrates a very high level of validity across all evaluated aspects. The content aspect obtained an Aiken's V value of 1.000, indicating perfect agreement among experts regarding the accuracy and relevance of the learning material. The presentation aspect achieved an Aiken's V value of 0.962, which also falls within the very valid category and indicates that the visual design, media organization, and clarity of information are considered highly appropriate. Furthermore, the characteristics aspect obtained an Aiken's V value of 1.000, reflecting strong agreement regarding the technological integration and usability of the media. Overall, the average Aiken's V value of 0.987 confirms that the developed AR media has a very high level of validity and is suitable for implementation in elementary science learning.

Table 4. Students' Cognitive Learning Outcomes on Water Cycle Concepts

Indicator	Score	Category
Explaining the usefulness of water for humans	3.20	Very good
Mentioning the uses of water for animals and plants	3.042	Good
Explaining the meaning of the water cycle	3.030	Good
Analyzing the causes of the water cycle	3.011	Good
Determining ways to maintain the sustainability of the water cycle	3.214	Very good
Analyzing the impact of the water cycle on life	3.041	Good
Determining ways to maintain the availability of clean water in life.	3.035	Good
Explaining the impact of water quality on life	3.017	Good
Average	3.074	Good

The results presented in Table 4 indicate that students' cognitive learning outcomes on the water cycle concept is generally in the good category, with an overall average score of 3.074. The highest score was obtained in the indicator determining ways to maintain the sustainability of the water cycle (3.214), followed by explaining the usefulness of water for humans (3.20), both categorized as very good. Meanwhile, other indicators, such as explaining the meaning of the water cycle, analyzing the causes of the water cycle, and determining ways to maintain clean water availability, were categorized as good, indicating that students were able to understand and analyze the concepts presented through the Subak-integrated AR media. These results suggest that the use of AR visualization integrated with local context can support students' conceptual understanding of water cycle processes in elementary science learning.

Discussion

The results of this study indicate that the use of Augmented Reality (AR) media integrated with the Subak system contributes significantly to improving the quality of elementary science learning, particularly in cognitive understanding and contextual engagement. The interactive three-dimensional visualization presented through AR allows students to observe the water cycle processes more concretely while linking them to the real-world irrigation practices of the Subak system. This approach makes abstract scientific concepts easier to understand and increases students' learning engagement. These findings can be interpreted through the perspective of Cognitive Load Theory, which explains that well-designed visual learning media can reduce extraneous cognitive load by presenting complex information in a clear and structured form (Sweller, 2011; Mayer, 2020). In the

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Subak-integrated AR media, dynamic visualization, interactive labels, and contextual representations help students process information more efficiently, thereby supporting deeper conceptual understanding of the water cycle. The integration of local wisdom also strengthens meaningful learning because students relate scientific knowledge to familiar cultural and environmental practices. However, the relatively limited number of participants and the availability of technological devices restrict the generalization of the findings. Future research should involve larger samples and broader experimental designs to further examine the effectiveness and scalability of locally contextualized AR-based science learning.

Conclusion

The results of this study indicate that the development of Augmented Reality (AR) learning media integrated with the Subak system has significant potential to improve the quality of elementary science learning, particularly in the topic of the water cycle. The validation results show that the developed media achieved a very high level of validity, with an Aiken's V index of 0.991, indicating strong agreement among experts regarding the suitability of the content, presentation, and media characteristics. In addition, the implementation results demonstrate that the media is effective in supporting students' understanding of science concepts, as reflected in the average learning outcome score of 3.074, which falls into the good category. The use of AR-based three-dimensional visualization helps students understand abstract processes such as evaporation, condensation, and precipitation through contextual representations linked to the Subak irrigation system. This integration allows students to connect scientific explanations with real environmental practices familiar to their daily lives. Furthermore, the incorporation of local wisdom strengthens the contextual relevance of learning while encouraging environmental awareness and appreciation of local culture. Overall, the findings suggest that Subak-integrated AR media provides an innovative approach to science learning that combines technological visualization with culturally meaningful contexts, supporting more engaging and effective learning experiences for elementary school students.

Recommendation

Based on the findings of this study, several recommendations are proposed to strengthen the implementation and sustainability of Subak integrated Augmented Reality (AR) in elementary science learning. Teachers are encouraged to adopt AR media not merely as a supplementary visualization tool, but as an integral part of contextual learning strategies that connect scientific concepts with students' local environments and cultural experiences. Schools and educational stakeholders should provide institutional support, including teacher training and adequate technological infrastructure, to ensure effective and equitable use of AR-based learning media. Curriculum developers are advised to systematically incorporate local wisdom-based digital media into science curricula to promote meaningful, student-centered learning. Future researchers should expand the scope of this study by involving larger and more diverse samples, applying experimental designs, and examining long-term impacts on cognitive, affective, and environmental awareness outcomes. In addition, further development of adaptive and cross-platform AR applications is recommended to enhance accessibility and scalability across different educational contexts.

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