



'HydroAR': An Innovative Augmented Reality Learning Media for Water Cycle Material in Elementary School

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Abstract

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The water cycle is a fundamental science topic in primary education; however, its abstract and dynamic processes are often difficult for students to understand, highlighting the need for interactive learning media that can visualize concepts clearly. The primary objective of this study was to develop and evaluate the feasibility and effectiveness of HydroAR, an AR-based learning medium, in improving primary students' understanding and interest in the water cycle. Utilising the 4D Research and Development (R&D) model comprising the Define, Design, Develop, and Disseminate stages. The research involved a limited-scale pilot study with 22 students and one teacher, followed by a wider dissemination trial involving 30 students in Cirebon Regency. Data were collected via material and media expert questionnaires, alongside teacher and student response surveys, and were subsequently analysed using both quantitative and qualitative methods. HydroAR was successfully developed with interactive visualizations that made abstract concepts clearer and more engaging. Expert evaluations rated it as very feasible. Student usability results showed acceptable SUS scores of 83.18% and 85.58%. The implementation increased learning interest and improved water cycle understanding, indicating AR's potential to support interactive teaching and effective science concept visualization.

INTRODUCTION

Background of the Study

The instructional process at the primary school level plays a pivotal role in establishing students' cognitive foundations, particularly within the domain of Natural and Social Sciences (NSS), where the water cycle constitutes a core topic. This subject matter is frequently regarded as challenging due to its reliance on abstract processes, which necessitate clear and concrete visualisation to be effectively comprehended by students (Fensham, 2011; Geelan et al., 2022). However, classroom instruction remains largely dominated by conventional resources, such as textbooks and worksheets, which often prove insufficient for illustrating dynamic natural phenomena. This reliance may constrain students' conceptual understanding, particularly among learners possessing visual and kinaesthetic learning styles (Yesilyurt et al., 2021). Consequently, there is an increasing imperative for innovative

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instructional media capable of effectively supporting students in the comprehension of abstract scientific concepts.

The rapid advancement of Augmented Reality (AR) technology has engendered new avenues for innovation in educational media, specifically regarding the presentation of abstract content requiring visualisation (Jamil et al., 2023; Joseph et al., 2025; Nazeer et al., 2023). AR-based instructional tools enable the integration of two- or three-dimensional virtual objects into the physical environment in real-time, thereby providing interactive and immersive learning experiences (Rukayah et al., 2022). This technology aligns with the increasing diversity of student learning styles and the requirement for differentiated instruction mandated by the Indonesian Independent Curriculum (*Kurikulum Merdeka*). Prior studies indicate that AR serves as an effective pedagogical resource by augmenting learner engagement and supporting the attainment of learning outcomes (Adi et al., 2025; Kartini et al., 2024; Kiourexidou et al., 2024).

Empirical evidence consistently demonstrates the positive impact of AR on students’ academic performance, motivation, and interest. AR is recognised for its capacity to present compelling three-dimensional visualisations that stimulate curiosity and deepen understanding (Goebert & Greenhalgh, 2020; Sirakaya, 2018; Wang & Zhang, 2025). Various studies confirm that AR facilitates students’ ability to visualise abstract concepts, structure knowledge, and construct conceptual models (Bishop et al., 2020; Drljević et al., 2022; Rukayah et al., 2023). In the specific context of NSS—which integrates natural and social science concepts to foster critical thinking, problem-solving, and contextual understanding (Indonesian Ministry of Education, Culture, Research and Technology, 2022; Price & Schmitz, 2016; Priyatin, 2021). AR offers a promising solution to address instructional challenges such as limited resources, the abstraction of content, and declining student motivation (Alverson et al., 2006; Zahra, 2024).

Problem of the Study

The teaching of the water cycle in elementary schools often faces challenges because the concepts are abstract, dynamic, and difficult for students to visualize through conventional teaching methods such as textbooks and static images. As a result, many students experience low conceptual understanding, limited engagement, and reduced learning motivation (Fitri et al., 2025). In addition, the integration of interactive digital media in elementary science learning is still limited, and teachers often lack innovative tools that can present scientific processes in a concrete and meaningful way (Şimşek, 2024). Although augmented reality (AR) has the potential to enhance visualization and interactivity in learning, its application for water cycle material at the elementary level remains insufficiently developed and studied (Kalemkuş & Kalemkuş, 2023). Therefore, there is a need for innovative learning media that can support students’ conceptual understanding and engagement, leading to the development of HydroAR as an augmented reality-based learning solution.

Ideally, the integration of educational technology should enhance pedagogical effectiveness through the provision of interactive and adaptive instructional media that accommodate diverse learning styles. Augmented Reality (AR) is anticipated to play a strategic role in primary education by providing immersive visualisations that support conceptual understanding. However, within the Indonesian context, the implementation of AR in primary schools remains restricted. Although innovations have been introduced across various educational tiers, their application at the primary level is minimal. Hidayat et al. (2021) indicate that a paucity of research specifically addresses AR utilisation in primary education. Moreover, structural constraints, including limited technological infrastructure, insufficient teacher readiness, and restricted access to AR devices, continue to impede its effective adoption in schools.

Research’s State of the Art

Previous studies have highlighted the importance of integrating technology-based learning media to support elementary students’ understanding of abstract science concepts (Pratiwi et al., 2025). Theoretical perspectives such as constructivism and multimedia learning emphasize that students learn more effectively when information is presented through interactive, visual, and meaningful representations (Wahidin et al., 2025). In line with this view, digital learning media, including animations, simulations, and interactive applications, have been widely developed to improve conceptual understanding, motivation, and engagement in science learning. Augmented

Reality (AR), in particular, has gained increasing attention because it enables the integration of virtual objects into real-world environments, allowing students to observe scientific processes that are difficult to visualize through conventional instruction (Zekeik et al., 2025).

Augmented Reality (AR) offers significant benefits for teaching water cycle material in elementary school by transforming abstract and invisible processes into concrete, interactive visual experiences (Pratama et al., 2025). The water cycle involves dynamic and cyclical phenomena such as evaporation, condensation, and precipitation that are difficult for young learners to observe directly through traditional instruction. AR enables students to visualize these processes in three-dimensional and real-time representations, helping them understand the sequence, relationships, and continuity of the cycle more clearly. In addition, AR-based learning media can increase students' attention, motivation, and active participation, while supporting meaningful learning through exploration and interaction (Nadyarta et al., 2025). As a result, the use of AR in water cycle instruction has the potential to improve conceptual understanding and make science learning more engaging and effective for elementary students.

Existing research on AR-based instructional media for water cycle topics in primary schools consistently reports positive impacts on learning outcomes and student engagement. Developmental studies exhibit a recurring pattern of high media validity, favourable responses from teachers and students, and significant improvements in academic achievement (Amelia & Isdaryanti, 2024; Sujana et al., 2019). These findings suggest that AR-supported visualisation effectively facilitates the comprehension of abstract scientific concepts. Furthermore, user-centred development approaches involving experts, teachers, and students have been proven to enhance the feasibility and instructional relevance of such tools (Atut & Patonah, 2023). Corroborating studies also highlight that AR augments motivation, engagement, and conceptual grasp by offering immersive and stimulating learning experiences (Akçayır & Akçayır, 2017; Cheng & Tsai, 2013; Nasir et al., 2023; Santos et al., 2014). Nevertheless, despite these consistent findings, research specifically addressing AR-based water cycle instruction at the primary level remains limited and fragmented. This underscores the necessity for more systematic and pedagogically grounded development (Masurkar et al., 2024; Supriyadi et al., 2024).

Gap Study and Objective

Prior scholarship has established that AR-based media can enhance learning outcomes, motivation, and engagement in science education, including the water cycle (Akçayır & Akçayır, 2017; Amelia & Isdaryanti, 2024). It has also emphasised the importance of contextualised and user-centred design (Atut & Patonah, 2023; Nasir et al., 2023). Despite this, a distinct gap remains. Existing literature predominantly focuses on learning effectiveness, whereas studies that specifically analyse development needs and user responses at the primary level are scarce (Masneri et al., 2022; Masurkar et al., 2024; Supriyadi et al., 2024). Consequently, this study aimed to analyse the requirements for developing 'HydroAR' as an AR-based instructional medium for the water cycle. It further seeks to determine the feasibility of the tool and to evaluate teacher and student responses towards its utilisation in primary schools.

METHOD

Type and Design

This study employed the Research and Development (R&D) methodology, utilising the 4D model—Define, Design, Develop, and Disseminate—as established by Thiagarajan, Semmel, and Semmel (Washington, n.d.). This methodological framework is frequently applied in the development of educational products, particularly in the creation of instructional tools and innovative learning media. The 4D model is widely recognised for its efficacy in developing high-quality modules suitable for primary school students (Suryadi et al., 2019). The implementation of the 4D model in this study proceeded through four distinct stages. The Define stage entailed identifying learning needs, analysing student characteristics, and determining water cycle materials aligned with the Phase C Learning Outcomes of the Merdeka Curriculum (Independent Curriculum). These objectives were achieved through literature reviews, teacher interviews, documentation, and the analysis of learning outcomes.

The Design stage involved the creation of storyboards, media flowcharts, and AR interface designs grounded in user-centred principles, alongside the preparation of research instruments for expert validation and user responses. During the Develop stage, an initial HydroAR prototype was produced and validated by material and media experts. This was followed by a limited pilot study involving 22 primary school students and one teacher. Revisions to the media were implemented based on the feedback received, and effectiveness was examined through pre-test and post-test comparisons. Finally, the Disseminate stage encompassed a wider-scale trial to evaluate student responses to the refined HydroAR instructional medium.

Data and Data Sources

This study employed questionnaires as the primary instruments for data collection, comprising product feasibility questionnaires for media and material experts, as well as user response questionnaires for teachers and students. The feasibility questionnaire utilised a 4-point Likert scale, with scores ranging from a minimum of 1 (strongly disagree) to a maximum of 4 (strongly agree) for each item. Higher scores denoted superior media quality in terms of content accuracy, media design, interactivity, and usability. Conversely, user response data were collected using the System Usability Scale (SUS), which yields scores ranging from a minimum of 0 to a maximum of 100. These scores were utilised to determine the overall usability level of the HydroAR learning media.

Data Collection Technique

The research data were collected using specific questionnaire instruments. The first instrument was designed for media and subject matter experts to assess the feasibility of the developed learning media. Media experts evaluated the media from technical perspectives, including efficiency, design, visual aesthetics, technical quality, and software functionality. Simultaneously, subject matter experts assessed the substantive aspects and the alignment of the content with the curriculum. This assessment was conducted using a Likert scale with categories ranging from ‘very feasible’ to ‘less feasible’. Furthermore, the second instrument comprised a user response questionnaire intended for completion by teachers and students. This instrument was utilised to determine the user reception of the developed media. Responses focused on the attractiveness of the media, the suitability of the content, and linguistic appropriateness. The data derived from this questionnaire were analysed to ascertain the extent to which the developed instructional medium aligned with user requirements.

Furthermore, during this stage, the research instruments comprising validation questionnaires for experts and response questionnaires for users were developed. Specifically, these included validation instruments for media and subject matter experts, alongside response instruments for students and teachers. The media expert questionnaire was designed to evaluate the feasibility of the media regarding efficiency, design, and visual aesthetics, technical quality, and software attributes. Similarly, the subject matter expert questionnaire was formulated to assess the material in terms of substance and content. Additionally, the user response questionnaires aimed to gauge student and teacher feedback concerning the attractiveness of the media, the suitability of the content, and linguistic appropriateness. The details of the designed questionnaire instruments are presented in Table 1, Table 2, Table 3, and Table 4 below.

Table 1. Media Expert Instrument

Aspects assessed	Indicators / Statements
Efficiency	Ease of Media Workflow
	The media is easy to use and operate
	The program operation is simple
Visual Design and Appearance	Clarity of Instructions and Aesthetics
	Instructions for use are clear
	Features are consistent throughout
	Language is appropriate for students
	The design appearance is attractive
	Images, sounds, and animations are appropriate
	Colours used are appropriate
The text is clear and interactive	

Aspects assessed	Indicators / Statements
Technical Quality	Menu layout is intuitive
	The media is engaging
Software	Presentation of material aligns with learning objectives
	The program is presented systematically
	Maintainability.
	Usability (ease of use).
	Compatibility (media operates across multiple platforms).
	Reusability.

Table 2. Material Expert Validation Instrument

Aspects assessed	Indicators / Statements
Substance	Material is in accordance with the learning objectives.
	The material aligns with the specified indicators.
	Description of the material is clear.
	The provision of exercises is adequate.
	Presentation of exercises is appropriate.
	Language is clear.
Content	Ease of media operation
	Clarity of material provision
	Systematic presentation of material
	Ease of text comprehension
	Ease of understanding the language used
	Appropriateness of images within the material

Table 3. Student Response Instrument

Aspects	Indicator/Statement
Media Appeal	I am interested in using the media
	I am enthusiastic and happy to use the media
	I feel more curious after using the media
	I find learning in class more enjoyable
Content	The media contains attractive images, text, and animations
	I find it easier to understand the material
	The material presented is clear and easy to understand
Language Use	I can easily understand the language used
	I can understand the usage instructions provided
	I find the media easy to use

Table 4. Teacher Response Instrument

Aspect	Indicator/Statement
Media Appeal	I am interested in using the media
	I am enthusiastic about using media
	I feel more curious after using the media
	I feel that learning in class has become more interactive
Content	Learning objectives align with the available textbooks/materials
	I find it easier to convey the material using this media
	I easily understand the material provided.
Language Use	I can easily understand the language used in the media
	I can understand the usage instructions provided
	I find the media easy to use

Data Analysis

Data analysis in this study was conducted utilising both qualitative and quantitative approaches. Product feasibility analysis was undertaken to assess the viability of the instructional media and the associated materials. Both components were ultimately compiled based on expert assessments using a Likert scale. A score of 4 denotes an ‘Excellent’ rating, indicating that the media meets the criteria optimally. A score of 3 indicates ‘Good’, suggesting that while the aspect is satisfactory, there remains room for improvement. A score of 2 represents a ‘Sufficient’ category, implying that improvement is required to enhance effectiveness. Conversely, a score of 1 is categorised as ‘Poor’, indicating that the aspect fails to meet standards and necessitates significant improvement. The criteria for media feasibility assessment are detailed in Table 5.

Table 5. Media feasibility criteria based on Likert scales

Assessment	Score
Excellent	4
Good	3
Fair	2
Poor	1

The data obtained from the questionnaires were subsequently calculated using the percentage formula presented in below.

$$\text{Percentage of feasibility (\%)} = \frac{\text{Total score obtained}}{\text{Maximum possible score}} \times 100$$

Following the calculation of the feasibility percentage, the data are interpreted according to predetermined feasibility categories. These criteria serve to assess the extent to which the developed media meets expected quality standards. If the feasibility score falls within the 81%–100% range, the media is categorised as ‘highly feasible’ for implementation without the need for significant revision. A score falling within the 61%–80% range classifies the media as ‘feasible’, though minor improvements to enhance quality remain permissible. Furthermore, scores within the 41%–60% range render the media ‘moderately feasible’, indicating a requirement for revision or further development to optimise its utility. Conversely, if the feasibility percentage falls below 40%, the media is categorised as ‘not feasible’ or unfit; this necessitates comprehensive improvement or redevelopment to satisfy the required standards. The specific criteria for assessing media feasibility are presented in Table 6.

Table 6. Media Feasibility Criteria Based on Percentage

Percentage	Criteria
81%-100%	Highly Feasible
61%-80%	Feasible
41%-60%	Moderately Feasible
0%-20%	Not Feasible

Furthermore, user response data were collected via questionnaires administered to both students and teachers. These instruments comprised a series of items designed to measure the reception of the instructional media. The data were collected utilising a Likert scale and subsequently processed using the System Usability Scale (SUS) formula. The user response assessment criteria are outlined in Table 7.

Table 7. User Response Criteria

Statement	Score
Strongly Agree	4
Agree	3
Disagree	2
Strongly Disagree	1

Following data collection, the data were analysed using the mean value formula. Once the average responses from respondents were calculated, the subsequent step involved determining the range of the System Usability Scale (SUS) testing, based on Brooke's adaptation as illustrated in Figure 1 (Vlachogianni & Tselios, 2022).

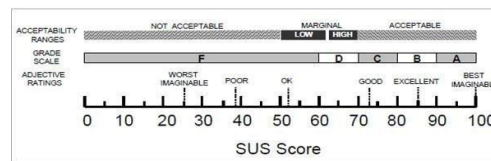


Figure 1. SUS (System Usability Scale) Score

RESULTS

This section details the research phases, encompassing the Define, Design, Develop, and Disseminate (4D) stages.

Define Stage

Student Curriculum Analysis

Student and curriculum analyses indicated that 'HydroAR' was developed to accommodate diverse learning styles and curricular demands. Interviews with teachers and 22 fifth-grade students revealed a variation in learning preferences: 1 auditory learner (4%), 14 visual learners (64%), and 7 kinaesthetic learners (32%). This diversity necessitates flexible instructional media that supports both independent and collaborative learning. Students demonstrated a strong preference for visual and experiential learning, suggesting that AR-based media would be effective in stimulating curiosity and engagement. HydroAR aligns with Phase C of the Independent Curriculum (Kurikulum Merdeka, Years 5–6) and supports learning outcomes related to the water cycle through exploration, observation, investigation, and simple experimentation. Furthermore, the media facilitates formative assessment, reflection, and communication, thereby promoting meaningful, contextual, and higher-order learning.

Design

The instructional media was designed by integrating various elements—including subject material, audio, video, and 3D projects—tailored to visual, auditory, and kinaesthetic learning styles. HydroAR was developed using a combination of software applications, specifically Articulate Storyline 3, Canva, and Assemblr. The interface encompasses key educational components: learning outcomes, instructional objectives, subject matter, interactive activities, assessment mechanisms, reflective exercises, and development team information. The design layout of HydroAR is presented in Figure 2.

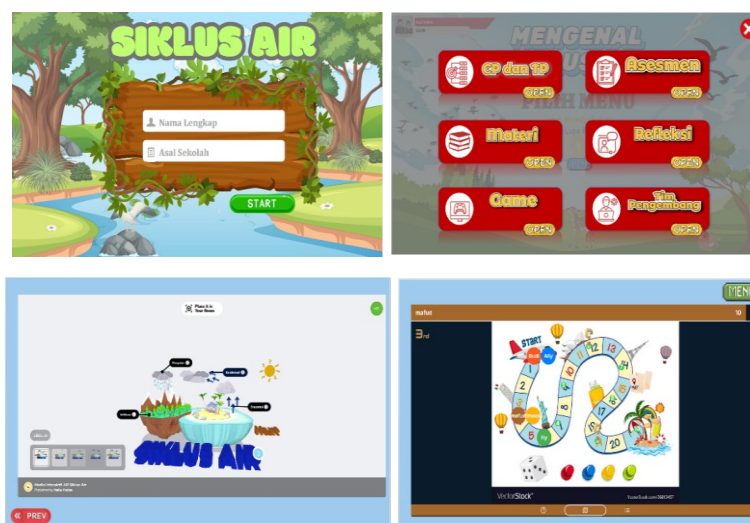


Figure 2. The Outcomes of the Developed HydroAR Media Design.

Develop

This stage presents the validation results from two expert validators (media and subject matter experts) and the pilot study involving 22 students and one primary school teacher in the Cirebon Regency area. The results of the media and subject matter expert validation for HydroAR are detailed in Table 8.

Table 8. Media Expert Assessment Results

Assessment	Efficiency Aspect	Design and Visual Aspects	Technical Quality Aspects	Software Aspects	Percentage	Criteria
Expert 1	12	29	11	14	91.7%	Very Feasible
Expert 2	12	31	12	16	98.6%	Very Feasible
Total	24	60	23	40	95.15%	Very Feasible

Table 8 presents the evaluation results from media experts, covering efficiency, design, visual appearance, technical quality, and software aspects. The results indicate that the media achieved a feasibility percentage of 95.15%, categorised as ‘Very Feasible’. However, the qualitative feedback indicated a status of ‘Feasible for use with revision’, specifically noting the need for additional navigation buttons. Furthermore, the feedback confirms that the instructional media is suitable for application in Year 5 science instruction to enhance student understanding.

Table 9. Material Expert Assessment Results

Assessment	Substance	Content Aspect	Percentage	Criteria
Expert 1	23	28	98.07%	Very Feasible
Expert 2	23	27	96.15%	Very Feasible
Total	6	55	97.2%	Very Feasible

The results of the feasibility validation conducted by subject matter experts are presented in Table 9, specifically evaluating aspects of substance and content. The assessment indicates that the developed instructional media achieved a feasibility percentage of 97.2%, categorising it as ‘very feasible’. In addition to the quantitative evaluation, the subject matter experts provided constructive qualitative feedback, confirming the media’s relevance for Year 5 (primary school) students. Based on these suggestions, several revisions were implemented: refining the accuracy of scientific terminology regarding the water cycle, improving the alignment between learning objectives and the presented content, clarifying key concepts, and adjusting the sequence of materials to better scaffold students’ conceptual understanding. These improvements were executed to enhance content clarity, coherence, and instructional suitability prior to further testing. Having established the feasibility of the media and materials, the results of the small-scale pilot study regarding user responses are presented below. Table 10 details the specific responses from the 22 participating students.

Table 10. Student Response Data

Respondent	SUS Score (Total * 2.5)	Respondent	SUS Score (Total * 2.5)
1.	85	11.	77.5
2.	90	12.	77.5
3.	87.5	13.	67.5
4.	80	14.	87.5
5.	82.5	15.	75
6.	77.5	16.	82.5
7.	95	17.	82.5
8.	95	18.	72.5
9.	85	19.	82.5
10.	77.5	20.	92.5
11.	77.5	21.	85
12.	77.5	22.	92.5

Based on the analysis of the System Usability Scale (SUS) data, the tested HydroAR media achieved a mean score of 83.18, placing it within the 'Good' to 'Excellent' category. The scores ranged from a minimum of 67.5 to a maximum of 95, with the highest score awarded by two respondents and the lowest by one. The high scores suggest that the majority of respondents were satisfied with the visual appearance, ease of use, and features available within the instructional media. However, the presence of lower scores indicates that certain aspects require refinement. Specifically, feedback highlighted the need to improve material clarity and navigation usability. While the highest ratings were observed in user satisfaction and operational ease, the lowest ratings pertained to the clarity of the material. Consequently, although the media is classified as feasible, revisions addressing material clarity are necessary.

Furthermore, the calculation using the SUS yielded an average score of 83.18, which is categorised as 'Acceptable' and approaches the 'Excellent' threshold. According to the criteria established in the questionnaire instrument, this corresponds to Grade Range B, indicating that the AR-based media is suitable for implementation in the learning process. Referring to Table 11, the teacher's assessment yielded a perfect score of 4 across all evaluated items, resulting in a 100% feasibility level (Grade A) within the acceptable category. Therefore, the media is considered highly feasible and effective for classroom instruction. The results of the teacher's response are detailed in Table 11 below.

Table 11. Teacher Response Result Data

Respondent	Item Score Value										Total	SUS Score (Total *2,5)
	1	2	3	4	5	6	7	8	9	10		
Class Teacher Grade V	4	4	4	4	4	4	4	4	4	4	40	100

The Effectiveness of HydroAR Learning Media

Based on the study results, it can be concluded that the integration of Augmented Reality technology in Year 5 primary science instruction successfully enhanced student interest and learning outcomes. In the pre-cycle phase, student interest was low, with only 40% of students meeting the mastery criteria. Conventional instruction, characterised by lecturing methods and traditional media, resulted in student disengagement and difficulties in comprehending the water cycle material. The effectiveness of HydroAR media in Cycle I was measured following its implementation. The results indicated a marked increase in student interest, evidenced by their enthusiasm during the trial. Learning outcomes also improved, with 60% of the 22 students achieving mastery. Despite this improvement, 13 students had not yet reached the maximum score; consequently, further improvements were implemented in Cycle II. Figure 3 illustrates the percentage of student learning outcomes in Cycles I and II following the utilisation of the media.

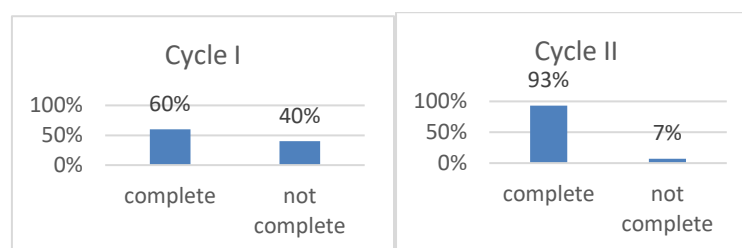


Figure 3. Percentage of Student Learning Outcomes in Cycle I and Cycle II Following Media Utilisation

Reflecting on Cycle I, it was observed that students began to demonstrate enthusiasm for the learning process. However, the attainment of learning outcomes had not yet fully met the established standards. In Cycle I, only 60% of students achieved the mastery criteria, leaving approximately 13 students who had yet to meet the required standards. Consequently, in Cycle II, the instructional strategy was enhanced through the implementation of collaborative group learning, rendering the process more effective and efficient. As a result, 93.3% of students achieved the criteria, demonstrating a significant improvement compared to the previous cycle. Additionally, teacher

performance improved from 85.4% in Cycle I to 93.7% in Cycle II, placing it within the ‘Very Good’ category.

Disseminate

Following the preceding three research stages, the media underwent revision based on feedback from media experts, subject matter experts, students, and teachers. A large-scale trial was subsequently conducted with 30 randomly selected primary school students. The results of the user responses from these 30 students are presented in Table 12 below.

Table 12. Results of User Responses

Respondent	SUS Score (Total*2.5)	Respondent	SUS Score (Total*2.5)	Respondent	SUS Score (Total*2.5)
1.	85	11.	77.5	21.	90
2.	90	12.	77.5	22.	92.5
3.	87.5	13.	82.5	23.	82.5
4.	80	14.	87.5	24.	77.5
5.	82.5	15.	85	25.	82.5
6.	77.5	16.	82.5	26.	92.5
7.	95	17.	82.5	27.	85
8.	95	18.	87.5	28.	92.5
9.	85	19.	82.5	29.	92.5
10.	77.5	20.	92.5	30.	87.5

Referring to Table 12, the mean System Usability Scale (SUS) score for the 30 respondents was 85.58, indicating that the usability level of the media is excellent. Consequently, the SUS interpretation falls within the ‘Acceptable’ and ‘Excellent’ categories, suggesting that users found the system highly intuitive and reported a positive experience. Based on the criteria established in the questionnaire instrument, the HydroAR instructional media achieved a Grade B. The scores ranged from a minimum of 77.5 to a maximum of 95, with the majority of scores falling between 80 and 95.

DISCUSSIONS

The Developed of HydroAR learning media

The findings at the Define stage indicate that student diversity, particularly regarding learning styles, plays a crucial role in determining the design of effective instructional media. The dominance of visual (64%) and kinaesthetic (32%) learners among the 22 Year 5 students confirms the necessity for media that emphasises visual representation and experiential learning. This condition supports the integration of Augmented Reality (AR), which allows abstract concepts—such as the water cycle—to be explored through interactive visualisation. Wahyuni et al. (2020) assert that AR enables students to represent abstract concepts in a more tangible and comprehensible form. Furthermore, curriculum analysis demonstrates that HydroAR aligns well with Phase C of the Independent Curriculum (Kurikulum Merdeka), which emphasises exploration, observation, investigation, and the development of scientific process skills. Thus, the design of HydroAR addresses not only learner characteristics but also curricular demands for meaningful, flexible, and context-based learning.

During the Design and Develop stages, HydroAR was constructed using a user-centred approach, integrating multimedia elements and AR features to support diverse learning preferences. The high feasibility scores awarded by media experts (95.15%) and subject matter experts (97.2%) indicate that the media meets technical, visual, and content quality standards. Revisions suggested by experts, such as improving navigation and refining scientific terminology, contributed to enhancing instructional clarity and usability. User evaluations further substantiated these findings, as student responses yielded an average SUS score of 83.18, categorised as acceptable to excellent. These results suggest that HydroAR not only functions effectively as a learning medium but also provides a positive user experience that promotes ease of use, engagement, and instructional clarity.

The effectiveness testing demonstrates that HydroAR positively influenced students’ learning interest and outcomes. The increase in mastery from 60% in Cycle I to 93.3% in Cycle II indicates that

AR-based media, when combined with collaborative learning strategies, can significantly enhance pedagogical effectiveness. Teacher responses further confirmed this finding, with a perfect feasibility score indicating strong instructional acceptance. In the Disseminate stage, the large-scale trial involving 30 students resulted in an average SUS score of 85.58, categorised as excellent, demonstrating consistent usability and positive learning experiences. These findings suggest that HydroAR possesses strong potential for broader classroom implementation and underscores the role of AR-based media as an effective solution for teaching abstract scientific concepts at the primary level. As Muhsim (2022) notes, "Science without technology will not advance, while technology without science has no foundation." This statement emphasises the intrinsic interrelation between science and technology. Integrating technology into instruction, particularly in science education, can create a significantly more engaging and interactive learning experience.

Feasibility of the HydroAR Learning Media

The results of the feasibility tests conducted by media and subject matter experts corroborate previous research, which posits that educational game-based learning media can foster an active and engaging learning experience. Such media also serve to enhance students' comprehension of the subject matter (Ramansyah, 2015). Through the utilisation of digital media, students not only acquire a superior conceptual understanding but also develop digital literacy. This aligns with Rochmah and Labudasari (2020), who define digital literacy as an essential competency for organising information and compiling knowledge from diverse sources. Furthermore, findings by Buchori et al. (2016) support the notion that mobile-based Augmented Reality (AR) learning media can effectively build student character while demonstrating high practicality. The results of the feasibility validation conducted by subject matter experts are presented in Table 10. This validation process assessed two primary components: substance, which encompasses accuracy, clarity, and the alignment of learning content with the curriculum; and content structure, which includes systematic presentation, readability, and the appropriateness of illustrations or supporting media. Based on this analysis, the HydroAR media achieved a total feasibility score of 97.2%, classifying it within the 'very feasible' category. This high score indicates that the media content meets the requisite academic standards and is appropriate for classroom implementation, particularly for Year 5 primary school students.

The subject matter experts involved in the validation process provided several positive observations. Notably, it was emphasised that the learning materials were well-aligned with the instructional objectives and competencies outlined in the Indonesian curriculum, specifically for science topics in Phase C (Years 5–6). The content was also commended for being clear, age-appropriate, and engaging, thereby supporting the meaningful learning experience anticipated from technology-enhanced instruction. This finding aligns with research by Arsyad (as cited in Hijriyani et al., 2025), who highlighted that learning media must be evaluated based on their relevance to learners' developmental stages and curricular goals. According to Arsyad, learning materials that are visually engaging, accurate, and systematically organised are more likely to improve students' cognitive engagement and comprehension, particularly in scientific subjects.

Additionally, Ni'mah et al. (2024) found that learning media integrating visual, auditory, and kinaesthetic elements—such as those found in AR-based applications—can significantly enhance students' conceptual understanding by providing interactive and contextual experiences. The researchers emphasised that aligning educational media with learners' real-world experiences and curricular expectations contributes to increased learning motivation and improved academic performance. Through its structured presentation of scientific content (such as the water cycle) accompanied by interactive 3D visualisations, HydroAR provides a multisensory learning experience. The integration of text, audio, and augmented visuals helps bridge the gap between abstract scientific concepts and students' everyday experiences, thereby increasing both the retention and transfer of knowledge. Thus, the validation results confirm that HydroAR is not only technically sound but also pedagogically suitable for primary school students, reinforcing the conclusion that the media possesses strong potential for effective implementation in real classroom contexts.

The effectiveness of the HydroAR Learning Media

The findings regarding effectiveness were derived from ten questionnaire items designed to assess students' perceptions of the HydroAR learning media. The first item, evaluating the visual appeal of the media display, received a score of 104, indicating that the majority of students found the HydroAR visuals engaging. This was complemented by the second item, measuring user satisfaction, which yielded a score of 110, suggesting a high level of enjoyment in using the media. Regarding curiosity and comprehension, the third item focused on stimulation and scored 99, reflecting that students generally agreed the media encouraged their inquisitiveness. Similarly, the fourth item, assessing the ease of understanding the material, also received a score of 99, implying that students found HydroAR helpful in learning about the water cycle. In terms of content quality, the fifth item addressed the inclusion of interesting images, text, and animations, receiving a score of 102, which indicates positive responses. The sixth item evaluated the media's effectiveness in aiding comprehension of the water cycle, scoring 101, further supporting the view that HydroAR facilitated understanding.

Finally, regarding clarity and usability, the seventh item utilised negative phrasing to query whether the media was unclear. This item received a score of 101, with the majority of responses disagreeing with the negative statement, thereby confirming that students found the content clear and accessible. The eighth item, focusing on the simplicity of the language used, scored 100, indicating general agreement that the language was easy to understand. The ninth item examined the clarity of instructions, showing that most students found the directions comprehensible. The tenth item, concerning the ease of operation, received the highest score of 111, demonstrating strong agreement that the media was user-friendly and straightforward to operate. Overall, the data indicate that HydroAR was well-received by students, excelling not only in design and usability but also in its effectiveness in supporting the learning process.

These results indicate that the majority of respondents evaluated the HydroAR system positively. The overall reception of the HydroAR media among students was favourable, as evidenced by the consistently high ratings across nearly all questionnaire items. Notably, the highest scores were recorded for visual presentation, user satisfaction, and ease of operation, highlighting the system's key strengths. A deeper analysis of student responses reveals several factors contributing to this positive perception. First, the media display was considered engaging due to its integration of 3D visuals, text, images, and animations, which collectively enhanced student interest in the learning material. This form of visualisation rendered the concept of the water cycle more tangible and accessible compared to conventional instructional media. Second, the interactive features of HydroAR were effective in stimulating student curiosity. The ability to interact with 3D objects allowed learners to explore the water cycle in a more immersive manner, fostering deeper engagement with the content. Third, students reported that the media facilitated comprehension of the subject matter, as reflected in the high score for the item assessing the media's support in understanding the water cycle. Although a minority of respondents indicated some difficulty regarding the clarity of usage instructions, this issue appears limited in scope and potentially rectifiable through minor revisions. Overall, the findings underscore HydroAR's potential as an effective and user-friendly educational tool for enhancing learning experiences in science education.

The high questionnaire scores reflect strong intrinsic motivation to explore digital media, particularly Augmented Reality (AR). This aligns with studies highlighting AR's capacity to enhance learning motivation and outcomes (Rochmah & Labudasari, 2019; Setiawan et al., 2023). Students perceived the visuals as attractive, immersive, and effective in making abstract concepts—such as the water cycle more concrete. Interactive features increased enjoyment and active participation, including among typically passive learners. AR objects were considered highly explorable and supportive of faster comprehension. While navigation, language, and instructions were generally clear, some students required adaptation time and suggested additional guidance, such as video tutorials. Minor device compatibility issues were also reported.

Consequently, the positive responses to each questionnaire item can be attributed to the effectiveness of the HydroAR media in delivering engaging and interactive 3D animations, the implementation of user-friendly language, the simplicity of the interface, and the integration of multimodal features. However, several responses received relatively lower scores, particularly

regarding the clarity of usage instructions and the comprehensibility of specific media content. These findings suggest the necessity for further refinement of instructional components to minimise confusion, particularly for students engaging with AR-based media for the first time.

Furthermore, based on the reflection from Cycle I, it was observed that students began to demonstrate greater enthusiasm for the learning activities. However, the attainment of learning outcomes had not yet fully met the established standards. In Cycle I, only 60% of students met the minimum criteria, implying that 13 students still fell short. To address this, the instructional strategy was revised in Cycle II through the implementation of group-based learning, which rendered the process more effective and efficient. As a result, 93.3% of students met the learning criteria, indicating a significant improvement compared to the previous cycle. Additionally, teacher performance improved from 85.4% in Cycle I to 93.7% in Cycle II, classifying it within the 'very good' category.

The results demonstrate that the HydroAR instructional media is effective in increasing student interest and learning outcomes regarding water cycle materials. This technology provides a more interactive and enjoyable learning experience, corroborating previous research which states that learners understand and retain material better when instruction involves visual and interactive elements. These findings accord with Ode (2014), who posits that students tend to retain more information from what they hear, see, and feel compared to auditory input alone. Augmented Reality technology facilitates critical thinking and creates a more pleasant learning atmosphere compared to non-technological approaches. This aligns with research suggesting that AR media effectively influences students' critical thinking (Andriani & Ramadani, 2022; Kularbphettong et al., 2019; Rukayah et al., 2023; Saidin et al., 2024). Furthermore, this study aligns with findings by Amelia and Isdaryanti (2024) and Sujana et al. (2019), which indicate that AR media can improve student learning outcomes. The research is also supported by Qumillaila et al. (2017), whose results proved AR to be an effective alternative for biology learning media.

The data obtained also align with Mulia and Bangun, (2023), whose research indicated that the use of AR media received a positive response from users, with an average score of 82.6% (categorised as 'very good'). Furthermore, HydroAR has been proven to attract student attention and provide a more compelling experience for learning activities. This is supported by Bishop et al. (2020), who highlight that AR provides a more interesting learning experience and can better shape knowledge. AR is also proven to be useful in clarifying the message or information conveyed, rather than relying solely on the teacher's explanation (Andriani & Ramadani, 2022). Engaging and innovative learning media will naturally increase student enthusiasm. Augmented Reality serves as a versatile tool in educational media, enabling the visualisation of abstract concepts in a more tangible and realistic manner. By integrating theoretical explanations, practical applications, and interactive games, AR enhances teaching and learning activities, making them more dynamic. Furthermore, AR supports students in improving their conceptual understanding by aligning media design with diverse learning styles, thereby fostering an interactive and student-centred learning environment. Based on this theoretical framework, the learning media developed in this study were well accepted by both students and teachers, as it aligns with student needs and characteristics. Additionally, unstructured interviews conducted during classroom implementation indicate that, on average, both students and teachers perceived significant benefits following the use of the HydroAR learning media.

CONCLUSION

This study contributes to the existing body of knowledge by introducing HydroAR, an Augmented Reality (AR)-based instructional medium developed utilising the 4D model, specifically tailored for primary science education regarding the water cycle. In contrast to conventional media, HydroAR integrates interactive visualisations, quizzes, videos, and games to bolster students' conceptual understanding and learning engagement. Evidence from expert validation, user feedback, and effectiveness testing demonstrates that HydroAR is both feasible and effective in enhancing student comprehension and interest, particularly regarding abstract scientific concepts. The scope of this study was restricted to a small-scale implementation focusing on a single topic with a limited cohort of participants. Consequently, it is recommended that future research incorporates larger sample sizes, extended implementation durations, and robust experimental designs to evaluate learning gains more

comprehensively. Furthermore, the continued development of AR-based media for other science topics is suggested to broaden the pedagogical applications of this technology. The findings imply that AR-based instructional media can serve as an effective instrument for enhancing engagement and conceptual understanding in primary science education. Educators are encouraged to integrate AR-supported tools to accommodate diverse learning styles. Concurrently, policymakers and researchers should consider expanding the development of AR resources to foster innovative and meaningful learning environments

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