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Development and evaluation of ATOM digital learning application for enhancing early childhood science process skills

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ABSTRACT

This study developed and evaluated ATOM, an interactive digital application designed to support science process skills in early childhood. Using the ADDIE research and development model, the study involved expert validation, practicality assessments, and pretest–posttest evaluation with 47 children. ATOM incorporated interactive activities addressing observation, classification, prediction, inference, and communication. Media, content, and assessment instrument validity reached 91.4%, 98.0%, and 90.0%, respectively. Practicality scores were 97.98% in focus group assessment, 95.56% in small-scale testing with 10 children, and 97.2% during implementation. Mean science process skill scores increased from 48.58% to 87.85%, with a normalized gain of 0.765. The Wilcoxon signed-rank test indicated a statistically significant pretest–posttest difference ($p < 0.001$). ATOM demonstrated high validity and practicality and was associated with improved science process skills. Further controlled studies are needed to establish its independent effectiveness.



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Introduction

Digital technology has become increasingly integrated into early childhood education, influencing how learning activities are designed and delivered (Anditasari et al., 2018). Early childhood represents a critical developmental period in which children progressively acquire cognitive abilities, including fundamental science process skills such as observing, classifying, predicting, inferring, and communicating (Aprilianto & Mariana, 2018). Appropriate scientific stimulation during this period can support curiosity, critical thinking, and the development of early reasoning abilities (Ramadhani et al., 2024). Nevertheless, science education in early childhood settings continues to encounter challenges, particularly the limited availability of developmentally appropriate learning media that encourage active exploration and scientific inquiry (Wahyuningsih et al., 2021). These challenges highlight the importance of developing learning approaches that integrate meaningful scientific experiences with children's cognitive and developmental characteristics.

Digital learning technologies offer opportunities to create interactive educational environments through visualization, simulation, and immediate feedback (Oktaviani et al., 2022). Interactive applications can facilitate children's engagement by presenting learning activities in accessible and contextually meaningful formats (Anggreini & Nurdiah, 2020). However, technological integration alone does not guarantee improvements in scientific understanding, particularly when applications are insufficiently aligned with early childhood developmental needs (Kristyowati & Purwanto, 2019). Conventional teacher-centered instruction may also restrict opportunities for children to investigate scientific phenomena independently (Alexieva, 2019).

Consequently, limited exploratory experiences may constrain the development of observation, classification, and problem-solving skills (Malahayati et al., 2015). Effective digital learning media should therefore provide structured opportunities for scientific exploration while maintaining appropriate teacher guidance and meaningful interaction with physical learning environments.

Developing science process skills requires instructional experiences that actively engage children in observing phenomena, manipulating objects, identifying relationships, and communicating findings (Uslan et al., 2020). Interactive digital media can support these experiences through simulations, visual representations, and guided exploration (Putri & Harahap, 2018; Banseng et al., 2021). Previous studies have discussed the potential contribution of technology-supported learning to cognitive development and conceptual understanding (Smidts et al., 2018; Hiltrimartin et al., 2024). From a developmental perspective, learning through active engagement enables children to construct knowledge by connecting new experiences with existing understanding. Visual representations and animations may further facilitate the interpretation of scientific phenomena that are difficult to observe directly (Ernawati et al., 2018; Jusoh et al., 2023). Nevertheless, the educational contribution of these features depends on their alignment with specific learning objectives and measurable science process skill indicators.

The integration of educational games into digital learning environments provides additional opportunities to promote participation, motivation, and sustained engagement (Mahmudah, 2019; Sarte et al., 2021). Game-based activities can encourage children to experiment, make predictions, observe consequences, and reconsider their initial understanding through interactive feedback (Wahdini & Rachman, 2020; Rahman et al., 2022). However, increased motivation does not necessarily indicate improvements in scientific reasoning or inquiry skills. Previous research has addressed digital literacy, educational applications, and science learning across different educational contexts (Khairunnisa et al., 2022; Mulyani & Doyan, 2023). These studies provide a foundation for technology-supported education but do not directly establish the effectiveness of an integrated application specifically designed to assess multiple science process skills among children aged 5–6 years. Therefore, further investigation is required to determine how interactive digital activities can support measurable improvements in early childhood scientific inquiry.

Despite growing interest in technology-enhanced science education, the integration of developmentally appropriate interactive features with structured science process skill assessment remains an important research consideration (Banawi et al., 2022; Arwin et al., 2024). Existing literature provides insights into learning assessment, digital instructional approaches, and learner engagement, although these findings originate from different educational populations and contexts (Hafnidar et al., 2021; Yuningsih & Sunaryo, 2021). Addressing this issue requires an application that explicitly connects instructional activities with observation, classification, prediction, inference, and communication. The ATOM application was therefore designed to integrate drag-and-drop interactions, animated scientific phenomena, voice-guided instructions, and immediate feedback across five science themes: color mixing, floating and sinking, magnetism, states of matter, and plant growth. Its proposed contribution lies in combining these features within a structured learning environment that supports digital exploration followed by hands-on scientific activities.

Accordingly, this study aimed to develop and evaluate ATOM as an interactive digital learning application for strengthening science process skills among children aged 5–6 years. The development process adopted the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) framework to examine product validity, practicality, and learning outcomes. The application was designed to accommodate children's developmental characteristics while facilitating active engagement with scientific concepts (Williams et al., 2019; Utami et al., 2021). Specifically, the study evaluated expert validation results, implementation practicality, and changes in children's science process skills before and after using ATOM. Building on previous research concerning scientific literacy and technology-supported learning (Jufrida et al., 2019; Matt et al., 2022), this study contributes empirical evidence regarding the feasibility and educational potential of interactive science learning applications in early childhood education. The findings are expected to inform the development of developmentally appropriate digital learning media while providing a foundation for subsequent controlled investigations of instructional effectiveness.

Method

Research Design

This study employed a Research and Development (R&D) approach using the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model to develop and assess the ATOM digital learning application (Rizawati, 2022). The model provided a systematic framework for identifying learning needs, designing instructional activities, developing and validating the application, implementing the product, and evaluating

learning outcomes. The study focused on three aspects of product quality: validity, practicality, and effectiveness. Product validity was assessed through expert evaluation, practicality was examined through user assessments, and effectiveness was evaluated by comparing children's science process skills before and after the intervention.

Research Setting and Participants

The research was conducted at TK Negeri Pembina Karimun, Indonesia, beginning with a needs assessment in February 2026. The implementation phase involved 47 early childhood learners, while preliminary product testing was conducted with 10 children. Teachers participated in the needs assessment, product evaluation, and implementation activities. The participants were involved in activities designed to assess five science process skills: observing, classifying, predicting, inferring, and communicating. These indicators served as the basis for developing learning activities and evaluating children's scientific abilities.

Research Procedures

Analysis

The analysis stage identified instructional needs, children's developmental characteristics, and challenges in early childhood science education (Resmi et al., 2019). Data were collected through classroom observations, teacher interviews, and documentation. The assessment focused on existing instructional practices, the availability of digital learning media, and children's difficulties in performing basic scientific inquiry activities. The findings indicated that conventional teacher-centered instruction and limited interactive learning resources restricted opportunities for scientific exploration. These results informed the instructional requirements and functional specifications of the ATOM application.

Design

The design stage established the instructional structure, learning content, application interface, and assessment instruments (Noviana & Solichin, 2021). Five science themes were selected: color mixing, floating and sinking, magnetic exploration, states of matter, and plant growth. Learning activities were designed to support observation, classification, prediction, inference, and communication through interactive exploration. The application interface incorporated drag-and-drop activities, visual representations, voice-guided instructions, and immediate feedback to accommodate children's developmental characteristics. Assessment instruments were also prepared to evaluate product validity, practicality, and science process skill outcomes.

Development

The development stage involved constructing the ATOM application using the Unity engine and visual assets developed with Adobe design software. The application integrated interactive simulations, animated objects, auditory instructions, and responsive touchscreen features. Product validation covered three dimensions: media quality, science content, and assessment instrument validity. Expert feedback was used to identify weaknesses and guide product revisions. Improvements included completing voice-over instructions for children who had not yet developed reading proficiency and optimizing touchscreen responsiveness. Preliminary practicality assessments were conducted through a focus group discussion and small-scale testing involving 10 children.

Implementation

The implementation stage involved 47 children at TK Negeri Pembina Karimun. Before classroom implementation, teachers participated in a Training of Trainers (ToT) session to familiarize themselves with the application's features and instructional procedures. ATOM was integrated into science learning activities aligned with the Kurikulum Merdeka. The application was used to introduce scientific concepts through interactive digital exploration before children participated in related hands-on activities, including finger painting, seed planting, and magnetic object exploration. Teachers provided instructional guidance during the learning process, while implementation practicality was assessed to examine the application's suitability for classroom use (Manurung & Rohmah, 2021).

Evaluation

The evaluation stage examined product quality and changes in children's science process skills. Formative evaluation was conducted through expert validation, product revision, and preliminary practicality assessments. Summative evaluation focused on children's learning outcomes using pretest and posttest measurements. The assessment addressed five science process skill indicators: observing, classifying, predicting, inferring, and communicating. Changes in assessment scores were examined to determine whether children's performance improved following the implementation of ATOM.

Data Collection and Research Instruments

Data were collected through observations, interviews, documentation, expert validation, practicality assessments, and science process skill measurements. Classroom observations and teacher interviews were used to identify instructional needs, while documentation provided supporting information about learning activities.

Expert validation instruments assessed media quality, science content, and the suitability of assessment instruments. Practicality assessments examined the usability and classroom applicability of the developed application. Children's science process skills were evaluated through pretest and posttest assessments based on the five predetermined indicators.

Data Analysis

The data were analyzed using descriptive quantitative analysis and nonparametric statistical testing. Expert validation and practicality assessment results were expressed as percentages to describe product quality and usability. Children's science process skill outcomes were summarized using mean percentage scores obtained from the pretest and posttest assessments. The Wilcoxon signed-rank test was used to examine differences between paired pretest and posttest scores, with statistical significance established at ($p < 0.05$). Because the study did not report a control group, the analysis was interpreted as evidence of changes in science process skills following the intervention rather than definitive evidence of a causal effect attributable solely to ATOM.

Results and Discussions

The results of this study are presented in four main sections corresponding to the development and evaluation of the ATOM digital learning application. The first section describes the needs assessment, focusing on instructional challenges and children's science process skills. The second presents the application design, development, and expert validation findings. The third reports practicality assessments conducted during preliminary testing and classroom implementation. The final section examines changes in children's science process skills based on pretest and posttest measurements, normalized gain analysis, and the Wilcoxon signed-rank test. These findings provide empirical evidence regarding the validity, practicality, and learning outcomes associated with ATOM implementation in early childhood science education.

Needs Analysis

Table 1. Findings of the Initial Needs Assessment

Assessment Component	Findings	Identified Needs
Learning approach	Predominantly teacher-centered instruction	Active, child-centered learning
Digital learning media	Static presentations using Google Slides	Interactive digital activities
Science process skills	Difficulties in observing, classifying, predicting, inferring, and communicating	Structured scientific inquiry activities
Teacher responses	100% reported children's difficulties in basic scientific inquiry	Developmentally appropriate learning support
Learning engagement	Limited engagement reported during conventional instruction	Interactive feedback and guided exploration

The needs assessment conducted at TK Negeri Pembina Karimun in February 2026 identified limitations in instructional practices and available digital learning resources. All surveyed teachers (100%) reported difficulties among children in performing basic scientific inquiry activities, particularly observation, classification, prediction, inference, and communication. Existing learning activities relied predominantly on teacher-centered instruction and static presentation media, which provided limited opportunities for interactive exploration. These findings informed the development of ATOM as a digital learning application integrating scientific inquiry activities, interactive feedback, and developmentally appropriate instructional support. However, the number of surveyed teachers and baseline measurements for individual science process skills were not reported.

Product Design and Validation

Table 2. Expert Validation Results of the ATOM Application

Validation Dimension	Score (%)	Reported Category
Media validity	91.40	Very Valid
Science material validity	98.00	Very Valid
Evaluation instrument validity	90.00	Very Valid

Expert validation indicated favorable evaluations across all three assessed dimensions. Science material validity achieved the highest score (98.00%), followed by media validity (91.40%) and evaluation instrument validity (90.00%). These results suggest that the developed application met the assessment criteria applied by the

validators. The evaluation also informed revisions to voice-over instructions and touchscreen responsiveness, particularly to support children who had not yet developed reading proficiency. Nevertheless, the interpretation of these percentages requires further documentation of the validators' qualifications, assessment indicators, scoring procedures, and category thresholds.

Product Practicality and Implementation

Table 3. Practicality Assessment Across Development and Implementation Stages

Assessment Stage	Participants	Practicality (%)
Focus Group Discussion	Not reported	97.98
Small-scale testing	10 children	95.56
Classroom implementation	47 children	97.20

The practicality assessment yielded consistently high scores across the evaluation stages, ranging from 95.56% to 97.98%. The Focus Group Discussion produced the highest score (97.98%), while small-scale testing involving 10 children yielded 95.56%. During classroom implementation with 47 children, the practicality score reached 97.20%, indicating favorable usability assessments in the instructional setting. Implementation incorporated teacher training and integrated digital exploration with physical science activities, including color mixing, seed planting, and magnetic object exploration. Although the findings suggest that ATOM was considered practical, the results should be interpreted according to the assessment instruments and respondent groups used at each stage.

Changes in Science Process Skills

Table 4. Pretest–Posttest Comparison of Children's Science Process Skills

Evaluation Indicator	Result
Number of participants	47
Pretest mean (%)	48.58
Posttest mean (%)	87.85
Mean difference (percentage points)	+39.27
Reported N-Gain	0.765
N-Gain category	High
Wilcoxon signed-rank test	$p < 0.001$
Participants with improved scores	100%

The evaluation showed an increase in mean science process skill scores from 48.58% at pretest to 87.85% at posttest, representing an improvement of 39.27 percentage points. The reported normalized gain of 0.765 was classified as high, while the Wilcoxon signed-rank test indicated a statistically significant difference between the paired measurements ($p < 0.001$). All 47 participants reportedly demonstrated improved scores following the intervention. These findings indicate substantial improvements in science process skill performance during the study period; however, the absence of a control group prevents the observed changes from being attributed exclusively to the ATOM application.

Visualization of Science Process Skill Improvement

Figure 1 illustrates the increase in mean science process skill scores from 48.58% before the intervention to 87.85% afterward. The upward trajectory represents a 39.27-percentage-point improvement across the 47 participating children. The Wilcoxon signed-rank test further indicated a statistically significant difference between the two assessment periods ($p < 0.001$). Although these results demonstrate favorable learning outcomes following ATOM implementation, further controlled investigations are necessary to determine the application's independent contribution to children's scientific development.

The findings indicate that the ATOM digital learning application demonstrated favorable validity, practicality, and learning outcomes in early childhood science education. Expert validation scores reached 91.40% for media quality, 98.00% for science content, and 90.00% for assessment instruments, suggesting that the application met the evaluation criteria established during product development. These findings highlight the importance of aligning instructional content, interactive features, and assessment procedures with children's developmental characteristics. Williams et al. (2019) demonstrated the relevance of designing technology-based learning experiences specifically for early childhood education, while Kristyowati and Purwanto (2019) emphasized meaningful environmental exploration in developing scientific literacy. The relatively high content validation score suggests that ATOM's scientific themes were considered appropriate by the evaluators. Nevertheless, expert validation primarily establishes perceived product suitability rather than demonstrating its direct effectiveness in improving children's scientific understanding.

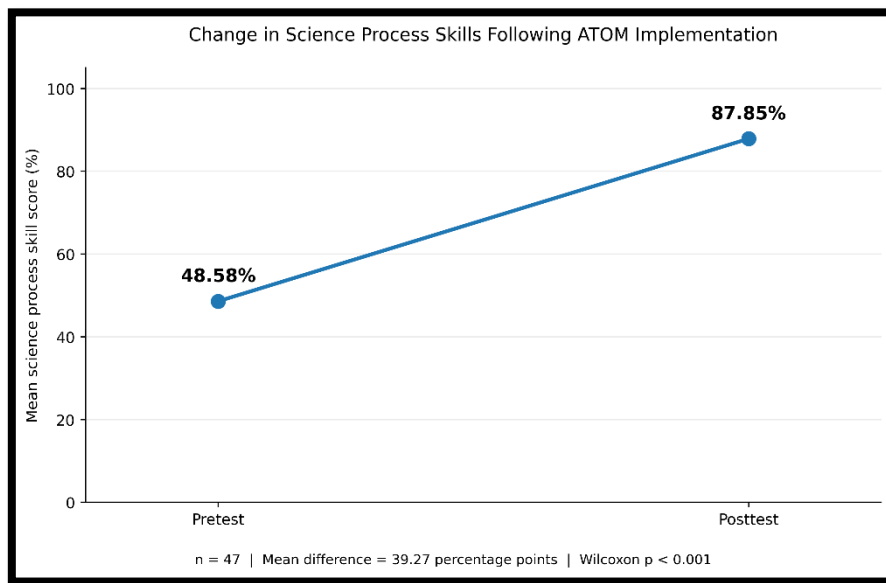


Figure 1. Changes in Mean Science Process Skill Scores

The practicality assessment produced scores of 97.98% during the focus group evaluation, 95.56% in preliminary testing with 10 children, and 97.20% during implementation involving 47 children. These findings suggest that ATOM was positively evaluated across different development and classroom assessment contexts. Its interactive features, including drag-and-drop activities, animated representations, voice-guided instructions, and immediate feedback, were designed to facilitate participation among children with emerging literacy skills. The importance of interactive digital learning environments is consistent with Suarsana et al. (2019), who investigated interactive learning media in supporting conceptual understanding, although their study involved a different educational population and subject area. Similarly, Arwin et al. (2024) examined the potential of digitally supported STEM learning to develop students' abilities through structured instructional experiences. However, the high practicality scores obtained in the present study should not be interpreted as direct evidence of improved learning performance because usability and educational effectiveness represent distinct dimensions of instructional quality.

The most notable finding was the increase in children's mean science process skill scores from 48.58% at pretest to 87.85% at posttest, representing an improvement of 39.27 percentage points. The reported normalized gain of 0.765 indicated a high level of improvement, while the Wilcoxon signed-rank test revealed a statistically significant difference between the two measurements ($p < 0.001$). All 47 participating children reportedly achieved higher posttest scores. These findings suggest that the learning activities implemented during the intervention were associated with meaningful improvements in children's scientific performance. From a developmental perspective, interactive exploration may provide opportunities for children to manipulate objects, observe changes, and construct preliminary explanations of scientific phenomena. Smidts et al. (2018) highlighted the relevance of object classification and cognitive flexibility in early childhood, while Putri and Harahap (2018) examined the relationship between scientific inquiry instruction and science process skills in a different educational context. Nevertheless, the present findings do not establish whether improvement occurred equally across observation, classification, prediction, inference, and communication, as indicator-specific results were not reported.

The educational contribution of ATOM may be understood through the integration of digital exploration and teacher-guided practical activities. Interactive simulations introduced scientific phenomena through visual and auditory representations, whereas subsequent activities, including color mixing, seed planting, and magnetic exploration, provided opportunities to investigate related concepts using physical materials. This instructional sequence is consistent with the importance of connecting scientific learning to observable experiences, as discussed by Kristyowati and Purwanto (2019). Williams et al. (2019) also illustrated how developmentally appropriate technology can introduce complex concepts through accessible learning activities. Furthermore, the application incorporated multiple science themes within a structured learning environment, potentially supporting the integration of scientific observation, conceptual understanding, and inquiry-based participation. However, the present study did not separately measure cognitive load, intrinsic motivation, or self-efficacy; therefore, the proposed contributions of multimedia presentation and interactive feedback to these psychological processes remain theoretical interpretations rather than empirically established mechanisms.

Despite the encouraging findings, several methodological limitations should be considered. The pretest–posttest evaluation involved 47 children without a reported control group, limiting causal interpretations of the observed 39.27-percent-age-point improvement. Teacher guidance, repeated assessment, children's developmental progression, and complementary hands-on activities may also have contributed to the learning outcomes. Moreover, the absence of indicator-specific analyses prevents conclusions regarding which science process skills benefited most from the intervention. The study therefore contributes preliminary evidence concerning the feasibility, practicality, and potential educational value of ATOM rather than definitive evidence of its independent effectiveness. Future research should employ controlled or quasi-experimental designs, examine individual science process skill indicators, and assess learning retention across different early childhood settings. Such investigations would strengthen the evidence base for technology-supported scientific inquiry and extend existing discussions of science learning and digital instructional development (Jufrida et al., 2019; Arwin et al., 2024).

Conclusions

This study successfully developed and evaluated ATOM as an interactive digital learning application to support science process skills in early childhood education. The findings demonstrate that ATOM meets the established validity and practicality criteria and is associated with improvements in children's observation, classification, prediction, inference, and communication skills. By integrating interactive digital activities with guided scientific exploration, ATOM offers a developmentally appropriate learning medium that supports active participation in science education. Further controlled research is recommended to establish its independent effectiveness across different early childhood learning environments.

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