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Development of Augmented Reality Learning Media Using a Deep Learning Pedagogical Approach to Improve Early Childhood Scientific Literacy

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ABSTRACT

Scientific literacy is a fundamental competency that should be developed from early childhood, yet many early childhood education institutions continue to rely on conventional instructional media that offer limited opportunities for interactive, meaningful science learning. Although Augmented Reality (AR) has demonstrated potential for enhancing learning engagement, few studies have integrated AR with a deep learning approach to foster early childhood scientific literacy through meaningful, mindful, and joyful learning experiences. Therefore, this study aimed to develop and evaluate Augmented Reality learning media based on a deep learning approach to improve children's scientific literacy at RA Al Qur'an Dina. This Research and Development (R&D) study employed the ADDIE model, consisting of analysis, design, development, implementation, and evaluation stages. Data were collected through interviews, observations, expert validation questionnaires, response questionnaires, and pretest–posttest instruments involving early childhood learners. The findings indicated that the developed media were valid and feasible, as assessed by media, material, and instrument experts. The results of the Focus Group Discussion (FGD), small group trials, and Training of Trainers (TOT) also confirmed that the media were practical, engaging, and easy to implement. Furthermore, large-group testing demonstrated a substantial improvement in children's scientific literacy, reflected in an N-Gain score of 0.98 (high category) and an effectiveness level of 97.93% (highly effective category). In conclusion, the developed Augmented Reality learning media effectively enhanced early childhood scientific literacy through interactive and meaningful learning experiences.

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1. INTRODUCTION

Scientific literacy has become one of the essential competencies required to prepare children for the challenges of the twenty-first century. It enables learners to understand natural phenomena, think critically, solve problems, and make evidence-based decisions in everyday life [1]. Developing scientific literacy from an early age is particularly important because early childhood represents a critical period for cognitive development, during which children actively construct knowledge through exploration, observation, and interaction with their environment [2]. Consequently, early childhood education should provide meaningful learning experiences that stimulate curiosity and encourage children to investigate scientific concepts through active participation rather than passive information reception. Education serves as a fundamental pillar in building an advanced and sustainable society [3]. Through education, individuals are equipped with the knowledge, skills, and values that enable them to develop their potential and make meaningful contributions to their personal lives and to society as a whole. Education does not merely focus on enhancing intellectual capacity, but also emphasizes the development of character and positive mental attitudes [4].

Technology provides numerous benefits across various fields and aspects of life, including education. Educational technology is not limited to scientific advancement alone; it also serves as an effective learning medium that aligns with the current needs of the educational sector [5]. The rapid development of digital technology has created numerous opportunities in education, including early childhood education (ECE) [6]. Learning media are no longer confined to conventional teaching aids; they have expanded to include advanced technologies such as Augmented Reality (AR). In this context, the use of AR enables children to experience learning processes that are more interactive, contextual, and enjoyable [7]. AR-based learning media have significant potential for implementation in ECE because they can present learning objects in realistic three-dimensional visual forms, thereby stimulating children's imagination and curiosity toward scientific concepts in a concrete manner [8].

Scientific literacy is regarded as one of the most essential foundational literacies for students, parents, and society at large. This was recognized by the World Economic Forum in 2015 as a prerequisite life skill for the 21st century, which can be developed through integrated education beginning within the family, continuing through schools, and extending into the wider community [9]. Science education plays a crucial role in developing learners who possess critical, logical, creative, innovative, and globally competitive thinking skills. Scientific literacy refers to the ability children must acquire to understand natural and social phenomena and make scientifically informed decisions that support healthier, more comfortable, and better lives [10].

Scientific literacy in early childhood refers to children's initial ability to observe, make predictions, and communicate their scientific experiences [11]. However, many early childhood education institutions still lack adequate learning media to support the development of children's scientific literacy. A study by Sarama and Clements (2018) found that young children can understand simple scientific concepts when provided with

learning media appropriate to their cognitive developmental stage, particularly through concrete, visual, and manipulative approaches [12].

Based on the results of a scientific literacy analysis questionnaire distributed to ECE teachers, empirical data revealed that 61.4% of teachers agreed that children's scientific literacy in the classroom still needs improvement. This finding indicates that children's ability to understand basic scientific concepts, such as cause-and-effect relationships, natural changes, and environmental phenomena, has not yet developed optimally in line with the expected learning outcomes of the ECE curriculum [13].

Furthermore, the data showed that approximately 63.6% of teachers agreed that children experience difficulties in understanding simple scientific concepts. In addition, 70.5% of teachers stated that children are less able to relate science learning to everyday life. These difficulties are reflected in children's limited ability to connect science learning with daily experiences, such as observing natural events or explaining the results of simple experiments [14]. More specifically, the results of the teacher questionnaire analysis regarding children's scientific literacy needs are presented in the following table:

Table 1. Analysis of Children's Scientific Literacy Needs

No	Indicator	Questionnaire Statement	Percentage of Teachers (%)	Interpretation
1	Need for improvement in scientific literacy	Children's scientific literacy in the classroom still needs improvement	61,4 %	Most teachers stated that children's scientific literacy skills have not yet developed optimally in accordance with ECE learning outcomes.
2	Understanding of simple scientific concepts	Children experience difficulties in understanding simple scientific concepts	63,6 %	Children still face challenges in understanding basic scientific concepts such as cause-and-effect relationships, natural changes, and environmental phenomena.
3	The connection between science and daily life	Children are less capable of relating science learning to everyday life	70,5 %	Children have not yet been able to connect science learning to real-life experiences, such as observing natural events or explaining the results of simple experiments.

The topic of "rainbows" is one of the most interesting subjects in basic science; however, it is often difficult for early childhood learners to understand due to its abstract nature. Children need to understand that a rainbow forms through the refraction and reflection of light, concepts that cannot always be directly observed in everyday situations. In addition, science learning in early childhood must be closely related to children's real-life experiences. Rainbows are among the natural phenomena that are familiar to children and highly appealing to them. Therefore, learning approaches that can present the rainbow phenomenon visually and interactively, such as through Augmented Reality (AR) media, are highly important. This learning media enables children to observe and explore the process of rainbow formation through realistic and easily understandable simulations.

Based on a survey on natural phenomena most recognized by early childhood learners, 43.8% of children were familiar with rainbows, placing them second after earthquakes (52.1%). These findings indicate that rainbows are among the natural phenomena that are relatively familiar within children's environments, although they are

not yet fully understood scientifically. In general, children recognize rainbows primarily from their visual beauty without understanding the scientific processes underlying their formation, such as light refraction and the role of rainwater. Therefore, the rainbow phenomenon was selected as the topic for developing learning media because it is considered highly potential as a bridge between children's visual experiences and deeper scientific understanding.

Through a deep learning approach that emphasizes meaningful, mindful, and joyful learning, the topic of rainbows can help children not only memorize the colors of the rainbow but also understand the relationship between light, water, and color formation through direct, interactive experiences. Augmented Reality (AR) media is an appropriate tool for visually and contextually representing this process, thereby effectively enhancing children's scientific literacy.

Previous studies have shown that Augmented Reality (AR) based media provide a positive impact on children's learning engagement. A study conducted by Dicky Juliansyach (2023) demonstrated that the use of Augmented Reality (AR) in education enhances students' interest in learning, conceptual understanding, and information retention. Meanwhile, research by Salsabila Cahyaningtyas (2020) on Augmented Reality (AR) media for early childhood learners found that children became more motivated and understood learning materials more easily. In addition, AR enabled children to learn while playing, thereby providing them with direct learning experiences. However, there are still limited studies that integrate Augmented Reality (AR) technology with artificial intelligence approaches, such as deep learning, to improve the quality of learning interaction and personalize learning materials according to children's abilities.

The deep learning approach in the development of learning media enables the media to provide intelligent responses to children's interactions, such as recognizing children's voices, identifying gestures, and delivering appropriate feedback. Consequently, learning media no longer function merely as passive tools but can adapt to children's learning styles. The implementation of deep learning within the context of Augmented Reality (AR) can create more meaningful learning experiences and strengthen children's understanding of scientific concepts such as rainbows [17].

RA Al Qur'an Dina Padangsidimpuan, as one of the early childhood education institutions oriented toward integrating science and Islamic values, is in significant need of innovative, effective, and engaging learning media. Based on preliminary observations at the institution, there is still a lack of innovative, interactive learning media, particularly for delivering science-related materials, such as natural phenomena. This condition makes the learning process less engaging, monotonous, and insufficient in helping children actively explore scientific phenomena in their surrounding environment.

In addition, the absence of Augmented Reality (AR) technology in early childhood learning activities at the institution is one of the factors hindering the enhancement of children's learning experiences. In fact, AR has been proven capable of presenting engaging three-dimensional visualizations, increasing students' interest in learning, and helping children understand abstract concepts in a more concrete, contextual way. By

utilizing this technology, children are not merely passive recipients of information but can also interact directly with learning objects visualized on digital devices.

Another challenge faced by the institution is the limited capacity of teachers in developing AR and deep learning-based digital learning media. Many teachers still experience limitations in utilizing technology to support creative and innovative learning processes. Consequently, science learning activities are still predominantly carried out using conventional approaches that emphasize memorization and verbal explanation rather than exploratory experiences that encourage children's curiosity. In fact, mastery of advanced educational technology is essential for teachers to develop adaptive learning media that align with learners' needs.

These limitations reveal a significant research gap. Although Augmented Reality has been widely recognized as an effective educational technology, few empirical studies have systematically evaluated AR learning media integrated with a deep learning approach using a comprehensive instructional design framework such as ADDIE. In addition, evidence on the effectiveness of such media in enhancing scientific literacy among early childhood learners, especially in Indonesian early childhood education settings, remains scarce.

The present study addresses these limitations by developing Augmented Reality learning media based on a deep learning approach that integrates meaningful, mindful, and joyful learning principles into science instruction. Unlike previous studies that primarily evaluated AR applications as visualization tools, this study combines instructional design, teacher capacity building through Training of Trainers (TOT), expert validation, Focus Group Discussions (FGD), small-group and large-group implementation, and effectiveness evaluation using pretest-posttest and N-Gain analyses. This integrated approach provides a more comprehensive model for developing and evaluating technology-supported learning media for early childhood education.

Therefore, this study aims to develop and evaluate Augmented Reality learning media based on a deep learning approach to improve children's scientific literacy at RA Al Qur'an Dina using the ADDIE Research and Development model. These conditions have implications for the low level of children's scientific literacy. Many early childhood learners still struggle to understand basic scientific concepts because the learning process is often abstract and theoretical. As a result, children's abilities to observe, reason, and understand natural phenomena around them have not yet developed optimally. Therefore, it is necessary to develop Augmented Reality-based learning media integrated with a Deep Learning approach to enhance children's scientific literacy through interactive, contextual, and enjoyable learning experiences.

2. METHOD

Research and Development Model

This study employed a Research and Development (R&D) design to develop and evaluate Augmented Reality (AR) learning media based on a deep learning approach for improving early childhood scientific literacy. The study adopted the ADDIE instructional design model, consisting of five sequential phases: Analysis, Design, Development,

Implementation, and Evaluation. The ADDIE model was selected because it provides a systematic framework for designing, validating, implementing, and evaluating educational products while supporting continuous improvement throughout the development process. Its educational philosophy emphasizes intentional, child-centered, innovative, authentic, and inspirational learning [18]. The ADDIE model is considered rational and comprehensive and can be applied to various forms of product development, including learning models, strategies, methods, media, and teaching materials, through systematic product development stages [19].

Research and Development Procedures

The research was conducted at RA Al-Qur'an Dina, Padangsidimpuan, Indonesia, during the 2025/2026 academic year. The institution was selected because preliminary observations indicated limited use of interactive digital learning media for science instruction and relatively low levels of children's scientific literacy [18]. The procedures for developing Augmented Reality learning media based on a Deep Learning approach to improve children's scientific literacy are as follows:

1. **Analysis Stage**

   This stage aimed to identify needs and problems underlying media development. The activities included:

   a. validating learning gaps related to low children's scientific literacy;
   b. determining instructional objectives to improve scientific literacy through technology-based media;
   c. identifying early childhood learners as the target audience;
   d. identifying required hardware and software resources;
   e. determining the media delivery system and estimating development costs; and
   f. preparing a research project management plan.

2. **Design Stage**

   This stage focused on planning the learning media according to identified needs. The activities included:

   a. selecting appropriate scientific literacy materials for early childhood learners;
   b. formulating learning objectives; and
   c. designing assessment strategies through literacy tests, observations, and response sheets.

3. **Development Stage**

   This stage involved transforming the design into a product. The activities included:

   a. developing learning content such as images, animations, and 3D AR objects;
   b. integrating deep learning technology into supporting media;
   c. preparing teacher guidelines;
   d. conducting formative revisions based on expert and practitioner feedback;
   e. conducting Focus Group Discussions (FGD); and
   f. carrying out pilot testing with small groups of children.

4. Implementation Stage

This stage involved applying the media in learning activities. The activities included:

a. training teachers to use AR media based on deep learning;
b. providing orientation sessions for children; and
c. Implementing the media in limited classroom science learning activities.

5. Evaluation Stage

This stage aimed to determine the quality of the media and its impact on children's scientific literacy. The activities included:

a. establishing evaluation criteria based on scientific literacy indicators;
b. selecting evaluation instruments such as literacy tests, observations, and response questionnaires; and
c. conducting formative and summative evaluations to measure media effectiveness and improve the product.

The participants consisted of 20 early childhood learners enrolled at RA Al-Qur'an Dina who participated in the implementation and effectiveness testing of the developed learning media. In addition, several early childhood teachers were involved in the needs analysis, Focus Group Discussion (FGD), Training of Trainers (TOT), and practicality evaluation. Three expert validators, including a media expert, a subject-matter expert, and an instrument expert, participated in the product validation process.

Sampling Technique

Participants were selected using purposive sampling. The school was intentionally chosen because it represented an early childhood education institution requiring innovative science learning media. Children and teachers directly involved in science learning activities were selected as research participants based on their relevance to the study objectives.

Data Sources

The study utilized both primary and secondary data. Primary data were obtained from observations, interviews, expert validation, teacher response questionnaires, children's scientific literacy assessments, and pretest-posttest results. Secondary data included curriculum documents, relevant educational policies, and prior studies on Augmented Reality, deep learning, and scientific literacy.

Data Collection Techniques

Data collection was conducted throughout the ADDIE development process using multiple techniques. Interviews and classroom observations were carried out during the analysis stage to identify learning needs and instructional problems. Expert validation questionnaires were administered during the development stage to evaluate the feasibility of the learning media and research instruments. Focus Group Discussions (FGD) and small-group trials were conducted to obtain qualitative feedback for product refinement. During implementation, teachers participated in Training of Trainers (TOT)

activities before using the developed media in classroom learning. Children's scientific literacy was measured through pretests and posttests, while teacher and student responses were collected using structured questionnaires and observation sheets.

Research Instruments

The research employed several instruments, including interview guidelines, classroom observation sheets, expert validation questionnaires, teacher response questionnaires, children's scientific literacy assessment sheets, and pretest-posttest instruments. The scientific literacy instrument evaluated children's abilities to observe scientific phenomena, understand simple scientific concepts, communicate observations, and relate science to everyday experiences.

Variables and Measurement

The independent variable was the Augmented Reality learning media based on a deep learning approach, while the dependent variable was children's scientific literacy. Scientific literacy was assessed through indicators including observation skills, conceptual understanding, scientific communication, and application of scientific knowledge to everyday situations. Learning improvement was measured by comparing pretest and posttest scores using the normalized gain (N-Gain) index.

Validity and Reliability

The developed learning media and research instruments were evaluated through expert judgment involving media, material, and instrument experts to establish content validity. Suggestions from the validators were incorporated into product revisions before field implementation. Instrument reliability was ensured through repeated evaluation and consistency checks throughout the development process, ensuring the instruments' suitability for early childhood assessment.

Development Procedures

The development process followed the five stages of the ADDIE model.

Analysis. Learning needs, curriculum requirements, learner characteristics, technological resources, instructional objectives, and existing learning problems were identified through observations and interviews.

Design. Learning objectives, instructional content, assessment strategies, interface design, storyboards, and scientific literacy indicators were prepared before product development.

Development. The Augmented Reality learning media, including three-dimensional objects, animations, narration, and teacher guidelines, were developed and integrated using a deep learning approach that emphasizes meaningful, mindful, and joyful learning. Expert validation, Focus Group Discussions (FGD), formative revisions, and small-group trials were subsequently conducted.

Implementation. Teachers participated in Training of Trainers (TOT) activities before implementing the developed media in classroom science learning. Children then used the AR media during learning activities under teacher supervision.

Evaluation. Formative evaluation was conducted throughout product development, while summative evaluation assessed the media's effectiveness through pretest-posttest comparisons, observation results, teacher responses, and N-Gain analysis.

Data Analysis

Qualitative data obtained from interviews, observations, Focus Group Discussions, and expert feedback were analyzed descriptively to identify learning needs and improve the developed media. Quantitative data obtained from validation questionnaires, response questionnaires, and scientific literacy assessments were analyzed using descriptive statistics. The effectiveness of the learning media was evaluated by calculating the Normalized Gain (N-Gain) based on pretest and posttest scores. The resulting N-Gain values were interpreted according to standard effectiveness criteria to determine the magnitude of improvement in children's scientific literacy.

Ethical Considerations

Permission to conduct the study was obtained from RA Al-Qur'an Dina's management prior to data collection. Teachers and parents were informed about the objectives and procedures of the research, and participation was voluntary. The identities of all participants were kept confidential, and the collected data were used exclusively for research purposes, with children's privacy and well-being protected throughout the study.

3. RESULTS AND DISCUSSION

3.1. Result

This study applied the ADDIE development model, which consists of five stages: analysis, design, development, implementation, and evaluation. Each stage was conducted systematically to create appropriate learning media that meet the learning needs of early childhood learners and support the improvement of children’s scientific literacy.

Analysis Stage

Needs Analysis

Based on the scientific literacy needs analysis table, it is evident that the scientific literacy of early childhood learners still needs improvement. This is indicated by the percentage of respondents who agreed (61.4%) and strongly agreed (25%) with the statement that children’s scientific literacy in the classroom still needs enhancement. In addition, 63.6% of respondents agreed, and 9.1% strongly agreed, that children still experience difficulties in understanding simple scientific concepts. Regarding children’s ability to relate science learning to everyday life, 70.5% of respondents agreed that children still lacked this ability. These findings indicate that children’s scientific literacy skills are still at an early stage, thereby requiring learning media that are more engaging and concrete.

The results of the analysis of children's scientific literacy needs obtained from the teacher questionnaire are presented as follows:

Table 2. Results of Scientific Literacy Needs Analysis

NO	Indicator	Statement	Response (%)				
			STS	TS	TAP	S	SS
1	Current Condition of Children's Scientific Literacy	Children's scientific literacy in my classroom still needs improvement	9,1	4,5	0	61,4	25
		Children experience difficulties in understanding simple scientific concepts	2,3	18,2	6,8	63,6	9,1
		Children are less capable of relating science learning to everyday life	2,3	22,7	2,3	70,5	2,3
2	Teachers' Needs for Scientific Literacy Learning	Teachers require specific guidance for developing early childhood scientific literacy	2,3	0	2,3	61,4	34,1
		Teachers need examples of science activities appropriate to early childhood characteristics	4,5	0	0	65,9	29,5
		Teachers require various learning methods to improve children's scientific literacy	2,3	0	2,3	72,7	22,7
3	Needs for Learning Media and Resources	Existing science learning media are still limited	2,3	13,6	2,3	75	6,8
		Teachers need engaging and easy to use learning media	2,3	2,3	2,3	59,1	34,1
		Visual and interactive media are highly needed in early childhood science learning	0	4,5	0	65,9	29,5
4	Needs for Strengthening Teacher Competence	Teachers require training related to early childhood scientific literacy	2,3	2,3	0	68,2	27,3
		Teachers need assistance in designing meaningful science activities	2,3	0	13,6	65,9	18,2
		Teachers require improved understanding of effective science learning approaches	4,5	0	4,5	70,5	20,5
5	Needs for Learning Development and Innovation	The development of new learning media is necessary to improve children's scientific literacy	0	2,3	6,8	75	15,9
		Science learning based on exploration and direct experience should be expanded	2,3	0	6,8	70,5	20,5
		Innovation in science learning in ECE is highly needed to improve learning quality	0	2,3	2,3	75	20,5

Curriculum Analysis

Based on the analysis of learning outcomes (Capaian Pembelajaran/CP), it was found that learning at the early childhood education level is directed toward developing six aspects of child development, one of which is the cognitive aspect related to scientific literacy. Scientific literacy refers to an individual's ability to understand, evaluate, and apply scientific concepts in everyday life. This is supported by studies showing that scientific literacy is not limited to knowledge acquisition, but also includes critical thinking and evidence-based problem-solving skills [20].

Furthermore, the analysis of learning objectives (Tujuan Pembelajaran/TP) and learning objective pathways (Alur Tujuan Pembelajaran/ATP) showed that the science materials at RA Al Qur'an Dina are closely related to simple concepts connected to children's daily lives, such as the introduction of objects and natural phenomena. These materials require concrete visualization in order to be easily understood. The use of Augmented Reality technology was considered relevant because it can present three-dimensional, interactive objects, thereby helping children understand abstract concepts more realistically. Recent studies have shown that the use of AR in science learning in early childhood educationan improve children's understanding, engagement, and motivation to learn [21].

In curriculum implementation, learning is also directed toward meaningful and enjoyable learning experiences. This aligns with the deep learning approach, which emphasizes mindful, joyful, and meaningful learning. The Merdeka Curriculum provides teachers with flexibility to develop innovative learning media that support children's active engagement. The literature indicates that integrating technologies such as Augmented Reality into learning can enrich learning experiences, increase interaction, and deepen understanding of scientific concepts, particularly at the early childhood and elementary education levels [22].

In addition, the analysis of learning assessment indicated that assessment in early childhood education is authentic in nature, conducted through observation of children's activities during the learning process. Therefore, the developed learning media need to support exploratory and interactive activities. The use of AR has been proven not only to improve learning outcomes but also to increase active engagement and provide deeper learning experiences, making it highly consistent with the principles of authentic assessment.

Based on the results of the curriculum analysis, it can be concluded that the development of Augmented Reality learning media based on a deep learning approach is aligned with the demands of the Merdeka Curriculum for early childhood education at RA Al Qur'an Dina. This media is expected to support the achievement of learning outcomes, particularly in improving children's scientific literacy through concrete, interactive, and meaningful learning experiences.

Analysis of Learner Characteristics

Based on the observation results, children at RA Al Qur'an Dina demonstrate a high level of curiosity about their surroundings. They tend to ask questions actively, show interest in new things, and display enthusiasm for activities involving visual elements and play. This is consistent with the cognitive development theory proposed by Jean Piaget, which states that early childhood learners are in the preoperational stage, where they more easily understand concepts through concrete representations, images, and direct experiences rather than abstract explanations.

In terms of learning styles, the children tend to be visual and kinesthetic learners. They learn more easily through pictures, animations, and interactive activities that involve movement and exploration. Therefore, the use of technology-based learning media, such as

Augmented Reality, is highly appropriate because it can present objects in attractive three-dimensional forms that allow children to interact with them directly.

Furthermore, from a social-emotional perspective, children are more motivated to learn in environments that are enjoyable and nonmonotonous. They tend to become bored quickly when learning activities are conducted solely through lecture-based methods. This supports the implementation of a deep learning approach that emphasizes joyful learning to keep children actively engaged throughout the learning process.

The scientific literacy skills of children at RA Al Qur'an Dina are still at an early stage, limited to recognizing simple phenomena in their surroundings, such as objects, their properties, and basic forms of change. Children still require guidance in observing, questioning, and drawing simple conclusions. Therefore, learning media are needed that facilitate exploration and help children connect concepts to real-life experiences, in accordance with the principle of meaningful learning.

Based on the results of this analysis, it can be concluded that learners at RA Al Qur'an Dina require concrete, visual, interactive, and enjoyable learning media. Therefore, the development of Augmented Reality learning media based on a deep learning approach is considered highly suitable for supporting children's learning needs and optimally improving their scientific literacy skills.

Design Stage

The Augmented Reality (AR) learning media begins with a cover page that serves as the media's main identity, in the form of a card with a barcode for scanning to access the AR application. After that, users are directed to a user guide page that provides simple instructions for teachers and parents on how to operate the learning media effectively. Once the barcode is scanned, an initial display appears as an Assemblr link that gives users access to the AR learning media.

The main page contains the primary navigation menu with three available features, namely "View in 3D," "Scan Marker," and "Display in Your Room." The learning content is then presented through several sequential pages explaining the process of rainbow formation. Page 1 introduces the beginning of the process with the narration that a rainbow starts to form on a bright sunny day. Page 2 explains that the sky gradually becomes darker as dark clouds begin to gather. Page 3 describes how the sunlight is covered by dark clouds, and rain begins to fall. Page 4 continues the explanation by showing heavy rain as the sky grows even darker, with sunlight completely blocked.

Next, Page 5 explains that the rain starts to stop, the sun slowly reappears, and the sky begins to brighten again. Page 6 further illustrates that the rain has subsided, the sunlight becomes visible again, and the sky turns bright. On Page 7, the media explains the final process of rainbow formation, namely when sunlight passes through raindrops and dark clouds, causing the light to disperse into seven colors: red, orange, yellow, green, blue, indigo, and violet, which form a rainbow. Finally, the last page (Page 8) presents an animated video illustrating the complete process of rainbow formation to strengthen children's understanding of the concept.

Table 3. Design of Augmented Reality Learning Media

No	Framework	Description
1		Cover Page This page serves as the media's main identity, in the form of a card with a barcode for accessing the Augmented Reality (AR) learning media.
2		User Guide Contains simple instructions and guidance for teachers and parents on how to use the AR learning media.
3		Initial Display After the barcode is scanned, an Assemblr link appears, providing access to the Augmented Reality (AR) learning media.
4		Main Page Contains the main navigation page with three options for using the Augmented Reality (AR) learning media: View in 3D Scan Marker Display in Your Room
5		Contents page This page contains the contents of the media, which consists of 8 pages about the process of rainbow formation

Development Stage

The media development process began with the creation of learning content based on the previously designed framework. The learning materials were developed in the form of visuals, simple text, and audio adjusted to the characteristics of early childhood learners at RA Al Qur'an Dina. Furthermore, three-dimensional (3D) objects representing simple

scientific concepts, such as objects and their properties, were developed. These 3D objects were designed to be attractive, colorful, and easy for children to understand.

The next stage involved developing the Augmented Reality application that integrates markers with 3D objects. The markers were designed as specific images that, when scanned with a device camera, display 3D objects in real time. The media also included interactive features such as object rotation, zoom, and audio explanations to support children's understanding.

Implementation Stage

The implementation stage was the phase in which the developed learning media, revised based on expert validation, Focus Group Discussions (FGD), and small group trials, were applied in practice. At this stage, the Augmented Reality learning media based on a deep learning approach were tested on a larger scale to determine their effectiveness in improving children's scientific literacy at RA Al Qur'an Dina.

a. Training of Trainers (TOT)

Before conducting the large-group trial, a Training of Trainers (TOT) program was conducted for teachers who would use the learning media. The TOT activities aimed to provide teachers with an understanding of how to use Augmented Reality media, the steps involved in implementing deep learning-based learning, and techniques for assisting children while using the media.

During this activity, teachers were given demonstrations on how to use Augmented Reality media, including how to operate the application, use markers, and display 3D objects. Afterward, teachers were given opportunities to practice directly using the media. In this session, teachers explored various features, including scanning markers, observing 3D objects, and listening to narrations in the media. Through the implementation of TOT activities, it was expected that teachers would be able to apply media in the learning process optimally.

In addition to media practice sessions, the TOT activities also included learning simulations. Teachers were asked to practice using the media in simple learning scenarios to understand effective instructional steps better better. The activities were also accompanied by discussions and question-and-answer sessions to address the difficulties participants encountered.

b. Large Group Trial

The large-group trial was conducted as a continuation of the small-group trial and the Training of Trainers (TOT) activities. This stage aimed to determine the effectiveness of Augmented Reality learning media, based on a deep learning approach, in improving children's scientific literacy on a broader scale.

The large-group trial was implemented at RA Al Qur'an Dina by involving all or most of the students in a single class. The learning activities were conducted by classroom teachers who had participated in the TOT program, with the researcher accompanying them. The implementation of the learning activities was aligned with the previously prepared lesson plans.

The learning activities began with an apperception session to explore children's prior knowledge of the material being studied. Subsequently, the teacher reintroduced the Augmented Reality learning media and provided simple instructions regarding its use. The children were then allowed to use the media directly by scanning markers and observing the displayed three-dimensional objects.

Data collection at this stage was conducted using validated scientific literacy assessment instruments and observation sheets documenting children's activities during the learning process. In addition, initial and final abilities (pretest and posttest) were measured to determine the improvement in children's scientific literacy after using the learning media.

Pretest and Posttest Implementation

The pretest was conducted to assess children's initial scientific literacy before the implementation of Augmented Reality learning media based on a deep learning approach, using expert-validated instruments. After the learning process was completed, a posttest was administered using the same instruments to objectively compare results and assess improvement in children's scientific literacy. The posttest was implemented in an enjoyable learning environment adapted to the characteristics of early childhood learners at RA Al Qur'an Dina. The assessment instruments included observation sheets and simple tasks designed to evaluate children's abilities to observe, understand, and communicate scientific concepts, while teachers and researchers provided guidance to support effective participation without reducing assessment objectivity.

Table 4. Pretest and Posttest Results

No	Name	Pretest Result		Posttest Result	
		Score	Percentage	Score	Percentage
1	AZR	15	38%	40	100%
2	AH	12	30%	40	100%
3	AFD	11	28%	40	100%
4	AF	11	28%	40	100%
5	ANS	13	33%	38	95%
6	ADA	15	38%	40	100%
7	AH	12	30%	40	100%
8	AS	13	33%	40	100%
9	DEF	15	38%	38	95%
10	DKPP	14	35%	40	100%
11	FGID	12	30%	40	100%
12	FASS	13	33%	38	95%
13	FQGH	14	35%	40	100%
14	GH	15	38%	40	100%
15	HARP	14	35%	37	93%
16	HK	12	30%	38	95%
17	KSF	14	35%	40	100%
18	LAH	15	38%	40	100%
19	MRAF	14	35%	40	100%
20	MR	15	38%	40	100%
Total		269		789	
Average		13,45		39,45	

Based on the pretest results, the average score obtained by the students was 13.45, reflecting the initial condition of children's scientific literacy abilities before the implementation of Augmented Reality learning media based on a deep learning approach. After the learning process was completed, the posttest results showed a significant improvement, with the average score increasing to 39.45. This finding indicates that the use of interactive and visual Augmented Reality media positively contributed to the development of children's scientific literacy by helping them understand concepts more concretely and increasing their engagement in learning activities. To further strengthen the analysis of the media's effectiveness, the improvement in children's scientific literacy was also assessed using the N-Gain Score to objectively measure changes before and after the implementation of the learning media. The results of the N Gain Score calculation are presented as follows:

Table 5. N Gain Score

Nilai N Gain Score	Nilai N Gain Persen
0,98	97,93

Furthermore, to provide a more comprehensive interpretation of the N Gain Score calculation, the results were classified according to effectiveness criteria. This classification aimed to determine whether the improvement in children's scientific literacy abilities fell into the low, moderate, or high category. The effectiveness criteria are presented below:

Table 6. Effectiveness Criteria

Percentage	Criteria
80 100	Highly Effective
60 79	Effective
50 59	Moderately Effective
0 49	Ineffective

Based on the N Gain Score table, the average percentage was 97.93, which falls within the 80–100% range; therefore, it is categorized as Highly Effective.

Table 7. Classification of N Gain Score Levels

N Gain Score Range	Effectiveness Level
$g > 0,7$	High
$0,3 < g \leq 0,7$	Moderate
$g < 0,3$	Low

The average N Gain score of 0.98 falls within the range of $g > 0.7$ and is therefore categorized as having a high level of effectiveness. Based on the N-Gain Score results, it can be concluded that the Augmented Reality learning media based on a deep learning approach were effective in improving children's scientific literacy at RA Al Qur'an Dina.

Evaluation Stage

The evaluation stage is the final phase of the ADDIE development model, aimed at assessing the entire process and the outcomes of using Augmented Reality learning media based on a deep learning approach. The evaluation was conducted to determine the extent to which the media improved children's scientific literacy and to provide a basis for product refinement.

In this study, the evaluation was conducted both formatively and summatively. Formative evaluation was carried out at each stage of development, including expert validation, Focus Group Discussions (FGD), small-group trials, and product revisions. This evaluation aimed to improve and refine the media to ensure suitability with user needs and the characteristics of early childhood learners at RA Al Qur'an Dina.

Meanwhile, the summative evaluation was conducted during the implementation stage through large group trials. This evaluation aimed to determine the effectiveness of the media in improving children's scientific literacy. Evaluation data were obtained from pretest and posttest results, observation sheets, and teachers' responses regarding the use of the learning media. The analysis showed an improvement in children's scientific literacy after using the media, as indicated by the difference between pretest and posttest scores.

In addition, the observation results indicated that the Augmented Reality learning media increased children's engagement, activity, and enthusiasm during the learning process. Children found it easier to understand scientific concepts because they were presented visually and interactively. Teachers' responses also indicated that the media were practical to use and helped deliver learning materials more engagingly.

Based on the overall evaluation results, the Augmented Reality learning media developed in this study using a deep learning approach were deemed effective and feasible for use in learning activities at RA Al Qur'an Dina. Nevertheless, several limitations were identified, such as the need for supporting devices and the time required to adapt to using the media. Therefore, further development is recommended to optimize the media for broader implementation.

Thus, the evaluation stage demonstrated that the developed media not only met feasibility criteria but also positively impacted early childhood scientific literacy through meaningful, enjoyable, and interactive learning experiences.

3.2. Discussion

This study is a Research and Development (R&D) project aimed at developing Augmented Reality learning media based on a deep learning approach to improve children's scientific literacy on rainbows at RA Al Qur'an Dina. The development model used was the ADDIE model, which consists of five stages: analysis, design, development, implementation, and evaluation. These stages were carried out systematically to ensure that the developed media met the learning needs of early childhood learners and were suitable for use in the learning process [23].

At the analysis stage, the researcher conducted a needs analysis, curriculum analysis, and analysis of student characteristics at RA Al Qur'an Dina. The results showed that science learning for early childhood learners still relied on simple methods and had not

optimally utilized technology-based learning media. In addition, children's scientific literacy still needs improvement, as they experienced difficulties understanding abstract scientific concepts, especially the process of rainbow formation [24]. Therefore, learning media capable of providing concrete, interactive, and engaging learning experiences that align with early childhood characteristics were needed. This analysis served as the basis for developing Augmented Reality learning media using a deep learning approach [25]. These findings are in line with the study by Nabila Rahmawati (2023), which found that Augmented Reality-based media can help children understand abstract concepts through more realistic and interactive visualizations, thereby increasing children's motivation and engagement in science learning.

The next stage was the design stage, which involved preparing the learning media framework, determining the media format, and designing the media's appearance and content. At this stage, the researcher designed media with attractive visuals, bright colors, interactive animations, three-dimensional (3D) objects, audio narration, and simple navigation buttons to make it easy for early childhood learners to use. The material focused on the process of rainbow formation, using simple, communicative language. In addition, the media was designed using a deep learning approach that includes mindful, meaningful, and joyful learning, so that children could learn in a focused, meaningful, and enjoyable way. The researcher also developed research instruments, including validation sheets, practicality questionnaires, observation sheets, and scientific literacy test instruments for children. This design process is supported by the study by Siti Aisyah and Nurhayati (2024), which found that attractive, interactive learning media tailored to the characteristics of early childhood learners can increase learning interest and help children understand learning materials more easily.

At the development stage, the researcher began developing the learning media according to the prepared design. The development process included creating three-dimensional (3D) visual objects, animations of the rainbow formation process, audio narration, and Augmented Reality markers that could be scanned using Android smartphones. After the media were developed, validation was conducted by media experts, material experts, and research instrument experts to determine the media's feasibility. The validation results showed that the media were categorized as highly valid and feasible for use in the learning process. Furthermore, a Focus Group Discussion (FGD) was conducted with teachers to gather suggestions and feedback on the use of media. Based on the FGD results and revisions, the media was then tested with a small group to determine its practicality for learning activities. These findings are consistent with the study by Rina Marlina (2023), which showed that Augmented Reality-based learning media that had undergone expert validation and revision demonstrated high feasibility and practicality for use in early childhood learning processes.

The next stage was implementation, carried out through Training of Trainers (TOT) activities for teachers on the use of Augmented Reality learning media in the learning process. After teachers understood how to use the media, large group trials were conducted with students at RA Al Qur'an Dina. During the implementation stage, children appeared enthusiastic and active as they used the learning media. The media helped children

understand the process of rainbow formation more concretely through attractive animations and virtual objects. In addition, pretests and posttests were conducted to assess improvements in children's scientific literacy after using the learning media. The implementation results showed improvements in children's scientific literacy and positive responses from both teachers and students toward the use of Augmented Reality learning media.

The final stage was evaluation, conducted to assess the quality of the media and the success of the media development process. Evaluation was carried out formatively at each stage of development and summatively after implementation. The evaluation results indicated that the Augmented Reality learning media based on a deep learning approach was valid, practical, and effective for use in early childhood science learning. The media increased children's interest, attention, and involvement in the learning process. Furthermore, the use of technology-based media also helped teachers create a more interactive and enjoyable learning atmosphere. Therefore, the developed learning media can be used as an innovative alternative to improve children's scientific literacy at RA Al Qur'an Dina.

Research Limitations

This study still has several limitations that may affect the research results. The first limitation concerns the supporting devices used for the Augmented Reality media. Not all devices have the same specifications, so in some cases, the application required adjustments to run optimally. In addition, using the media still required teacher assistance because early childhood learners were not yet fully capable of operating the devices independently.

Another limitation was the relatively short duration of the research implementation. The use of the media in learning activities has not yet been sustained over a long period, so the long-term effects of the media on the continuous development of children's scientific literacy have not yet been fully identified. This study focused solely on improving scientific literacy within a predetermined time frame, as outlined in the research schedule.

In addition, the development of the learning media focused only on certain scientific literacy materials and indicators, aligned with the learning needs at RA Al Qur'an Dina. Therefore, the developed media still needs further improvement and development so that it can be applied to other learning materials with more diverse and interactive features.

Besides the limitations mentioned above, this study also had limitations related to teachers' and students' mastery of technology. Some teachers still needed time to adapt to the use of technology-based learning media, particularly Augmented Reality. This caused the implementation process to not run optimally during the initial stages of use. Early childhood learners also still require intensive guidance and assistance in using the devices during the learning process.

Another limitation concerned the process of measuring scientific literacy in early childhood learners. Scientific literacy assessment was conducted through observations and simple activities, so the assessment results were still influenced by children's emotional

states, attention levels, and the learning atmosphere during the activities. The characteristics of early childhood learners, whose concentration and moods change easily, also influenced the research observations.

This study also did not fully measure the effectiveness of the learning media compared to other learning media using more in-depth experimental methods. The research focused solely on the development and implementation of Augmented Reality learning media using a deep learning approach, without directly comparing them with other learning models or media. Therefore, further studies are needed to examine the effectiveness of the media more broadly using more complex research methods and involving larger samples.

4. CONCLUSION

This study developed Augmented Reality learning media based on a deep learning approach to improve early childhood scientific literacy, using the ADDIE development model. The findings indicate that the developed media achieved satisfactory levels of validity and feasibility, as assessed by experts, and received positive responses from teachers during implementation. The large-group trial also showed a substantial improvement in children's scientific literacy, suggesting that the media have strong potential to facilitate more interactive, meaningful, and engaging science learning for young children. Practically, the developed media can serve as an alternative instructional resource for early childhood teachers seeking to integrate digital technology into science learning while promoting children's observation, inquiry, and conceptual understanding. The findings also provide useful insights for early childhood education institutions on adopting technology-enhanced learning environments that support the development of scientific literacy.

Nevertheless, the findings should be interpreted within the scope of the present study. Future research should evaluate the effectiveness of the developed media using larger and more diverse samples, involve multiple early childhood education institutions, extend the duration of implementation, and employ more rigorous experimental designs, such as randomized controlled or quasi-experimental studies with comparison groups, to provide stronger evidence regarding its impact on children's scientific literacy.

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