



The Effectiveness of LENTERA-Based Interactive Media on Early Childhood Scientific Literacy: Learning Engagement as a Covariate

*Ni Luh Ika Windayani, Ni Wayan Risna Dewi, Ni Putu Widyasanti

Early Childhood Teacher Education, Faculty of Dharma Acarya, IAHN Mpu Kuturan, Buleleng, Indonesia

*Corresponding Author e-mail: windayaniika3@gmail.com

Received: May 2026; Revised: June 2026; Published: July 2026

Abstract

Scientific literacy is a fundamental competence that should be developed from early childhood. However, early childhood learning practices remain predominantly teacher-centered, minimally exploratory, and supported by static media, resulting in suboptimal learning engagement and scientific literacy outcomes. This study aimed to examine the effectiveness of LENTERA (Literacy and Research Exploration in Learning) based interactive media on early childhood students' scientific literacy, with learning engagement as a covariate. The media is a digital learning application that integrates illustrated stories, animated videos, observation activities, simple experiments, interactive quizzes, and reflection worksheets designed according to the stages of literacy, exploration, investigation, analysis, and reporting. A quasi-experimental design with a single-factor independent group and a covariate was employed. The participants were 64 early childhood education students randomly assigned to an experimental group and a control group. Data were collected using a scientific literacy test and a learning engagement observation sheet. Data were analyzed using descriptive statistics and ANCOVA after satisfying the assumptions of normality, homogeneity, linearity, and homogeneity of regression slopes. The findings revealed a significant difference between groups after controlling for learning engagement ($F_{(1,61)}=5.759$, $p=0.019$, $\eta^2=0.086$), with the experimental group achieving higher adjusted mean scores. Learning engagement also significantly affected scientific literacy ($F_{(1,61)}=33.157$, $p<0.001$, $\eta^2=0.352$). The study concludes that LENTERA-based interactive media is effective in enhancing early childhood students' scientific literacy and learning engagement.

Keywords: LENTERA learning model; Interactive media; Scientific literacy; Learning engagement; Early childhood education

How to Cite: Windayani, N. L. I., Dewi, N. W. R., & Widyasanti, N. P. (2026). The Effectiveness of LENTERA-Based Interactive Media on Early Childhood Scientific Literacy: Learning Engagement as a Covariate. *Prisma Sains : Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, 14(3), 1373–1386. <https://doi.org/10.33394/j-ps.v14i3.20748>



<https://doi.org/10.33394/j-ps.v14i3.20748>

Copyright© 2026, Windayani et al.

This is an open-access article under the [CC-BY](https://creativecommons.org/licenses/by/4.0/) License



INTRODUCTION

The scientific literacy is a fundamental competency which is essential to develop from an early age because it serves as the foundation for children to comprehend their environment, foster curiosity, and develop critical thinking and simple problem-solving skills (Doshi et al., 2024; Roy et al., 2025). Scientific literacy is comprehended not only as mastery of concepts, but also as the ability to observe, question, interpret phenomena, and make evidence-based decisions in everyday life (Zetterqvist & Bach, 2023; Cho, 2022; Mafarja et al., 2025; Warmansyah et al., 2022). Therefore, strengthening scientific literacy in Early Childhood Education is a crucial strategy in preparing a generation that is adaptive to developments in science and technology (Cho, 2022; Osborne & Allchin, 2024).

Various international reports indicate that the scientific literacy skills of students in developing countries remain low. The 2022 PISA results reported that most students have not

yet reached the minimum level of comprehending scientific concepts and applying them in real-life contexts (Roy et al., 2025). This condition indicates that the foundation of scientific literacy has not been optimally formed from the early stages of education (Eliza et al., 2025; Junaedi et al., 2025; Zetterqvist & Bach, 2023). Likewise, a UNESCO report emphasized that science learning for early childhood in many countries still does not emphasize exploratory and inquiry-based experiences, but is still dominated by passive instructional approaches.

This global condition is also reflected in early childhood education practices in Indonesia. The science learning process remains largely teacher-centered, with the use of static media, worksheet-based activities, and minimal hands-on exploration activities (Eliza et al., 2025; Junaedi et al., 2025; Zetterqvist & Bach, 2023). Children are given less opportunities to observe, experiment, ask questions, and draw conclusions independently, resulting in low learning engagement (Agustini et al., 2024; Obaki, 2017). Yet, learning engagement is a crucial factor that directly contributes to learning success. Children who are actively engaged, behaviorally, emotionally, and cognitively, tend to have a better comprehension of the concepts being learned.

These findings are reinforced by preliminary observations conducted by researchers in several early childhood education units in the Buleleng Regency cluster, Bali. They showed that science learning is still dominated by routine, task-oriented activities, such as naming pictures, bolding letters, or completing predetermined worksheets. This leaves children acting more as recipients of information than as active participants in the process of discovering concepts. In most of the observed classes, teachers primarily conveyed material verbally without involving children in observations, simple experiments, or meaningful discussions. Media use was limited to printed pictures and textbooks, while interactive media and concrete exploration tools were barely utilized. As a result, children appeared to lose focus easily, became bored quickly, and displayed little enthusiasm. They were rarely given opportunities to ask questions, predict, or express their observations. This lack of variety in activities and hands-on experiences leads to low levels of children's learning engagement, which ultimately impacts the development of scientific literacy, particularly in the ability to observe, categorize, and explain cause-and-effect relationships simply (Djamali & Kharismawati, 2023; Gkintoni et al., 2024).

One of the main factors influencing low scientific literacy and learning engagement in early childhood is the limited availability of engaging, contextual, and developmentally appropriate learning media (Nobre, J. N. P. et al. 2020; Obaki, S. O., 2017). In many early childhood education units, the media used are still static, such as printed images or worksheets, which provide insufficient visual stimulation and direct experiences for children. Non-interactive media makes children quickly lose focus, get bored easily, and are less motivated to engage in learning activities (Al Mamun, 2022; Nobre, J. N. P., et al. (2020). In fact, early childhood learns optimally through concrete, visual experiences and activities that involve the senses (Roy et al., 2025; Windayani & Widyasanti, 2025). Therefore, learning innovations are required that are able to provide active, fun, and meaningful learning experiences through the use of interactive media integrated with learning approaches that are apposite to the world of children.

The Literacy and Research Exploration in Learning (LENERA) model offers an approach that integrates literacy, exploration, and reflection activities into a meaningful learning environment (Windayani and Widyasanti 2025; Yıldız, T. (2025). This model places children at the center of learning by providing space for them to observe, ask questions, experiment, and communicate their findings in a simple manner. When implemented through interactive media, LENTERA has the potential to increase children's behavioral, emotional, and cognitive learning engagement, as well as assist them comprehend science concepts more concretely and contextually. LENTERA-based interactive media enables children to learn through a

combination of visuals, audio, animation, and exploratory activities, making learning more engaging and encouraging active participation.

Although various studies have shown that the use of interactive media, inquiry-based learning, and activity-based learning can improve students' learning outcomes and scientific literacy, several limitations remain. Most previous studies have focused on improving mastery of inquiry concepts or skills without integrating literacy activities, investigation-based exploration, reflection, and scientific communication into a single learning environment. Furthermore, research on early childhood scientific literacy focuses more on learning outcomes than on the process of scientific literacy development, which is formed through exploratory experiences, scientific play, and meaningful interactions with the learning environment (Fragkiadaki et al., 2023; Roy et al., 2026). This situation results in a limited comprehension of how the learning process can systematically develop early childhood scientific literacy through the integration of various interrelated learning activities.

Theoretically, the LENTERA model differs from conventional inquiry, exploratory, and interactive media learning models. Inquiry models generally emphasize the process of investigation to discover concepts, while LENTERA integrates four main interrelated components: literacy activities, simple exploration and investigation (research exploration), reflection on findings (reflection), and communication of learning outcomes (scientific communication). The integration of these four components enables students not only to acquire knowledge through exploration but also to develop the ability to comprehend information, connect experiences with scientific concepts, reflect on learning outcomes, and communicate findings systematically. When packaged in interactive media that utilizes visuals, using audio, animation, and manipulative activities, LENTERA provides a multimodal learning experience that enhances students' cognitive, emotional, and behavioral engagement throughout the learning process. Previous research has shown that multimodal interactions, exploration of phenomena, the use of concrete materials, and scientific communication contribute significantly to the development of early childhood science comprehension.

Scientific literacy is comprehended as a child's ability to observe scientific phenomena, ask simple questions, conduct basic explorations and investigations, explain scientific concepts related to everyday life, and communicate the results of observations simply in this study. These dimensions were chosen because they are the main foundation of scientific literacy in early childhood and serve as the basis for the development of scientific thinking, problem-solving, and evidence-based decision-making skills at subsequent levels of education. Through LENTERA's syntax, which integrates literacy activities, exploration, reflection, and communication, each dimension of scientific literacy is expected to develop more optimally than conventional learning.

This study also utilizes learning engagement as a covariate variable. Methodologically, learning engagement is not positioned as a mediator because this study does not aim to test the causal mechanisms explaining how treatment influences scientific literacy through engagement. This variable is also not treated as a moderator because the study did not test whether engagement levels strengthened or weakened the effect of the treatment. In its place, learning engagement was treated as a covariate because various studies have shown that learning engagement has a strong relationship with academic achievement and student learning outcomes. Hence, controlling for engagement through ANCOVA allows for a more accurate estimation of the effect of LENTERA-based interactive media on scientific literacy by reducing the influence of individual factors which do not become the focus of the treatment.

Theoretically, the LENTERA model differs from conventional inquiry, exploratory, and interactive media learning models. While inquiry models generally emphasize the process of investigation to discover concepts, LENTERA systematically integrates literacy activities, simple exploration and investigation (research exploration), reflection, scientific communication, and digital media-based interactions into a complete learning cycle (Roy et

al., 2026; Fragkiadaki et al., 2023). Literacy activities serve to build children's initial knowledge and scientific vocabulary through stories, images, videos, and contextual information relevant to everyday life. The exploration and investigation phases provide opportunities for children to observe phenomena, ask questions, make predictions, experiment, and gather information from their surroundings. The reflection phase helps children connect exploratory experiences with learned scientific concepts, thus forming a deeper understanding. Furthermore, the communication phase provides space for children to convey observations, explain findings, and discuss ideas simply. The integration of these four components is supported by interactive media that utilizes animation, audio, simple simulations, educational games, and direct feedback, creating a multimodal learning experience that aligns with the developmental characteristics of early childhood (Wilmes & Siry, 2024). Research shows that learning experiences that integrate exploration, scientific play, multimodal interaction, and active communication can help children develop a more meaningful and sustainable comprehension of scientific concepts (Fragkiadaki et al., 2023; Roy et al., 2026).

LENERA's uniqueness lies in the integration of literacy activities and the scientific exploration process, a feature that is not often found in previous learning models. Most previous research has focused on developing inquiry skills or using interactive media separately, whereas LENTERA connects the processes of reading and comprehending information, conducting exploration, reflecting on results, and communicating findings in a single, interconnected series of learning activities (Roy et al., 2026). Theoretically, this integration is expected to improve the key dimensions of early childhood scientific literacy, namely the ability to observe scientific phenomena, ask curiosity-based questions, conduct simple explorations and investigations, explain scientific concepts in everyday contexts, use observational evidence to draw simple conclusions, and communicate findings verbally and visually (Fragkiadaki et al., 2023; Roy et al., 2026). Thus, LENTERA is not only oriented towards mastering scientific concepts but also towards developing scientific thinking processes, which are the foundation of scientific literacy from an early age.

Based on this research gap, the novelty of this study lies not only in the use of ANCOVA with learning engagement as a covariate, but primarily in the development and testing of LENTERA-based interactive media that integrates literacy activities, investigation-based exploration, reflection, scientific communication, and digital interaction in a single learning environment specifically designed to develop various dimensions of early childhood scientific literacy. This conceptual novelty contributes to the development of early childhood science learning theory by demonstrating that literacy, scientific exploration, reflection, communication, and learning engagement are interacting components in shaping scientific literacy (Roy et al., 2026; Wilmes & Siry, 2024). Furthermore, this research provides a practical contribution in the form of alternative learning media that can facilitate more meaningful, interactive, and child-centered science learning.

METHOD

This study employed a quasi-experimental method with a single-factor independent group design involving one covariate variable. This design was used to analyze the effectiveness of LENTERA-based interactive media on the scientific literacy of early childhood education students by controlling for the influence of learning engagement as a covariate variable. The study was conducted in pre-formed groups (intact groups), thus participants were not randomly assigned to experimental and control groups. The research procedure consisted of three stages: preparation (pre-experiment), treatment implementation, and evaluation (post-experiment). The research design and variable constellation are presented in Table 1.

Table 1. Research Design

Learning Approach (A)			
LENTERA-based Interactive Media (A₁)		Conventional (A₂)	
X	Y	X	Y

Information:

- A1 : Experimental group (LENTERA-based interactive media)
- A2: : Control group (conventional learning)
- X : Learning engagement in science learning (covariate)
- Y : Early Childhood Education students' scientific literacy

The population in this study were all PAUD students who participated in science learning at the educational unit that was the research location. The sample was selected using a random sampling technique. The research subjects numbered 64 students consisting of 33 male students and 31 female students, with the age range of 5–6 years who were in group B (TK B). The sample was then divided into an experimental group and a control group according to the classes that had been previously formed. The inclusion criteria in this study included: (1) registered as active students in group B TK, (2) participating in learning activities regularly during the research, (3) obtaining permission from parents/guardians to participate in the research, and (4) not having developmental disabilities that could affect engagement in the learning activities provided. All participants had relatively similar learning backgrounds because they came from PAUD units that implemented similar science curriculum and learning materials and had never received learning using LENTERA-based interactive media. To ensure the initial equality of the two groups before treatment, initial measurements were conducted on scientific literacy skills and learning engagement. The analysis showed no significant differences between the experimental and control groups at baseline, thus both groups were considered to have equivalent characteristics before treatment.

The intervention was implemented over six 70 minute sessions. The science material taught focused on plants, including plant parts, plant requirements for growth, the plant growth process, the functions of plant parts, and the benefits of plants in everyday life. The experimental group participated in learning using LENTERA-based interactive media, while the control group participated in learning using methods and media commonly used by teachers in schools, such as oral explanations, picture books, and children's worksheets.

The LENTERA-based interactive media was developed in the form of a digital learning application that combines illustrated stories, animations, learning videos, interactive quizzes, observation activities, and reflection sheets. Learning in the experimental group followed the LENTERA syntax, consisting of literacy activities, simple exploration and investigation, reflection, and communication of learning outcomes. In the literacy phase, children observed pictures, read or listened to stories, and watched videos about plants. In the exploration phase, children directly observed plants, identified plant parts, made simple predictions, and experimented with planting seeds. In the reflection stage, children discuss their observations and relate them to information obtained from the media. Next, in the communication stage, children share their observations, explain the changes that occurred in the plants, and present their verdicts in simple terms to their peers and teachers.

One example of a LENTERA-based task is observing the growth of mung bean seeds. Children are asked to observe daily changes, record their observations using simple pictures or symbols, discuss factors that influence plant growth, and present their observations to the class. This activity is designed to develop the ability to observe, ask questions, gather evidence, draw simple conclusions, and communicate findings as part of scientific literacy.

Children's scientific literacy data was collected using an observation sheet consisting of 15 statements. This instrument was used to measure children's scientific literacy skills during

learning activities. The development of scientific literacy indicators refers to the concept of early childhood scientific literacy proposed by Deanna M. Kuhn and Marilyn Fleer, and the scientific literacy framework developed by the Organisation for Economic Co-operation and Development (OECD), which is tailored to the developmental characteristics of early childhood. The indicators measured include: (1) the ability to observe scientific phenomena or objects, (2) the ability to ask simple questions based on observations, (3) the ability to conduct simple explorations and investigations, (4) the ability to group or compare objects based on certain characteristics, (5) the ability to explain simple scientific concepts related to everyday life, (6) the ability to use observations as a basis for drawing simple conclusions, and (7) the ability to communicate observations verbally and visually (Fleer, 2022; Fragkiadaki et al., 2023; OECD, 2023). Each item is assessed using a four-level scoring rubric: 1 (Not Yet Developing), 2 (Beginning to Develop), 3 (Developing as Expected), and 4 (Developing Very Well). The total score is obtained by accumulating the scores for all observation items, with higher scores indicating a higher level of scientific literacy.

One example of an observation item is “children are able to explain changes that occur in plants after observations.” For the ability to communicate observation results, a score of 1 is given if the child is unable to communicate observations, a score of 2 if the child communicates information with full teacher assistance, a score of 3 if the child is able to communicate most of the observations independently, and a score of 4 if the child is able to communicate observations completely, clearly, and independently. To facilitate interpretation of the results, scientific literacy scores are categorized into four levels: very low, low, high, and very high, based on a predetermined score range.

The instrument’s content validity was tested using the Aiken’s V index through expert judgment. The validation process involved three experts: an early childhood education expert, an early childhood science learning expert, and an educational evaluation expert. Validated aspects included the indicator’s suitability to the scientific literacy construct, clarity of item wording, suitability to early childhood developmental characteristics, measurability of the indicator, and the instrument’s relevance to the research objectives. The analysis showed that all items obtained Aiken’s V coefficients that were in the valid category, making them suitable for use in research. Furthermore, the instrument’s reliability was tested through internal consistency testing using Cronbach’s Alpha. The test results indicate that the instrument has a high level of reliability, thus it can be used to measure children’s scientific literacy consistently. The results of the instrument validity test using the Aiken’s V formula showed an average value of 0.89 with a valid category, while the results of the instrument item reliability test obtained a coefficient of 0.91 which is included in the very reliable category, thus the instrument is declared suitable for use in research.

In this study, learning engagement was treated as a covariate variable because it was measured before the treatment was implemented through observations of children’s learning activities during regular classroom lessons. This initial measurement aimed to obtain an overview of the level of learning engagement students had before being exposed to LENTERA-based interactive media. Hence, learning engagement represents a baseline characteristic that theoretically could influence scientific literacy achievement, nevertheless is not a consequence of the treatment. Using learning engagement as a covariate in the ANCOVA analysis was intended to control for pre-existing individual variation, allowing for a more accurate and objective estimate of the effect of LENTERA-based interactive media on scientific literacy.

RESULT AND DISCUSSION

Result

This section presents the results of data analysis to examine the effectiveness of interactive media based on the LENTERA learning model on early childhood students’ scientific literacy, with learning engagement as a covariate. The analysis was conducted using ANCOVA after all statistical assumptions were met.

Descriptive Analysis

Before controlling for the covariate, descriptive statistics were calculated to provide an overview of students' scientific literacy scores in both groups.

Table 2. Descriptive Statistics of Scientific Literacy

Learning Approach	Mean	Std. Deviation	N
Experimental group	41.41	3.859	32
Control group	38.06	3.537	32
Total	39.73	4.040	64

Based on Table 2, The results indicate that the experimental group achieved a higher mean score ($M = 41.41$) than the control group ($M = 38.06$), suggesting an initial advantage of the LENTERA-based interactive media prior to statistical adjustment.

Requirements Analysis Testing

Before testing the hypothesis using ancova, analysis requirements tests were first carried out, including: (1) testing the normality of data distribution, (2) testing the homogeneity of variance, and (3) testing the linearity and significance of regression between the covariable and the dependent variable.

Normality Test

The normality test of data distribution is intended to obtain data on whether the sample comes from a normally distributed population or not. In this study, the normality test uses the help of SPSS 16 for windows which uses the normality test and Kolmogorov Smirnow. The results of the normality test with the help of SPSS 16 for windows which uses the normality test from Kolmogorov Smirnow are presented in Table 3.

Table 3. Normality Test Results

Learning Approach	Kolmogorov-Smirnov ^a			Shapiro-Wilk			
	Statistic	df	Sig.	Statistic	df	Sig.	
Residual for Y	Experimental group	.106	32	.200*	.960	32	.281
	Control group	.125	32	.200*	.954	32	.184

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Based on Table 3 shows that the significance level of the Kolmogorov Smirnov normality test on the six data groups is greater than the specified data significance level. Thus, H_0 is accepted and H_1 is rejected. Thus all groups, the data distribution is normally distributed.

Homogeneity of Variance Test

The homogeneity of variance test is used to obtain data that the variance of the groups to be compared have homogeneous characteristics or in other words to determine whether the groups are worthy of being compared. In this study, the homogeneity of variance test uses the help of SPSS 16 for windows which uses the Levene Error variance equality test. The results of the analysis are shown in Table 4.

Table 4. Test of Homogeneity of Variances Using Levene's Test of Equality of Error Variances

Dependent Variable	F	df ₁	df ₂	Sig.
Science literacy	.008	1	62	.929

Table 4 shows that the level of significance of Levene's test of Equality of Error variances of the learning presentation data group is greater than the specified level of significance, namely $0.929 > 0.05$. Thus, H_0 is accepted and H_1 is rejected. Thus all data groups have homogeneous variances.

Linearity Test

The linearity test was conducted to examine whether the relationship between the dependent variable and the covariate followed a linear pattern. The test was performed using SPSS 16 for Windows by evaluating the significance of the F value for deviation from linearity. The results indicate that the relationship between students’ scientific literacy and learning engagement is linear. This linear pattern is illustrated in Figure 1.

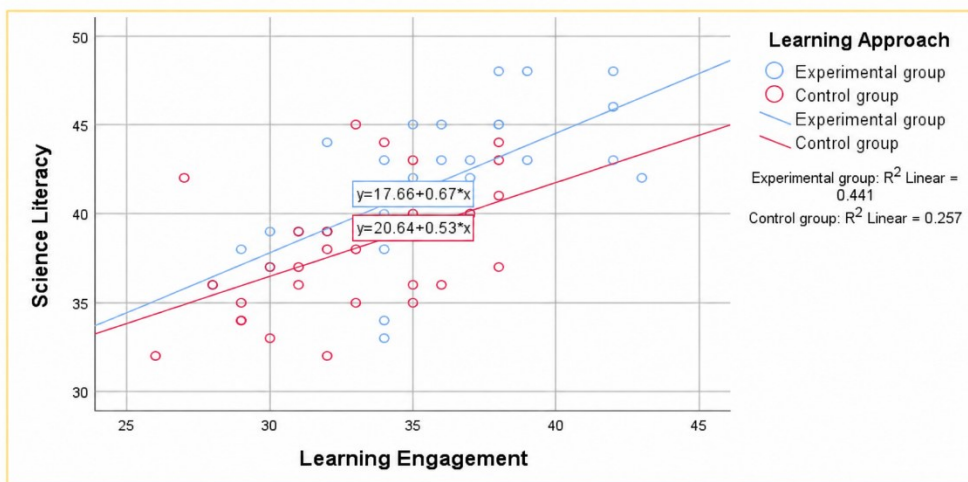


Figure 1. Data Linearity

Based on Figure 1, the relationship between learning engagement and scientific literacy shows a positive linear pattern in both groups. This is indicated by the scatterplot, with a regression line forming a positive slope in both the experimental group ($y = 17.66 + 0.67x$) and the control group ($y = 20.64 + 0.53x$), thus meeting the linearity assumption in the ANCOVA analysis.

After the ancova test requirements are met, the hypothesis test calculation can be carried out. The difference in pedagogical competence between students who follow the Lentera learning model based on the intensity of involvement in learning and students who follow conventional learning is tested using ancova assisted by SPSS 16 for windows, this hypothesis will be accepted if the significance value of F in the inter-subject effect test is smaller and the specified significance level (significance $F < 0.05$). The results of the calculation are shown in Table 5.

Table 5. ANCOVA Analysis Results for Science Literacy

Source of Variation	Type III Sum of Sqrs.	df	Mean Sqr.	F	Sig.	η^2
Learning Engagement	299.181	1	299.181	33.157	0.000	0.352
Learning Approach	51.961	1	51.961	5.759	0.019	0.086
Error	550.413	61	9.023			

The ANCOVA analysis results in Table 5 show that the overall model is significant, $F(2,61) = 26.491$, $p < 0.001$, with an R^2 value of 0.465 and an Adjusted R^2 of 0.447. This indicates that 46.5% of the variation in science literacy can be explained by learning approaches and learning engagement. Learning engagement significantly influenced scientific literacy, $F(1,61) = 33.157$, $p < 0.001$, with an effect size (partial eta squared) of 0.352. This value indicates that approximately 35.2% of the variation in scientific literacy is related to student learning engagement.

Furthermore, after controlling for the influence of learning engagement, the learning approach still significantly influenced scientific literacy, $F(1,61) = 5.759$, $p = 0.019$, with a partial eta squared value of 0.086. Based on Cohen’s criteria, this value indicates a moderate effect size. These results indicate that the use of LENTERA-based interactive media significantly contributes to improve the scientific literacy of early childhood education

students, beyond the influence of student learning engagement. Then the results of the termination coefficient are shown in Table 6.

Table 6. Covariable Correlation Coefficient on Scientific Literacy

		Learning Engagement	Scientific Literacy
Learning Engagement	Pearson Correlation	1	.644**
	Sig. (2-tailed)		.000
	N	64	64
Scientific Literacy	Pearson Correlation	.644**	1
	Sig. (2-tailed)	.000	
	N	64	64

** . Correlation is significant at the 0.01 level (2-tailed).

The results of the analysis in Table 6 show that there is a positive and significant relationship between learning engagement and scientific literacy ($r = 0.644$, $p < 0.001$). This indicates that students with higher levels of engagement tend to demonstrate better scientific literacy. Hence, learning engagement was considered an appropriate covariate in the ANCOVA model.

To facilitate interpretation of the ANCOVA results, the adjusted means (*estimated marginal means*) and standard errors for both groups were calculated after controlling for the effect of learning engagement. The results are presented in Table 7.

Table 7. Adjusted Means and Standard Errors of Scientific Literacy Scores

Learning Approach	Mean	Std. Error	95% CI
Experimental Group	41.20	0.53	40.14–42.25
Control Group	38.27	0.53	37.22–39.33

Discussion

The results of this study indicate that interactive media based on the LENTERA model is effective in improving the scientific literacy of early childhood education students, with learning engagement as a covariate. Based on the ANCOVA results, there was a significant difference between the experimental and control groups after controlling for the influence of learning engagement ($F = 5.759$; $p = 0.019$). The average corrected scientific literacy score of the experimental group was higher than that of the control group, indicating that the use of LENTERA-based interactive media has a positive impact on children's scientific literacy skills. This finding reinforces the view that child-centered, interactive, and exploration-based learning can create more meaningful learning experiences and improve learning outcomes.

LENTERA-based interactive media is designed to provide active learning experiences through simple activities of observing, asking questions, experimenting, and communicating results. This approach encourages children to be directly involved in the learning process, therefore they do not only receive information but also build comprehension through concrete experiences. The results showed that learning engagement significantly contributed to improved scientific literacy ($F = 33.157$; $p < 0.001$), meaning that the higher the child's engagement, the higher their scientific literacy achievement. This finding aligns with various studies that suggest learning engagement is a key factor in improving learning outcomes, particularly in activity-based and exploratory learning.

The strong relationship between learning engagement and scientific literacy is also demonstrated by the correlation analysis, which showed a significant positive relationship ($r = 0.644$; $p < 0.001$). This indicates that children who are actively engaged, behaviorally, emotionally, and cognitively, tend to have better scientific literacy skills. In the context of the LENTERA model, learning engagement serves not only as a supporting factor but also as a mechanism that strengthens the influence of interactive media on scientific literacy

achievement. Children who actively ask questions, experiment, and discuss demonstrate a deeper comprehension of the scientific concepts they are learning (Flanagan and Symonds, 2021).

The improvement in scientific literacy in the experimental group was inseparable from the characteristics of the activities contained in the LENTERA-based interactive media. During the learning process, children did not only receive information through animations, images, and videos about plants, but also engaged in a series of literacy activities, including observation, exploration, reflection, and communication. During the observation stage, children were guided to observe the characteristics of plant parts, changes in plant growth, and basic plant needs through visual media and direct observation. These activities contributed to improving the ability to observe scientific phenomena, which is one of the main indicators of early childhood scientific literacy (Fragkiadaki et al., 2023).

Furthermore, LENTERA-based interactive media provided opportunities for children to classify and compare objects based on specific characteristics, such as grouping plants by leaf size, flower colour, or water requirements. Children were also encouraged to make simple predictions, such as estimating the condition of plants that were not receiving enough water or sunlight. These prediction and classification activities assisted children develop early scientific thinking skills, particularly in recognizing cause-and-effect relationships and using observational evidence to draw simple conclusions. During the reflection stage, children are encouraged to connect their observations to everyday experiences, making scientific concepts more meaningful and easier to comprehend.

The communication component in LENTERA is also thought to contribute significantly to improve scientific literacy. After conducting observations and explorations, children are given the opportunity to explain their findings verbally and visually through group discussions, simple presentations, and drawing activities. These activities do not only help children develop communication skills but also strengthen conceptual comprehension, requiring them to organize and explain the information they have gathered. Hence, the improvement in scientific literacy found in this study stems not only from the use of interactive media but also from the integration of literacy activities, observation, classification, prediction, reflection, and communication, which are characteristic of the LENTERA model.

These findings align with previous research showing that interactive media can increase learning engagement and comprehension of scientific concepts in early childhood (Al Mamun, 2022; Nobre et al., 2020). These findings are also consistent with research by Wilmes and Siry (2024), which showed that children's interactions with materials, media, and resource-rich learning environments can enhance observational skills, communication skills, and scientific concept formation. Furthermore, these findings support the findings of Fragkiadaki, Fleeer, and Rai (2023), which asserted that the development of scientific concepts in early childhood occurs optimally when children engage in meaningful exploration, investigation, and communication activities.

Nevertheless, this study differs from previous research. Most previous studies examined the effectiveness of interactive media or inquiry-based learning separately, whereas this study integrates literacy activities, investigation-based exploration, reflection, scientific communication, and digital interaction into a single learning environment through the LENTERA model. Thus, these results provide additional evidence that the development of early childhood scientific literacy is influenced not only by the use of technology or exploration activities alone, but also by the integration of various learning activities that support the holistic scientific thinking process.

There are several limitations that need to be considered when interpreting the findings. First, the study sample size was relatively limited, involving only 64 early childhood education (PAUD) students from a single study area, thus generalizing the results to a broader population requires caution. Second, the study used a quasi-experimental design with pre-existing classes,

thus the randomization process was not fully feasible at the individual level. Third, although treatment implementation was monitored through observation sheets for learning implementation, the level of consistency in implementation between meetings and between educators was not analyzed in depth. Fourth, teacher factors have the potential to influence the study results because differences in teaching style, experience, and ability to facilitate interactive learning cannot be fully controlled for. Fifth, this study did not use pretest data on scientific literacy, thus the equivalence of students' initial abilities was based solely on group characteristics and covariate control through ANCOVA. Sixth, the possibility of contamination between groups remains possible because students come from relatively close educational environments and potentially share learning experiences during the study.

Based on these limitations, future research is recommended to involve a larger and more diverse sample size, use an experimental design that allows for more robust randomization, measure treatment implementation more systematically, and combine pretest and posttest data to obtain a more accurate estimate of the treatment effect. Furthermore, future research could examine the role of learning engagement as a mediator or moderator to more comprehensively understand the mechanisms of influence of LENTERA-based interactive media on the development of early childhood scientific literacy.

CONCLUSION

Based on the research results and discussion, it can be concluded that the research findings indicate that LENTERA-based interactive media has the potential to support the development of early childhood scientific literacy after controlling for the influence of learning engagement. The analysis revealed a significant difference between the group learning using LENTERA-based interactive media and the group participating in conventional learning, with higher scientific literacy achievements in the intervention group. Furthermore, learning engagement was shown to have a strong relationship with scientific literacy, indicating that children's active participation during the learning process is a crucial factor in supporting the development of scientific literacy skills.

These findings indicate that the integration of literacy activities, observation, exploration, reflection, and communication facilitated through interactive media based on LENTERA can be a promising approach to support science learning in early childhood. Practically, the results of this study provide implications for early childhood education teachers to design more interactive and child-centered science learning by utilizing digital media that encourage children to observe phenomena, ask questions, conduct simple explorations, and communicate their findings. However, given the limitations of the study design and sample size, further research with a wider sample size and a more robust experimental design is needed to confirm these findings and expand their generalizability.

RECOMMENDATION

This study has several limitations. First, the limited sample size in one region requires caution in generalizing the results. Second, the use of a quasi-experimental design allows for the presence of extraneous variables that have not been fully controlled for. Third, the measurement of scientific literacy still focuses on learning outcomes, thus not fully reflecting the process of children's engagement.

Based on these limitations, future research is recommended to involve a broader and more diverse sample, use a more robust experimental design, and integrate a mixed methods approach to comprehensively examine the learning process and outcomes. Furthermore, follow-up studies could explore the impact of the LENTERA model on other aspects of children's development, such as creativity, communication, and social skills.

ACKNOWLEDGMENTS

The authors express their deepest gratitude to all parties who provided assistance and support in the implementation of this research. Special thanks are extended to those who provided financial support through the

DIPA Fund of STAHN Mpu Kuturan Singaraja, Bali, Indonesia, which made this research possible. The author also express sincere gratitude to the parents for their unwavering support, both moral and spiritual, which served as a primary source of motivation in completing this work. All contributions, prayers, and encouragement from various parties were invaluable and played a crucial role in the smooth running of this research process.

FUNDING INFORMATION

This research was supported by the DIPA Fund of STAHN Mpu Kuturan Singaraja, Bali, Indonesia.

AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Ni Luh Ika Windayani	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Ni Wayan Risna Dewi	✓	✓	✓	✓	✓	✓		✓	✓		✓		✓	
Ni Putu Widyasanti	✓	✓			✓	✓		✓	✓		✓			

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

- Agustini, R., Meilanie, R. S. M., & Pujiastuti, S. I. (2024). Enhancing critical thinking and curiosity in early childhood through inquiry-based science learning. *Aulad: Journal on Early Childhood*, 7(3), 734–743. <https://doi.org/10.31004/aulad.v7i3.780>
- Al Mamun, M. A. (2022). Fostering self-regulation and engaged exploration during the learner-content interaction process: The role of scaffolding in the online inquiry-based learning environment. *Interactive Technology and Smart Education*, 19(4), 482–509. <https://doi.org/10.1108/ITSE-11-2021-0195>
- Bodrova, E., & Leong, D. J. (2007). Tools of the mind: The Vygotskian approach to early childhood education. *Early Childhood Education Journal*, 35(2), 111–116. <https://doi.org/10.1007/s10643-007-0161-6>
- Cao, C., Zhang, T., & Xin, T. (2024). The effect of reading engagement on scientific literacy: An analysis based on the XGBoost method. *Frontiers in Psychology*, 15. <https://doi.org/10.3389/fpsyg.2024.1329724>
- Cho, E. H. (2022). Cultivating science literacy through the general education curriculum. *The Korean Association of General Education*, 16(5), 203–216. <https://doi.org/10.46392/kjge.2022.16.5.20>
- Djamali, M. F., & Kharismawati, I. (2023). Development of e-book learning media in introducing science for early childhood. *Jurnal Obsesi: Jurnal Pendidikan Anak Usia Dini*, 7(6), 6937–6949. <https://doi.org/10.31004/obsesi.v7i6.5410>
- Doshi, A., Weinert, S., & Attig, M. (2024). Self-regulatory abilities as predictors of scientific literacy among children in preschool and primary school years. *Learning and Individual Differences*, 114, 102515. <https://doi.org/10.1016/j.lindif.2024.102515>
- Eliza, D., Mulyeni, T., Yulsyofriend, Y., Mahyuddin, N., Erita, Y., & Dhanil, M. (2025). Implementation of project-based learning in improving scientific literacy in early childhood education: A systematic literature review. *Journal of Baltic Science Education*, 24(1), 71–91. <https://doi.org/10.33225/jbse/25.24.71>
- Etnawati, S. (2022). Implementasi teori Vygotsky terhadap perkembangan bahasa anak usia dini. *Jurnal Pendidikan*, 22(2), 130–138. <https://doi.org/10.52850/jpn.v22i2.3824>
- Flanagan, R. M., & Symonds, J. E. (2021). Self-talk in middle childhood: A mechanism for motivational resilience during learning. *Psychology in the Schools*, 58(6), 1007–1025. <https://doi.org/10.1002/pits.22484>
- Fleer, M. (2016). Theorising play in the early years. *Cambridge Journal of Education*, 46(4), 535–554. <https://doi.org/10.1080/0305764X.2015.1118430>

- Fragkiadaki, G., Fleer, M., & Rai, P. (2023). *Science Concept Formation During Infancy, Toddlerhood, and Early Childhood: Developing a Scientific Motive Over Time*. *Research in Science Education*, 53, 275–294. <https://doi.org/10.1007/s11165-022-10053-x>.
- Gkintoni, E., Vantaraki, F., Skoulidi, C., Anastassopoulos, P., & Vantarakis, A. (2024). Promoting physical and mental health among children and adolescents via gamification—A conceptual systematic review. *Behavioral Sciences*, 14(2), 102. <https://doi.org/10.3390/bs14020102>
- Hantulu, N. I., Ardini, P. P., & Rawanti, S. (2025). The influence of cooking class center on children's science skills at TK Negeri Pembina, Gorontalo City. *Indonesian Journal of Early Childhood Education Studies*, 14(1), 15–23. <https://doi.org/10.15294/ijeces.v14i1.21921>
- Hautakangas, M., Kumpulainen, K., & Uusitalo, L. (2022). Children developing self-regulation skills in a Kids' Skills intervention programme in Finnish early childhood education and care. *Early Child Development and Care*, 192(10), 1626–1642. <https://doi.org/10.1080/03004430.2021.1918125>
- Junaedi, A., Cahyani, A., & Prastika, L. R. (2025). Analysis of science activities at the early childhood level: A case study of teachers' topics and challenges in Bandung City and Bandung Regency. *Kiddo: Jurnal Pendidikan Islam Anak Usia Dini*, 6(2), 477–489. <https://doi.org/10.19105/kiddo.v6i2.19180>
- Kumar, V., Choudhary, S. K., & Singh, R. (2024). Environmental socio-scientific issues as contexts in developing scientific literacy in science education: A systematic literature review. *Social Sciences & Humanities Open*, 9, 100765. <https://doi.org/10.1016/j.ssaho.2023.100765>
- Mafarja, N., Zulnadi, H., & Mohamad, M. M. (2025). Virtual learning environment to improve scientific literacy: A systematic review. *Research in Science & Technological Education*, 1–25. <https://doi.org/10.1080/02635143.2025.2547927>
- Nobre, J. N. P., et al. (2020). Quality of interactive media use in early childhood and child development: A multicriteria analysis. *Jornal de Pediatria*, 96(3), 310–317. <https://doi.org/10.1016/j.jpmed.2018.11.015>
- Brauchli, V., Sticca, F., Edelsbrunner, P., von Wyl, A., & Lannen, P. (2024). Are screen media the new pacifiers? The role of parenting stress and parental attitudes for children's screen time in early childhood. *Computers in Human Behavior*, 152. <https://doi.org/10.1016/j.chb.2023.108057>
- Obaki, S. O. (2017). Impact of classroom environment on children's social behavior. *International Journal of Education and Practice*, 5(1), 1–7. <https://doi.org/10.18488/journal.61/2017.5.1/61.1.1.7>
- OECD. (2023). *PISA 2022 results (Volume II)*. <https://doi.org/10.1787/a97db61c-en>
- Osborne, J., & Allchin, D. (2024). Science literacy in the twenty-first century: Informed trust and the competent outsider. *International Journal of Science Education*, 1–22. <https://doi.org/10.1080/09500693.2024.2331980>
- Panhwar, I. A., Usman, M., Panhwar, F., & Surahio, T. A. (2025). Exploring the impact of zone of proximal development and scaffolding in second language acquisition: A comparative study of Vygotskian and Freirean approaches. *Social Science Review Archives*, 3(1), 1166–1176. <https://doi.org/10.70670/sra.v3i1.416>
- Peleg, A., & Levy, S. T. (2026). Repairing toys as engineering learning: Tool use, problem-solving, and emotions in early childhood. *Early Childhood Education Journal*. <https://doi.org/10.1007/s10643-026-02130-x>
- Roy, G., Sikder, S., & Danaia, L. (2025). Adopting scientific literacy in early years from empirical studies on formal education: A systematic review of the literature. *International Journal of STEM Education*, 12(1), 26. <https://doi.org/10.1186/s40594-025-00547-1>
- Warmansyah, J., Sabri, A., Nasution, M., Amalina, A., Safna, A., & Fitri, A. (2022). Early numeracy skills in early childhood: The effect of numbered heads together cooperative

- learning methods. *Electronic Journal of Education, Social Economics and Technology*, 3(2), 75–82. <https://doi.org/10.33122/ejeset.v3i2.76>
- Wilmes, S. E. D., & Siry, C. (2024). *Engaging with Materials and the Body: Young Plurilingual Children's Resource-Rich Interactions in Science Investigations*. *Research in Science & Technological Education*, 42(1), 114–132. <https://doi.org/10.1080/02635143.2023.2298353>
- Windayani, N. L. I., & Widyasanti, N. P. (2025). The effectiveness of character-integrated quantum learning on students' learning motivation in early childhood science courses. *International Journal of Elementary Education*, 9(2), 189–197. <https://doi.org/10.23887/ijee.v9i2.95790>
- Windayani, N. L. I., Widiana, W., Suranata, K., & Riastini, P. N. (2025). The effectiveness of the LENTERA learning model to improve pedagogical competence with the covariable of intensity of involvement in science learning in early childhood teacher education program. *International Journal of Innovative Research and Scientific Studies*, 8(6), 813–821. <https://doi.org/10.53894/ijirss.v8i6.9731>
- Yaşar Yusumut, B., Gözümlü, A. İ. C., & İlgin, Ş. (2026). Self-regulation and problem solving in early childhood: The mediating role of number sense. *Current Psychology*, 45, 466. <https://doi.org/10.1007/s12144-026-09070-0>
- Yıldız, T. (2025). From constructivism to cultural cognition: A comparative analysis of Piaget, Vygotsky, and Tomasello's theories of cognitive development. *Humanitas - Uluslararası Sosyal Bilimler Dergisi*, 13(25), 411–429. <https://doi.org/10.20304/humanitas.1601228>
- Zetterqvist, A., & Bach, F. (2023). Epistemic knowledge – A vital part of scientific literacy? *International Journal of Science Education*, 45(6), 484501. <https://doi.org/10.1080/09500693.2023.2166372>