



Enhancing early childhood science literacy through deep learning–based instruction using simple coding games

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Abstract. This study addresses the need to strengthen science literacy in early childhood education in response to rapid technological and scientific development in the digital era. Science literacy in early years is essential for developing children's ability to think critically, solve problems, and understand basic scientific concepts through meaningful learning experiences. This study examined the effect of deep learning–based instruction using simple coding games on science literacy. Using a quantitative quasi-experimental nonequivalent control group design, 63 children aged 5–6 years from TK Dewi Kunti I and II were selected via cluster random sampling, with intact classes assigned to the experimental and control groups. The experimental group received coding-based deep-learning instruction, while the control group received conventional instruction. Data were analyzed using descriptive and inferential statistics. The results indicate that

children who participated in deep-learning–based coding activities demonstrated better development of science literacy than those in conventional learning settings. The findings suggest that integrating simple coding games into a deep learning framework can be an effective and engaging strategy to support science literacy in early childhood education. This study recommends further research with broader samples and longer intervention periods to strengthen implementation in diverse educational contexts.

Introduction

The rapid advancement of technology and scientific knowledge in the digital era necessitates the early development of science literacy. Science literacy encompasses not only an understanding of basic scientific concepts but also the ability to think critically, solve problems, and apply knowledge in real-life contexts (Sanjiartha et al., 2024). In the global context, strengthening science literacy in early childhood is increasingly regarded as a foundational element for preparing children to engage with a knowledge- and technology-based society. Early childhood (ages 0–6) represents a *golden age* of development, during which cognitive abilities, creativity, and logical thinking develop rapidly (Bonita et al., 2022). Therefore, innovative learning approaches that align with children's developmental characteristics are essential to foster deep interest and understanding of science.

One learning approach considered effective in achieving this goal is deep learning, which emphasizes conceptual understanding through direct experience, exploration, and reflection (Azizah et al., 2025; Arifin et al., 2024). Unlike surface learning, which primarily focuses on memorization, deep learning encourages learners to construct meaning and connect knowledge with real-world experiences. In early childhood education, this approach can be naturally integrated

through play, as play represents children's primary and most meaningful mode of learning (Fahmi et al., 2024).

Despite the increasing emphasis on science literacy in early childhood education, several reports indicate that young children's science process skills remain underdeveloped. Preliminary classroom observations in the participating institutions revealed that science learning activities were predominantly teacher-centered and focused on memorization rather than exploration and conceptual understanding. Children showed limited engagement in inquiry-based tasks such as predicting, experimenting, and reflecting on outcomes. These conditions suggest a gap between the intended goals of science literacy development and actual classroom practices, highlighting the urgent need for innovative and developmentally appropriate instructional approaches (Widana & Ratnaya, 2021).

In line with global curriculum developments, coding and computational thinking are increasingly positioned as cross-curricular competencies rather than purely technical skills (Mills, 2025). Research indicates that coding activities in early childhood can strengthen various forms of literacy, including science literacy, through processes such as observation, prediction, solution testing, and reflection on outcomes. A meta-analysis conducted by Alonso-garcía et al. (2024) demonstrates that coding and educational robotics-based interventions in early childhood consistently yield positive effects on the development of computational thinking, particularly in logical reasoning, problem-solving, and causal sequencing. These abilities constitute core cognitive components that also underpin science literacy, especially in processes involving observation, prediction, and evidence-based reasoning.

A growing body of empirical research supports the effectiveness of play-based approaches in enhancing science literacy among young children. Widayati et al. (2020) found that science problem-solving games had a significant positive impact on the science process skills of children aged 5–6 years, particularly in observation, classification, and conclusion-drawing. These findings are reinforced by Wardhani et al. (2020), who reported that children's active engagement in problem-based play significantly enhances critical thinking skills and meaningful understanding of science. Furthermore, Andari et al. (2020) demonstrated that the implementation of interactive scientific learning, particularly activities resembling coding processes, contributed directly to improved science literacy among elementary school students, indicating the continuity of benefits from early childhood education onward. Through interactive and play-based approaches, children are not only actively engaged but also better able to grasp complex scientific concepts. Additionally, research by Mustika & Suyadi (2021) revealed that educational play tools contribute not only to cognitive development but also to the moral and affective development of young children, highlighting the multidimensional impact of play-based learning.

Empirical studies across diverse contexts further reinforce these findings. Louka & Papadakis (2024) reported that the use of Scratch Jr as a block-based coding tool among preschool children across various European countries significantly enhanced children's computational competencies, including systematic thinking and understanding of the logical relationships between commands. These findings underscore the role of simple coding games as cognitive scaffolds that support conceptual understanding, which can be transferred to science learning through exploration and problem-solving.

Within the broader literacy context, a systematic review by Bautista et al. (2024) revealed that the use of educational technologies and digital games positively contributes to early literacy development by increasing engagement, promoting independent exploration, and enhancing contextual meaning-making. Although the primary focus of the review was general literacy, the

identified learning mechanisms, such as active engagement, reflection, and meaning construction, are conceptually aligned with the development of science literacy in early childhood. This suggests that coding games, as a form of digital play, possess cross-literacy potential, including science literacy.

In the context of digital play, recent research trends indicate a paradigm shift from mere technology use toward the intentional design of meaningful learning experiences. In coding-related contexts, particularly through game-based approaches, the potential to develop both digital and science literacy is substantial (Munawar et al., 2023). Highlighted how the Robokids STEAM coding game can serve as an effective tool for digital literacy education in early childhood settings, while also emphasizing the need for supportive policies and teacher training. Similarly, a systematic review on digital play in the early years by Khoo et al. (2025) emphasized that well-designed digital games can support conceptual learning, self-regulation, and children's scientific exploration. Yang et al. (2025) further demonstrated that computational curricula incorporating coding activities positively impact not only computational skills but also general cognitive abilities and children's conceptual understanding, which are directly relevant to science literacy.

Nevertheless, the implementation of coding-based play learning is influenced by contextual factors, particularly teachers' readiness and perceptions. Alotaibi (2023) emphasized that early childhood educators' adoption of digital tools is shaped by technological competence, pedagogical beliefs, institutional support, and perceptions of instructional value. These findings suggest that the effectiveness of deep learning-based coding games depends not only on activity design but also on teachers' capacity to facilitate exploration, reflection, and conceptual dialogue, which are central to deep learning.

Despite the growing body of research highlighting the potential of coding games and digital play in early childhood education, there remains a notable lack of studies that explicitly examine the impact of deep learning-based instruction through simple coding games on early childhood science literacy. Most prior research has focused on computational thinking, digital literacy, or general STEM approaches without positioning deep learning as the primary conceptual framework. Yet, deep learning holds significant potential to deepen children's scientific understanding through reflection, conceptual integration, and meaningful application within play-based contexts.

While previous studies have demonstrated the benefits of coding activities for computational thinking and general cognitive development (Alonso-García et al., 2024; Louka & Papadakis, 2024), and others have highlighted the effectiveness of deep learning approaches in promoting conceptual understanding (Azizah et al., 2025), no study to date has explicitly integrated deep learning as a pedagogical framework within simple coding games to examine their direct impact on early childhood science literacy. Addressing this gap, the present study integrates deep learning-based instruction with simple coding games to empirically investigate their combined effect on science literacy among children aged 5–6 years. It is hypothesized that children who receive deep learning-based coding instruction will demonstrate significantly higher science literacy outcomes than those who receive conventional instruction. By providing empirical evidence within a play-based early childhood context, this study contributes to the development of innovative science learning models oriented toward deep conceptual understanding and 21st-century literacy demands (Purnadewi & Widana, 2023).

Method

Research Method and Design

This study employed a quantitative, quasi-experimental design to examine the causal relationship between implementing deep-learning-based instruction through simple coding games and early childhood science literacy. The research was conducted in an authentic school setting; therefore, the researchers did not have full authority to randomly assign participants at the individual level. Consequently, a nonequivalent control group design was selected, allowing comparison of learning outcomes between the treatment and comparison groups despite the absence of full randomization (Sugiyono, 2022). This design was considered appropriate because it provides a balance between scientific control and practical feasibility within early childhood education settings. By involving relatively comparable experimental and control groups, the researchers were able to observe the effects of the instructional intervention more objectively while minimizing disruption to regular classroom activities.

Participants and Sampling Technique

The research participants were children aged 5–6 years from two early childhood education institutions, namely TK Dewi Kunti I and TK Dewi Kunti II, totaling 63 children. The study was conducted during the first semester of the 2025/2026 academic year. The assignment of experimental and control groups was conducted at the class level (cluster) rather than at the individual level; therefore, cluster random sampling was employed. Using this technique, classes with relatively similar characteristics, such as children's age, number of students, curriculum, and socioeconomic background, were randomly assigned to the experimental or control group.

This approach aimed to reduce selection bias and enhance the study's internal validity, although it does not fully meet the criteria for a true experimental design. The distribution of research participants is presented in Table 1.

Table 1. Distribution of Experimental and Control Classes

Institution	Experimental Class	Control Class
TK Dewi Kunti I	B1 (16 students)	B2 (15 students)
TK Dewi Kunti II	B2 (16 students)	B1 (16 students)
Total	32 students	31 students

The cross-institutional assignment of experimental and control classes was intentionally implemented to minimize the influence of institutional and teacher-related factors on the research outcomes.

Research Setting and Timeline

The study was conducted over six weeks, with two sessions per week, resulting in a total of 12 intervention sessions. Each session lasted approximately 45 minutes, following the regular instructional schedule of early childhood classrooms. The study was conducted in three main stages: preparation, intervention implementation, and outcome measurement. In the experimental group, children participated in deep learning-based instruction through simple coding games (X_1). The intervention was designed according to deep learning principles, which included: 1) exploration of science concepts through contextual problems, 2) unplugged coding-based play activities (e.g., arranging sequences of commands to simulate cause-and-effect relationships), and 3) simple reflection activities through guided discussions and questions that encouraged children to connect the play activities with the science concepts being learned.

In contrast, the control group received instruction using conventional teaching methods (X_2), such as teacher explanations, question-and-answer sessions, and worksheet-based activities, without incorporating coding or computational thinking-based games. After the intervention period, observations (O) were conducted to assess children's science literacy in both groups. Schematically, the research design can be illustrated as follows:

R	X_1	O
R	X_2	O

Image 1. Research Design

The independent variable in this study was the instructional model, consisting of: (1) deep learning-based instruction through simple coding games (X_1) as applied to the experimental group, and (2) conventional instruction (X_2) as applied to the control group. In the experimental group, children engaged in science-related coding activities using unplugged coding games, whereas the control group learned through traditional methods such as lectures and worksheets.

The dependent variable was early childhood science literacy (O), measured across three main dimensions: 1) cognitive aspect, referring to children's understanding of basic science concepts such as cause-and-effect relationships; 2) procedural aspect, referring to the ability to conduct simple observations and experiments; and 3) scientific attitude, including curiosity and perseverance. Data were collected through observations and documentation of children's activities throughout the intervention.

Data Collection Techniques and Research Instruments

Several validated instruments were used to measure early childhood science literacy, drawing on established assessment standards in prior studies. The observation sheet for scientific attitudes was developed based on the rubric used by [Widayati et al. \(2020\)](#) for assessing children's science process skills, with modifications to align the indicators with coding-based play activities. The science concept understanding test was adapted from the instrument developed by [Andari et al. \(2020\)](#), employing image-based items and simple questions appropriate to the cognitive characteristics of children aged 5–6 years. To assess the procedural dimension, this study adopted documentation techniques from [Munawar et al. \(2023\)](#), combining screen recordings (for digital activities) and photographs of children's work products (for unplugged coding tasks) to capture observable scientific practices.

The Method section has been revised to provide a clearer explanation of the procedures used to assess instrument validity and reliability. Content validity of the observation sheet and science literacy assessment instruments was established through expert judgment involving specialists in early childhood education and science learning. Revisions were made in response to their feedback to ensure alignment with science literacy indicators and developmental appropriateness. To ensure scoring consistency, inter-rater reliability was calculated for observational data, demonstrating satisfactory agreement between raters.

In addition, the duration and frequency of the intervention have now been explicitly specified. The intervention was conducted over six weeks, with two sessions per week, and each session lasted approximately 45 minutes. This clarification enhances methodological transparency and supports the study's replicability. During the implementation phase, the classroom teachers served as the primary instructors, delivering the learning activities in accordance with the prepared lesson plans. Prior to the intervention, teachers were provided with structured guidance and orientation to

ensure consistency in instructional delivery across sessions. The researchers assumed the role of non-participant observers, systematically documenting children's learning processes and behaviors using structured observation sheets. This role division was intentionally designed to maintain natural classroom dynamics, reduce potential researcher-induced bias, and enhance the study's ecological validity.

Data Analysis Techniques

The quantitative data obtained were analyzed using inferential statistics. The initial analysis involved descriptive statistics, including calculation of means, standard deviations, and minimum and maximum values for each group. Subsequently, assumption tests were conducted, comprising the Shapiro–Wilk normality test and Levene's test for homogeneity of variance, to ensure that the data met the assumptions for parametric analysis (Usmadi, 2020). After these assumptions were met, differences in science literacy between the experimental and control groups were analyzed using an independent-samples t-test. All statistical analyses were conducted at a significance level of 0.05

Results and Discussion

After the entire sequence of learning activities was implemented in accordance with the research design (as illustrated in image 2), the scientific literacy skills of early childhood learners in both groups were assessed using a predetermined and previously validated instrument. This assessment was conducted at the end of the intervention phase to capture children's learning outcomes as a cumulative result of the instructional processes they experienced. The collected data were then analyzed sequentially and systematically. Descriptive analysis was first employed to provide an overview of the data characteristics, including mean scores, score distributions, and patterns of scientific literacy development within each group. Subsequently, prerequisite tests were conducted to ensure that the assumptions required for further statistical analysis, such as normality and homogeneity of variance, were adequately met. Finally, inferential statistical analysis was applied to empirically examine the effect of the treatment on children's scientific literacy skills, thereby determining whether the observed differences between groups reflected a genuine instructional effect rather than random variation.



Image 2. Implementation of the Study in the Control and Experimental Classes

Image 2 illustrates the procedural flow of the study in both the control and experimental classes, highlighting the sequence of instructional activities and assessment stages for each group. While both groups followed the same learning duration and assessment schedule, the experimental class received the designated instructional treatment, whereas the control class was taught using conventional learning approaches. This parallel structure was designed to ensure that any differences in learning

outcomes could be attributed to the instructional intervention rather than to extraneous factors such as time allocation or assessment conditions.

The initial stage of data analysis was intended to provide an overall profile of children's science literacy abilities in both the control and experimental groups. Descriptive statistical analysis was employed to summarize the central tendencies and variability of the observed data, allowing for a preliminary comparison between groups prior to inferential testing. The results of this descriptive analysis are presented in Table 2, which serves as a foundational reference for interpreting subsequent statistical analyses.

Table 2. Descriptive Statistics of Science Literacy Ability in the Control and Experimental Groups

Statistic	Control Group	Experimental Group
Number of Students (N)	31	32
Mean	75.97	81.72
Median	75	81.25
Mode	65	80
Standard Deviation	8.00	7.70
Variance	64.03	59.23
Range	30	35
Minimum	60	60
Maximum	90	95
Total Score	2355	2615

Based on the data presented in Table 2, the experimental group achieved a higher mean science literacy score than the control group. This difference is evident not only in the mean values but also in the median and mode, indicating that the score distribution of the experimental group tended to fall within a higher range. In addition, the standard deviation of the experimental group was slightly lower than that of the control group, suggesting a relatively more homogeneous distribution of scores. Importantly, this pattern implies that the observed improvement was not limited to a small subset of high-performing children but rather reflected a more consistent enhancement of science literacy across the group. Such homogeneity is pedagogically meaningful in early childhood education, where learning interventions are expected to support diverse developmental levels. These findings, therefore, provide an initial indication that deep learning-based instruction through simple coding games has the potential to enhance early childhood science literacy more evenly across learners, warranting further confirmation through inferential statistical analysis. To enhance data readability, the comparison of mean scores between groups is visually presented in Image 3.

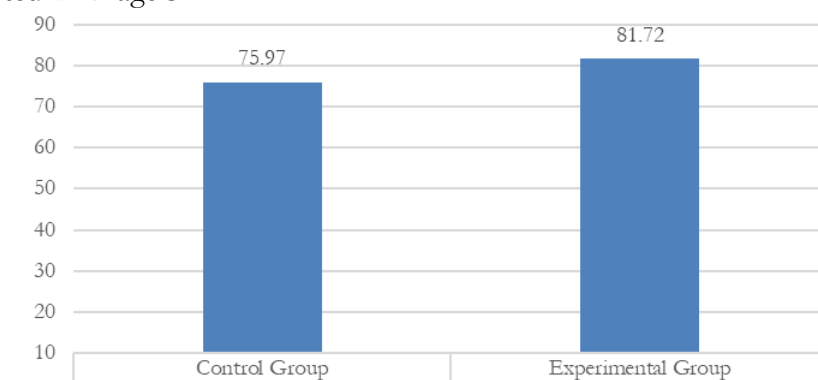


Image 3. Comparison of Mean Science Literacy Scores Between the Control and Experimental Groups

As shown in Image 3, the experimental group ($M = 81.72$) clearly outperformed the control group ($M = 75.97$). The visual gap between the two bars reinforces the numerical difference reported in Table 2 and allows readers to quickly grasp the magnitude of improvement associated with the intervention. Although the difference appears moderate at the descriptive level, the consistent upward shift in central tendency indicators (mean, median, and mode) suggests that the instructional treatment contributed to a systematic enhancement rather than incidental variation. The graphical representation, therefore, strengthens the interpretative clarity of the findings and supports the subsequent inferential analysis.

Prior to conducting inferential analysis, the data were examined to ensure that the required statistical assumptions were satisfied. This step is essential to determine the appropriateness of the inferential tests to be applied and to reduce the risk of biased or invalid conclusions. Specifically, tests of normality were conducted to assess whether the distribution of science literacy scores in both the control and experimental groups approximated a normal distribution, while homogeneity tests were used to examine the equality of variances between groups. The results of these normality and homogeneity tests are presented in Table 3 and serve as the basis for selecting the most suitable inferential statistical procedures for subsequent analysis.

Table 3. Results of Assumption Testing

Statistical Test	Control Group	Experimental Group	Interpretation
Normality Test (Shapiro–Wilk)	$W = 0.961$	$W = 0.956$	Both datasets are normally distributed
Homogeneity Test (Levene’s)	$F = 0.152$	–	Variances are homogeneous

The results of the Shapiro–Wilk test indicate that the science literacy scores in both the control and experimental groups were normally distributed. In addition, Levene's test confirmed the homogeneity of variances between the two groups. The fulfillment of these assumptions supports the use of a parametric statistical approach, thereby enabling more robust estimation of group differences. Consequently, subsequent analysis was conducted using an independent samples t-test, which is specifically designed to compare means between two independent groups under the assumption of normality and equal variance.

Following the assumption tests, inferential analysis proceeded with the independent samples t-test to examine the effect of implementing deep learning through simple coding games on early childhood science literacy. This analysis aimed to determine whether the observed differences in mean scores between the experimental and control groups were statistically significant rather than attributable to random variation. A summary of the t-test results is presented in Table 4, which forms the empirical basis for interpreting the effectiveness of the instructional intervention.

Table 4. Summary of Independent Samples t-Test Results

Component	Result
t-value	-2.907
t-critical	± 2.000
Degrees of Freedom	61
Decision	Reject H_0
Significance	$p < 0.05$
Effect Size	0.733 (moderate-to-large effect)

The t-test results show that the calculated t-value (-2.907) falls outside the critical t-value range (± 2.000) at 61 degrees of freedom and a significance level of 0.05. Accordingly, the null hypothesis

(H_0) was rejected, indicating a statistically significant difference in science literacy ability between children in the experimental group and those in the control group. The effect size value of 0.733 indicates a moderate-to-large effect, suggesting that the observed difference is not only statistically significant but also educationally meaningful within the context of early childhood learning.

The findings of this study demonstrate that implementing deep learning–based instruction through simple coding games significantly improves early childhood science literacy. This conclusion is supported by the difference in mean science literacy scores between the experimental group ($M = 81.72$) and the control group ($M = 75.97$), as well as by the t -test results showing statistical significance ($p < 0.05$) and an effect size of 0.733, which falls within the moderate-to-large range. From a quantitative perspective, this effect size indicates that the observed differences are not merely statistically detectable but also educationally meaningful. Such a magnitude suggests that the intervention has practical relevance for classroom implementation, particularly in early childhood education contexts where instructional time and cognitive readiness are often constrained. Substantively, these results indicate that integrating simple coding games as educational media effectively supports children's engagement with scientific concepts, both developmentally appropriate and cognitively enriching (Astini et al., 2023).

Conceptually, these findings are strongly aligned with the deep learning paradigm in education, which emphasizes meaningful learning through active engagement, exploration, and authentic problem-solving rather than surface-level task completion. Deep learning encourages learners to construct understanding through reasoning, reflection, and iterative interaction with learning materials. In early childhood contexts, such processes are particularly important because young children learn most effectively through concrete experiences and active involvement. Recent studies indicate that deep learning approaches are more effective when children are engaged in activities that require them to explore cause-and-effect relationships and reflect on the outcomes of their actions (Giannakoulas & Xinogalos, 2024). Simple coding games inherently embody these principles by placing children in situations where they must anticipate outcomes, test ideas, and revise their thinking based on immediate feedback, thus fostering deeper conceptual understanding.

From the perspective of educational media theory, the effectiveness of simple coding games can also be explained by their ability to translate abstract scientific concepts into concrete, interactive experiences. Educational media play a crucial role in mediating learning by providing representations that align with learners' cognitive and developmental characteristics. Astini et al. (2023) argue that well-designed educational games enhance learning efficiency by transforming complex phenomena into enjoyable and meaningful activities. In the present study, coding games functioned as mediational tools that bridged the gap between abstract scientific reasoning and children's concrete operational thinking, allowing learners to grasp scientific ideas through manipulation, experimentation, and play.

The importance of fostering science literacy in early childhood has been widely emphasized in the literature. Early childhood represents a critical period for laying the foundations of scientific thinking, curiosity, and inquiry. Kutluca & Mercan (2022) highlight that engaging in science experiences during these formative years encourages children to ask questions, explore their environment, and develop an interest in understanding natural phenomena. Moreover, contemporary conceptions of science literacy extend beyond the acquisition of factual knowledge to include the ability to apply scientific understanding to real-world contexts (Cansız & Cansız, 2019). The findings of this study support this broader view by demonstrating that coding-based learning activities promote not only content-related understanding but also scientific practices such as observing, predicting, testing, and explaining outcomes.

Consistent with constructivist learning theory, early childhood science literacy develops optimally when children actively engage in exploration and reflection. Constructivist perspectives emphasize that knowledge is constructed through interaction with the environment rather than transmitted directly from teacher to learner. Play-based learning has therefore been identified as the most appropriate pedagogical approach for early childhood education, as it allows children to construct meaning through hands-on experiences and social interaction (Bers et al., 2019; Kociubuk & Campana, 2024). In this study, simple coding games operationalized constructivist principles by embedding scientific reasoning within playful, goal-oriented activities. Children were not passive recipients of information; instead, they actively constructed understanding by experimenting with sequences, observing outcomes, and modifying their actions accordingly.

More specifically, simple coding games served as cognitive scaffolds that integrated playful interaction with structured thinking processes. Tasks such as sequencing instructions, predicting outcomes, and debugging errors required children to engage in core scientific practices, including observing patterns, forming hypotheses, testing actions, and drawing conclusions. These activities align closely with the characteristics of effective early science instruction identified by Gerde et al. (2013), who emphasize integrating inquiry-based practices into early childhood curricula to foster critical thinking, collaboration, and resilience. The present findings provide empirical support for these claims by demonstrating measurable improvements in science literacy following engagement with coding-based learning activities.

Another important dimension of the findings concerns computational thinking (CT) as a potential cognitive mediator linking coding activities to science literacy outcomes. A growing body of research suggests that coding and educational robotics enhance CT skills in early childhood, particularly in areas such as logical reasoning, problem decomposition, and pattern recognition (Alonso-garcía et al., 2024; Louka & Papadakis, 2024). In this study, CT can be conceptualized as a set of transferable cognitive processes that support scientific reasoning. Skills such as sequencing actions, anticipating consequences, and identifying patterns are fundamental to understanding cause-and-effect relationships in science. Children who develop these skills through coding activities may therefore be better equipped to engage with scientific concepts and practices.

This interpretation is supported by previous studies indicating that coding experiences provide both cognitive and affective benefits for young learners. Lee (2019) reports that coding activities not only enhance cognitive development but also increase children's interest in STEM-related learning and support socio-emotional skills (Widana et al., 2021). Similarly, Fenty et al. (2025) highlight the potential of coding activities to enrich literacy instruction by fostering deeper engagement and structured thinking. The present study extends this body of research by demonstrating that coding-based activities can also contribute meaningfully to early childhood science literacy, thereby reinforcing the interdisciplinary value of coding as an educational tool.

The moderate-to-large effect size observed in this study is consistent with findings from recent meta-analyses reporting positive effects of coding and robotics interventions on young children's cognitive outcomes, despite considerable heterogeneity across studies (Alonso-garcía et al., 2024). This heterogeneity suggests that the effectiveness of coding-based interventions is highly dependent on contextual factors such as instructional design, implementation duration, and the quality of teacher facilitation. In this study, the structured integration of coding games within a deep learning framework likely contributed to the observed outcomes by ensuring that activities were pedagogically intentional rather than incidental.

Importantly, the lower standard deviation observed in the experimental group compared to the control group indicates that the intervention produced more homogeneous science literacy

outcomes. This finding suggests that simple coding game-based instruction may be particularly effective in promoting inclusive learning environments that accommodate children with diverse initial ability levels. [Chu et al. \(2024\)](#) argue that well-designed game-based learning environments allow children to learn at their own pace while remaining engaged in shared learning goals, thereby reducing achievement gaps. The present findings lend empirical support to this argument by demonstrating more consistent performance among children exposed to coding-based deep learning activities.

From an instructional perspective, teachers' role remains critical to the success of coding-based learning interventions. [Campbell \(2018\)](#) emphasizes that professional development is necessary to align teachers' beliefs with effective practices in literacy and coding instruction. Without such alignment, digital tools risk being used superficially, limiting their educational impact. [Thompson et al. \(2025\)](#) further argue that embedding computational thinking within broader literacy and narrative-based contexts enhances conceptual integration and transfer. These perspectives highlight that the benefits of coding games observed in this study are likely contingent upon intentional instructional design and active teacher facilitation.

Furthermore, the findings contribute to ongoing debates regarding the role of digital technology in early childhood education. While concerns about excessive screen time persist, this study provides evidence that purposefully designed digital play, grounded in deep learning principles, can yield meaningful educational benefits. The key distinction lies not in the presence of technology itself but in how it is integrated into learning experiences. When digital tools are aligned with clear learning objectives and supported by effective pedagogy, they can serve as powerful mediators of learning rather than distractions ([Astini et al., 2023](#); [Alonso-garcía et al., 2024](#)).

Overall, the findings of this study extend existing research by providing robust empirical evidence that deep learning-based instruction through simple coding games is an effective strategy for enhancing early childhood science literacy. The primary contribution of this study lies in its integrative approach, which combines deep learning theory, constructivist pedagogy, educational media, and computational thinking within a single, quantitatively evaluated intervention. By demonstrating both statistically significant and pedagogically meaningful outcomes, this research advances theoretical understanding while offering practical implications for early childhood educators seeking to design innovative, inclusive, and developmentally appropriate learning experiences aligned with the demands of 21st-century education.

Despite the meaningful findings reported in this study, several limitations should be acknowledged to provide a balanced interpretation of the results. First, the use of a quasi-experimental nonequivalent control group design limits full causal inference, as individual random assignment was not implemented. Although cluster random sampling reduced selection bias, uncontrolled group differences may still exist. Second, the relatively small sample ($N = 63$) drawn from two institutions limits generalizability. Future studies involving larger and more diverse populations are needed to strengthen external validity. Third, the intervention lasted only six weeks, so the long-term sustainability of the observed improvements remains unknown. Longitudinal research is recommended to examine retention and developmental impact over time. Finally, although computational thinking is proposed as a mediating mechanism, this relationship was not empirically tested. Future research could apply mediation analysis to examine the cognitive pathways linking coding activities and science literacy outcomes.

Beyond its acknowledged limitations, this study offers several important novelties. First, it provides one of the few empirical investigations that explicitly integrates deep learning pedagogy with simple coding games within the context of early childhood science literacy. While previous research has

examined coding, robotics, or computational thinking in early childhood education, these studies have predominantly focused on cognitive development or STEM-related skills in isolation. The present study advances the field by positioning coding-based activities within a deep learning framework and empirically testing their impact on science literacy as a multidimensional construct (cognitive, procedural, and attitudinal). Second, this research introduces a theoretically grounded integrative model that connects deep learning theory, constructivist pedagogy, educational media theory, and computational thinking within a single intervention design. Rather than treating coding merely as a technological tool, the study conceptualizes it as a pedagogical scaffold that mediates scientific reasoning processes. This conceptual synthesis extends existing literature by offering a more coherent explanatory framework for how coding activities can meaningfully support early science learning. Third, the study contributes methodologically by quantitatively demonstrating not only statistical significance but also a moderate-to-large effect size within an authentic early childhood classroom setting. Many prior studies in this domain rely on small-scale qualitative explorations; in contrast, this research provides inferential statistical evidence of educational impact, thereby strengthening empirical claims regarding the effectiveness of coding-based deep learning interventions. Collectively, these contributions position the study as an advancement in understanding how structured, developmentally appropriate coding activities can be systematically integrated into early childhood science instruction to produce measurable and pedagogically meaningful outcomes.

Conclusion

This study concludes that deep learning-based instruction using simple coding games effectively enhances early childhood science literacy by engaging children in meaningful, structured, and play-based learning experiences. Through guided coding activities, children develop logical reasoning, explore cause-and-effect relationships, and construct scientific understanding in ways that are developmentally appropriate. Beyond its theoretical contribution, this study offers practical implications for early childhood educators. Simple coding games can be implemented as a structured instructional strategy, not merely as digital play, to foster inquiry, problem-solving, and scientific thinking within everyday classroom activities. When supported by intentional lesson design and active teacher facilitation, coding-based activities can create inclusive learning environments that accommodate diverse ability levels while maintaining high engagement. Future research is recommended to extend the implementation period, involve larger and more diverse samples, and examine long-term impacts across diverse early childhood educational contexts.

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