JPPIPA 11(7) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Development of Experimental Digital Comics to Stimulate Kindergarteners' Science Process Skills

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Received: May 04, 2025
Revised: June 13, 2025
Accepted: July 25, 2025
Published: July 31, 2025

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DOI: 10.29303/jppipa.v11i7.11696

Abstract: Science process skills play a vital role in the cognitive and scientific development of early childhood learners. However, learning media specifically designed to cultivate these skills, particularly those that are digital and incorporate experimental components are still limited in availability. This study aims to develop digital comic-based learning media through experiments to stimulate science process skills in kindergarten children aged 5-6 years at PAUD 3 Serangkai, West Lombok. The development model used is ADDIE, which includes the stages of analysis, design, development, implementation, and evaluation. Data were collected through material and media expert validation, small group trials, field trials, observations, and pretest-posttest of children's science process skills. The validation results show that this media is highly valid, with an average score of over 95% for both material and media design. The field trials, involving 36 children and two teachers, indicated that the media is very practical to use and successfully attracts interest and encourages active participation from the students in the learning processThe results of statistical analysis using the Paired Sample t-Test showed that the significance value (Sig. 2-tailed) was 0.000 < 0.05, indicating a statistically significant improvement in children's science process skills after using the media, particularly in the abilities to observe, classify, predict, measure, and communicate. This digital comic-based learning media through experiments effectively integrates engaging visuals with real experimental activities, providing a fun and meaningful learning experience. Therefore, this media is valid, practical, and effective as an innovative learning resource in early childhood education to optimally stimulate science process skills.

Keywords: Digital comic; Experiments; Kindergarteners; Learning media; Science process skills.

Introduction

Early Childhood Education (ECE) plays a fundamental role in forming the foundation of children's knowledge, character, and basic skills. ECE is designed not only to instill early knowledge but also to develop cognitive, motor, social-emotional aspects, as well as critical and analytical thinking skills holistically (Nababan & Tesmanto, 2021). One of the basic cognitive skills that must be introduced to young children is science skills, which are crucial in fostering analytical thinking patterns and problem-solving abilities (Bajuri in Nurhayati et al., 2024). Effective science learning from an early age is believed to offer broad benefits for children's development, including conceptual thinking and logic skills (Carin & Robert in Veronica & Yunanti, 2022; Nur in Yaswinda et al., 2023).

Science can essentially be understood as a process, product, and attitude that involves the scientific method to gain knowledge (Fatonah & Prasetyo in

How to Cite:
Fatwini, Astawan, I. G., & Bayu, G. W. (2025). Development of Experimental Digital Comics to Stimulate Kindergarteners' Science Process Skills. *Jurnal Penelitian Pendidikan IPA*, *11*(7), 540–552. https://doi.org/10.29303/jppipa.v11i7.11696

Muthmainnah et al., 2023). Science process skills (SPS) are scientific abilities to observe, classify, measure, communicate, as well as conduct experiments and draw conclusions (Putri, 2019; Patta in Nurhayati et al., 2024). SPS is a primary focus in science education because it plays a vital role in developing analytical abilities and deep scientific understanding in students, including young children (Rodliyah, 2023; Sriwarthini, 2023).

According to Semiawan et al (in Fatmawati, 2024), the goal of teaching science process skills to young children is to provide opportunities for them to try and think critically, equip them with problem-solving skills, and facilitate their understanding of abstract science concepts at higher educational levels. Science learning for young children should ideally be conducted using an enjoyable approach that is close to the natural environment, allowing children to explore actively using their senses (Wisnu et al., 2021). A constructivist approach is highly relevant here, as it emphasizes the importance of children constructing their own understanding and knowledge based on direct experience (Isti`adah, 2020; Sugrah, 2019; Suryana et al., 2022).

To optimally develop science process skills, teachers need to engage children directly in science practice activities, one of which is through the experimental method. Experiments allow children to experience scientific processes firsthand, fostering curiosity, observation skills, and critical thinking abilities (Sari et al., 2021). Thus, learning through experiments not only equips children cognitively but also affects them emotionally and psychomotorically. However, the Trends in International Mathematics and Science Study (TIMSS) indicates that the mathematical and science abilities of Indonesian students are still relatively low compared to other countries. Data from TIMSS between 2003 and 2015 shows that Indonesia ranked low with an average score below the international standard (Hadi & Novaliyosi, 2019). This situation highlights the need for improvement in the quality of science education from the primary level, including ECE, considering the positive correlation between science process skills and science concept understanding (Trihono, 2022).

The low science process skills in young children are mostly due to the lack of opportunities for exploration and direct practice in science learning (Martha & Mayar, 2023). Learning that focuses mainly on student worksheets and traditional lecture methods prevents children from gaining concrete experiences that are essential for understanding science concepts (Mahabatillah, 2021; Utami & Desstya, 2021). Preliminary observations in West Lombok revealed that kindergarten teachers still dominate the learning process and rarely use experimental methods or digital learning media. Learning tends to be monotonous, with an emphasis on reading and memorization, leading to low science process skills among children (Jelita et al., 2022; Karseno & Astawan, 2021).

Although digital learning media, especially digital comics, are recognized as an effective means of increasing student engagement and understanding of science concepts (Madanipour & Cohrssen, 2019; Warmansyah et al., 2023). The reality on the ground shows a significant gap in the availability and utilization of such media in early childhood education, especially in West Lombok. Based on interviews and initial observations, there has been no use of digital comic media in the learning process at the schools where the study is being conducted. Teachers in these schools also admitted to lacking sufficient knowledge and skills to create and develop digital learning media, including digital comics. This results in science learning for young children still being dominated by conventional methods such as lectures and traditional media, causing children to miss out on interactive and enjoyable learning experiences.

This situation emphasizes the urgent need to develop innovative learning media that are not only visually appealing but also capable of facilitating experimental learning that optimally develops science process skills (SPS). Without appropriate media and teacher skill support in using it, the potential for science learning in young children will be severely limited, which ultimately negatively impacts their cognitive and scientific skills in the future (Adawiyah et al., 2020).

The urgency of this study is even more pronounced when linked to international studies such as TIMSS, which show the low science achievement of Indonesian students at the basic education level (Hadi & Novaliyosi, 2019). This indicates that improvements in the quality of early education must be made promptly by adopting innovative learning strategies and media that align with the current technological advancements.

The development of this experimental-based digital comic learning media offers a concrete solution to enhance students' learning motivation and active engagement, while also facilitating teachers in delivering science content in a more creative and effective manner. The comic is designed by integrating storylines that are contextualized to the local culture, natural environment, and daily life of children in West Lombok, thereby making science learning more meaningful and relevant. The presence of this media is expected to serve as a strategic alternative for teachers to present science materials in an engaging, creative, and accessible way.

Therefore, this research not only addresses the practical needs in the field but also contributes to the development of educational knowledge by offering a

learning media model that can be adapted and developed more broadly. This study is expected to serve as a foundation for improving science learning quality in early childhood education, especially in areas with limited access to digital learning media, ultimately supporting the development of a stronger foundation of knowledge and scientific skills in young children from an early age.

This study aims to produce a valid, practical, and effective prototype of digital comic-based learning media through experiments to stimulate science process skills in kindergarten children in West Lombok.

Method

The research method employed in this study is Research and Development (R&D) using the ADDIE design model. The ADDIE model was chosen due to its systematic and structured stages, encompassing Analysis, Design, Development, Implementation, and Evaluation. This model is highly appropriate for instructional media development as it facilitates a well-programmed and goal-oriented development process, allowing for the production of media that is valid, practical, and effective.

The subjects of this study are divided into two main groups. The first group consists of product assessment subjects, serving as validators to assess the product's validity. This group includes media experts and subject matter experts from Universitas Pendidikan Ganesha (UNDIKSHA) who possess competencies and experience in early childhood education (ECE) content and instructional media. The second group comprises the target users of the product, specifically 36 children aged 5–6 years (Group B students) and their teachers at PAUD 3 Serangkai, West Lombok. These target users were involved in evaluating the practicality and effectiveness of the product during the implementation phase. The selection of these subjects was aimed at ensuring that the product testing was conducted with users who are relevant and representative of the intended learner characteristics and educational context.

For the second subject group, this study adhered to ethical considerations related to research involving early childhood participants. Prior to implementation, the researcher obtained consent from parents or legal guardians as a form of approval for the children's participation in media-based learning activities. In addition, the researcher coordinated with the school administration and classroom teachers to ensure that all procedures were conducted safely, educationally, and in accordance with child protection principles.

Data collection instruments included questionnaires and observation sheets. The questionnaires were developed in several forms to assess product validity, media practicality, and user responses. The validity questionnaire was administered to media and content experts to evaluate aspects such as appearance quality, content accuracy, presentation, and language of the experimental-based digital comic media. Meanwhile, the practicality questionnaire was given to teachers as end-users to assess the appropriateness of the content, language, visuals, audio, and media presentation. All questionnaires employed a five-point Likert scale, ranging from "very good" to "very poor," which was then converted into numerical scores to generate quantitative data suitable for statistical analysis. The observation sheets were used to assess children's science process skills during the learning activities involving the digital comic media. The observed indicators included observing, classifying, predicting, measuring, and communicating, which are considered the core indicators of science process skills in early childhood education. The validity of the instruments was tested beforehand through expert judgment involving at least two domain experts.

The data Collection Techniques

The data collection techniques applied in this study involved the administration of questionnaires and the implementation of structured observations. Questionnaires were given to expert validators to assess the media's validity and to teachers to evaluate product practicality. Observations were conducted during learning sessions that utilized the digital comic media, aiming to document and analyze improvements in children's science process skills. The observations were carried out systematically and in a standardized manner to ensure the accuracy and representativeness of the data obtained. The application of these data collection techniques was intended to provide a comprehensive picture of the product's validity, practicality, and effectiveness.

Data Analysis in This Study Employed Both Qualitative and Quantitative Approaches.

To measure the validity of the product, questionnaires were distributed to content and media experts, consisting of several items rated on a 1–4 scale. The quantitative data were derived from the scoring results of these questionnaires using Formula 1.

$$Percentage\ (\%) = \frac{Obtained\ Scor}{Maximum\ Scor}\ x\ 100\% \quad (1)$$

The results of this calculation were then used to determine the feasibility of the instructional media. Table 1 presents the classification ranges for media feasibility categories.

Table 1. Product Validity Criteria

Percentage Score	Validity Criteria	Feasibility Criteria
85% < Score ≤ 100%	Very Valid	Highly Feasible
65% < Score ≤ 84%	Valid	Feasible
45% < Score ≤ 64%	Fairly Valid	Fairly Feasible
21% < Score ≤ 44%	Less Valid	Less Feasible
0% < Score ≤ 20%	Very Invalid	Not Feasible at All

The product's practicality data were obtained from teachers' or users' questionnaire responses using a rating scale, calculated with Fformula 2.

$$Percentage\ (\%) = \frac{Obtained\ Scor}{Maximum\ Scor}\ x\ 100\% \quad (2)$$

To determine the practicality level of the experimental-based digital comic instructional media, the overall average percentage from the teacher/user response questionnaire scores was calculated. This percentage was then interpreted into qualitative data based on the criteria presented in Table 2.

Table 2. Product Practicality Criteria

Percentage Score	Practicality Criteria
81% < score ≤ 100%	Very Practical
61% < score ≤ 80%	Practical
41% < score ≤ 60%	Fairly Practical
21% < score ≤ 40%	Less Practical
0% < score ≤ 20%	Not Practical at All

To evaluate the effectiveness of the experimental-based digital comic instructional media in enhancing children's science process skills, this study employed a paired sample t-test. The paired sample t-test, also known as the dependent t-test, is used to compare two variables within a single sample group. It is a statistical method commonly applied in development research to determine the effectiveness of a treatment by identifying significant differences between the mean score before and after the intervention is administered.

Result and Discussion

This instructional media development research was conducted at PAUD 3 Serangkai in West Lombok, with research subjects comprising 36 children aged 5–6 years in Group B. The findings of the development of the experimental-based digital comic instructional media are presented as follows:

Results of the Analysis Phase (Analyze)

The analysis phase serves as the foundational step in the development of instructional media, aimed at identifying real needs in the field to ensure that the developed product is accurate in its targeting and effective in its application. The analysis was carried out through direct observations and in-depth interviews with teachers at PAUD 3 Serangkai, West Lombok—the research site.

The observation results revealed that science process skills among children aged 5–6 years at the institution were still low, as indicated by the limited presence of science exploration activities involving observation, experimentation, and interactive discussion. Most teachers still relied on conventional instructional media such as posters, magazines, and static images to teach science concepts, without actively integrating digital media or experimental methods. Interviews with three teachers reinforced this finding; they admitted that digital media were rarely used in science instruction due to limited skills in media production and a lack of supporting infrastructure. Furthermore, experimental learning activities were rarely conducted, depriving children of opportunities for hands-on experiences that could stimulate their science process skills. In cases where videos were used, children typically only watched the content passively without engaging in real experimental activities.

Based on the results of the needs analysis, the researchers concluded that there is an urgent need to develop instructional media that integrate interactive digital features and simple experimental activities to better support the development of children's science process skills. Subsequently, the researchers selected learning content that aligns with the PAUD curriculum and is relevant to children's everyday experiences—namely, the theme of water, with subthemes focusing on soluble and insoluble materials and floating and sinking objects. This topic was chosen because it is easily observable in daily life and lends itself to fun and simple experiments. It is expected that this topic will stimulate children to engage in observing, classifying, predicting, measuring, and communicating—the core competencies of science process skills that this media aims to develop.

Results of the Design Phase

After the learning needs and instructional content were clearly identified, the design phase was carried out by developing a comprehensive and structured plan for the instructional media. During this stage, the researchers conducted both technical and conceptual planning for the experimental-based digital comic media, beginning with the selection of supporting applications. CapCut Pro was chosen for video editing, Ibis Paint X for image and character processing, and Adobe Express Animation for voice-over recordings of animated characters.

The researchers designed child-friendly characters tailored to the developmental characteristics of early childhood learners. The character references were

adapted from credible sources such as Pinterest to ensure the figures would serve as engaging and enjoyable learning companions for children. All visual assets—including backgrounds, animations, and sound effects—were carefully crafted to create an interactive and appealing learning environment.

The digital comic media was designed to include not only a narrative storyline but also hands-on experimental activities that actively engage children. The media is accessible across various platforms such as smartphones, computers, and laptops, enabling flexible implementation in diverse learning settings. A product prototype was then developed, comprising systematically structured pages, including:

- Cover Page: containing the title, university logo, and developer identity
- Opening Page: greeting children with simple, friendly language
- Learning Objectives Page: outlining the targeted science process skills in a clear and comprehensible manner
- User Guide Page: providing directions for children and teachers to optimize media use
- Character Introduction Page: serving as a motivational element for learners
- Content Pages: featuring storylines and character dialogues accompanied by simple experimental instructions
- Closing Page: offering a summary and encouraging children to continue experimenting
- Developer Profile Page: included for product documentation purposes

In addition, research instruments were prepared during this design phase to collect data on product validation and user responses. These instruments included:

- Product validation questionnaire for subject matter experts, assessing content relevance and language clarity
- Product validation questionnaire for media experts, evaluating technical and aesthetic aspects such as usability, visual design, and interactivity
- Practicality questionnaire for teachers as end-users, measuring the media's alignment with classroom learning needs
- Observation sheets, designed to assess children's science process skills while using the experimental-based digital comic media, with indicators covering the abilities to observe, classify, predict, measure, and communicate

All instruments were systematically developed and validated through expert judgment before being used for field data collection. With thorough planning and preparation during the design phase, the instructional media is expected to be developed and implemented effectively in the subsequent stages.

Results of the Development Phase

In the development phase, the product designed during the previous design stage was realized into a fully developed and ready-to-use experimental-based digital comic instructional media. The product development process was carried out systematically, following the structure and page components previously planned, to facilitate early childhood learners in understanding science process skills through an engaging and interactive approach.

The cover page was designed using easy-to-read fonts and a neat layout, creating a pleasant and professional first impression. The appearance of the cover page is presented in Figure 1.

Figure 1. Cover Page

The opening page contains a friendly greeting and motivational message, delivered in simple language to help children feel comfortable and enthusiastic about engaging in the learning process. The opening page of the digital comic is shown in Figure 2.

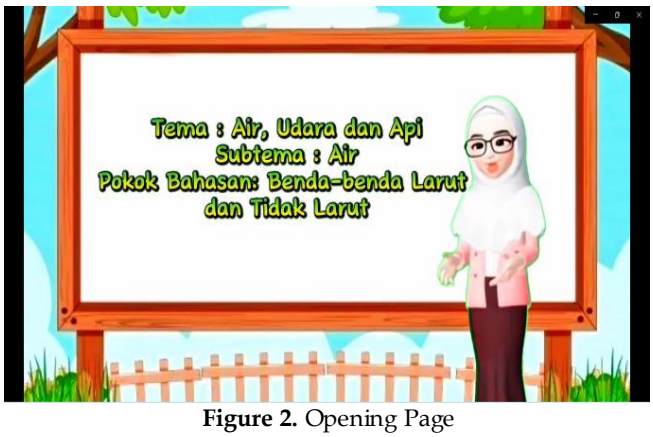

Figure 2. Opening Page

The learning objectives page presents a concise and clear outline of the intended outcomes, specifically focusing on the development of children's abilities to observe, classify, predict, measure, and communicate. The learning objectives page of the digital comic is shown in Figure 3.

Figure 3. Learning Objectives Page

Next, the user guide page contains brief instructions designed to guide both children and teachers in using the media effectively. The user guide page of the digital comic is presented in Figure 4.

Figure 4. User Guide Page

The character introduction page features illustrations and brief descriptions of the main characters, designed to be engaging and easily recognizable so that children feel connected and motivated. The character introduction page of the digital comic is shown in Figure 5.

Figure 5. Character Introduction Page

The title page presents the experimental theme using a visually varied design to maintain children's reading interest. Meanwhile, the content pages contain the storyline and character dialogues, along with experimental activities supported by illustrations and animations, enabling children to follow the steps progressively and gain a comprehensive understanding of science process skills. The title page of the digital comic is shown in Figure 6.

Figure 6. Title Page

The content pages form the core part of the digital comic, containing the narrative, character dialogues, and experimental activities to be carried out by the children. The material is structured progressively and systematically to align with the stages of science process skills development. Each experimental instruction is accompanied by illustrations and animations to enhance children's understanding and engagement. A visual representation of the developed content pages of the digital comic is presented in Figure 7.

Figure 7. Content Pages

The closing page presents a summary of the material along with motivational messages encouraging children to continue experimenting. Additionally, the developer profile page is included to enhance the media's credibility as a valid and high-quality product. A visual representation of the developed closing page of the digital comic is shown in Figure 8.

Figure 8. Closing Page

This page contains brief information about the media developer. The developer profile is presented in a professional manner to enhance the credibility of the product as a valid and high-quality instructional media. A visual representation of the developed developer profile page of the digital comic is shown in Figure 9.

Figure 9. Developer Profile

All pages were developed in an integrated manner using animation software to ensure that the media fulfills the aesthetic, functional, and educational aspects in accordance with the needs of kindergarten-aged children.

Upon completion of the product development, a validation process was conducted involving two groups of experts—subject matter experts and media experts—to ensure the quality and feasibility of the instructional media. The subject matter experts evaluated aspects such as the instructional content, alignment with the curriculum, the accuracy of science process skills concepts, and the clarity of language used. The results of the validation process are presented in Table 3.

Table 3. Results of Validation by Subject Matter Experts

Subject Matter Validator	Percentage (%)	Criteria
Validator 1	95.83	Highly Feasible
Validator 2	94.44	Highly Feasible
Average	95. 14	Highly Feasible

The validation results indicated an average score of 95.14%, categorized as highly feasible, suggesting that the content of the digital comic is relevant and suitable for use without the need for significant revisions. Meanwhile, the media experts evaluated aspects such as visual quality, design aesthetics, ease of use, and the appropriateness of the media for kindergarten children's characteristics.

Table 4. Results of Validation by Media Experts

Media Validator	Percentage (%)	Criteria
Validator 1	97.62	Highly Feasible
Validator 2	92.86	Highly Feasible
Average	95.24	Sangat layak

Based on Table 4, the validators provided an average score of 95.24%, which also falls into the "highly feasible" category. The validators offered several constructive suggestions, including the addition of extra pages in the digital comic, the inclusion of learning objectives at the beginning, the use of capital letters for the title on the cover page, the inclusion of a developer profile, and adjustments to the background color contrast to make the characters clearer and more engaging.

These expert suggestions served as the basis for the first revision (Revision I) of the product. During this revision phase, the media was improved by adding a learning objectives page at the beginning, numbering each page, capitalizing the title on the cover, specifying the target audience, including a developer profile page at the end, and enhancing the background color contrast to make the animated characters more prominent. These improvements were intended to refine the visual quality and presentation of the media, making it more effective and appealing for kindergarten-aged children.

Following the revisions, the media was once again assessed and confirmed to be feasible for use. The revised product, having met the established feasibility standards, was then ready for further trials and implementation in instructional settings to stimulate students' science process skills.

Results of the Implementation Phase

The implementation phase was carried out after the experimental-based digital comic instructional media was declared feasible by both subject matter and media experts during the development stage. The main

objective of this phase was to test the application of the media in an actual learning context at PAUD and to evaluate its impact on stimulating the science process skills of Group B children aged 5–6 years at PAUD 3 Serangkai, West Lombok Regency. The implementation subjects consisted of 36 children and two accompanying teachers. The researcher acted as an observer and media operator, while the teachers served as practitioners guiding the learning process.

The implementation began with a small group trial involving 12 children and 2 teachers. This initial trial aimed to assess content comprehension, visual appeal, and ease of use of the media within the classroom context. The learning session was conducted in a single meeting, focusing on exploring the comic content, children's interaction with the characters, and engagement in simple experiments. Observation and documentation showed a high level of enthusiasm from the children during the activities. The teachers provided feedback regarding the need for external speakers to improve audio clarity for better comprehension. This feedback was considered for the next revision. In terms of content, the media was considered sufficiently effective for broader trials.

The field trial was then conducted with 24 Group B children (11 boys and 13 girls). The learning process took place over two sessions, each covering a different topic: "soluble and insoluble materials" in the first session, and "floating and sinking objects" in the second. Each session lasted approximately 60 minutes and was held in a classroom equipped with technological devices such as an LCD projector and laptop. The teacher acted as an active facilitator, guiding children in understanding the story, conducting experiments, and relating their observations to everyday experiences. Children were encouraged to make predictions, observe, record results, and discuss with the teacher. They also carried out hands-on experiments in small groups using the prepared tools and materials, thereby reinforcing their understanding through practical activities.

In the media practicality test, teachers assessed the product based on content, language, visual presentation, and ease of use. The results of the teacher assessments for the developed product are presented in Table 5.

Table 5. Practicality Test Results

Respondent	Percentage	Criteria
Responden 1	82.29	Highly Feasible
Responden 2	84.38	Highly Feasible
Average Score	83.33	Highly Feasible

The average score from the teacher response questionnaire was 83.33%, which falls into the "highly feasible" category. Teachers provided positive feedback along with suggestions for future development of experimental media with more diverse topics.

To evaluate the effectiveness of the media in stimulating children's science process skills, a pretest and posttest were conducted before and after the use of the media. The data were analyzed using the Paired Sample t-Test with the aid of SPSS software. Prior to the t-test, assumption tests were conducted, including tests for normality and homogeneity. The Shapiro-Wilk normality test indicated that the data were normally distributed, with significance values above 0.05. The Levene's Test for homogeneity also confirmed that the data variance was homogeneous.

Once the data were confirmed to be normal and homogeneous, the analysis proceeded with the Paired Sample t-Test. The comparison of pretest and posttest scores related to children's science process skills is presented in Table 6.

Table 6. Results of the Paired Sample t-Test

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pre test	28.88	24	2.659	.543
	Post test	63.33	24	3.472	.709

Based on Table 6, the mean pretest score was 28.88, while the mean posttest score was 63.33. The analysis also indicated a mean difference of -34.458, which was calculated by subtracting the posttest score from the pretest score. This difference demonstrates an increase of 34.458 points in the average score after the use of the experimental-based digital comic instructional media, indicating a significant improvement in children's science process skills.

Table 7. Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Pre test - Post test	-34.458	4.021	.821	-36.156	-32.760	-41.978	23	.000

From the table above, the t-test calculation shows that the Sig. (2-tailed) value is 0.000, which is less than 0.05, indicating that the null hypothesis (H_0) is rejected and the alternative hypothesis (H_a) is accepted. This means that there is a significant difference between the science process skill scores before and after the children

used the experimental-based digital comic instructional media.

Thus, it can be concluded that the use of experimental-based digital comic media is effective in stimulating the science process skills of kindergarten children in West Lombok. The results of the t-test showed an average pretest score of 28.88 and a posttest score of 63.33, with a mean increase of 34.458 points. The significance value (2-tailed) of 0.000 < 0.05 indicates a statistically significant difference between the scores before and after the use of the media. Therefore, the alternative hypothesis is accepted, confirming that the experimental-based digital comic instructional media is effective in enhancing the science process skills of kindergarten children in West Lombok.

Result of Evaluation Phase

The evaluation phase represents the final stage in the development of the experimental-based digital comic instructional media, aiming to assess the quality and effectiveness of the media in enhancing science process skills among kindergarten children. This comprehensive evaluation was conducted after the completion of the analysis, design, development, and implementation phases. Evaluation data were obtained from the final validation by subject matter and media experts, classroom observations, and the improvement in children's science process skills based on pretest and posttest results.

The final validation results showed that the media was highly valid, with an average score of 95.14% for the content aspect and 95.24% for media design. These findings indicate that the content, visual appearance, and interactivity of the media meet instructional standards and align with the developmental characteristics of early childhood learners, rendering the media highly appropriate for use without major revisions.

The practicality of the media was demonstrated through teacher questionnaires and classroom observations, in which the majority of teachers reported that the media was easy to use, captivating for children, and helpful in delivering science concepts in a concrete manner. The average practicality score of 83.33% reflects that the media is highly practical for use in instructional settings.

In terms of effectiveness, the analysis of pretest and posttest results for children's science process skills showed a significant improvement. The average pretest score of 28.88 increased to 63.33 in the posttest, resulting in a mean difference of 34.458 points. This indicates that the media effectively stimulated children's abilities to observe, classify, predict, measure, and communicate.

In conclusion, the experimental-based digital comic media developed in this study has been proven to be valid, practical, and effective in enhancing kindergarten children's science process skills, making it a feasible instructional tool for early childhood education.

Discussion

The data analysis results indicate that the experimental-based digital comic instructional media developed in this study meets the criteria of validity, practicality, and effectiveness in stimulating science process skills among kindergarten children. The validity of the product is supported by high expert evaluation scores from both content and media specialists, affirming the alignment of content with targeted competencies and its pedagogical relevance for early childhood learners. This finding is in line with Crăciun & Bunoiu, (2019), who emphasized that digital comics can simplify abstract concepts through appealing contextual visualizations, making them highly compatible with the cognitive characteristics of young children. Furthermore, Choiriyah & Hidayah, (2023) noted that digital comics not only convey conceptual understanding but also foster metacognitive skills, such as critical thinking and reflection.

In terms of practicality, the field trials demonstrated that the media was easy to use by both teachers and children, with positive responses toward the characters, narratives, and experimental activities. These findings support the study by Fardiana et al., (2022), which concluded that interactive media enhances student engagement and communication. Similarly, Sumantri & Putri, 2021) and Wahyunisari et al., 2023) found that digital comics are effective in delivering abstract material in a concrete and enjoyable manner, thereby facilitating children's learning processes.

The effectiveness of the media was further confirmed by the Paired Sample t-Test statistical analysis, which showed a significant improvement in children's science process skills following the use of the media. Studies by Leuenberger et al., (2019) and (Santhalia & Yuliati, 2021) also support the idea that experiment-based learning effectively cultivates foundational scientific skills such as observing, classifying, predicting, measuring, and communicating. This media combines visual storytelling with hands-on experimental activities, encouraging children to become active participants in the learning process. This approach aligns with the perspective of Maghfiroh & Kuswanto, (2021), who asserted that digital comics are effective in facilitating inquiry-based learning and problem-solving.

The results of this study indicate that the use of digital comics in early childhood science learning significantly contributes to the development of science process skills. This medium functions not only as an engaging visual aid but also as a learning tool that is

adaptive to technological advancements and the learning characteristics of today's children. These findings align with the study by Radeswandri et al. (2021), which emphasized that digital comics are modern educational media that respond positively to technological developments and are widely accessible to various groups. Digital comics enable young children to engage actively in learning through contextual and enjoyable visual narratives, thereby naturally enhancing their understanding of scientific concepts.

In addition to providing visual appeal and increasing learning motivation, digital comics also contribute to the effectiveness of learning in digital contexts. İlhan et al. (2021) noted that the use of digital comics in online learning makes the learning process more engaging, interactive, and effective—especially in situations that require adaptation beyond traditional classroom environments. This suggests that digital comics possess high flexibility for use in various settings, including both face-to-face and distance learning.

Furthermore, the cognitive impact of interacting with digital comics is reflected in students' ability to construct knowledge and develop more independent learning strategies. Findings from Apostolou and Linardatos (2023) showed that students involved in the creation of digital comics experienced improvements in knowledge construction and a reduction in cognitive load during learning activities. In the context of early childhood education, this can be interpreted as an increase in emerging critical thinking and creativity—both of which are foundational elements in the development of science process skills. In other words, this medium not only facilitates the delivery of information but also fosters meaningful and constructive learning experiences.

The findings of this study further confirm that experimental learning through digital comic media offers tangible contributions to the enhancement of early childhood science process skills. These results are in line with Deslauriers et al. (2019), who demonstrated that active learner engagement in the learning process leads to objectively higher academic achievement compared to students' subjective perception of their own understanding. Moreover, the experimental learning model embedded within the media not only facilitates direct exploration but also lays an initial foundation for the development of critical thinking and basic problem-solving abilities, in accordance with the developmental stage of young children. This is consistent with the findings of Grundgeiger et al. (2022), who revealed that a combination of technology-based interactive learning and hands-on practice significantly enhances procedural skills. Although their study focused on higher education contexts, the underlying pedagogical principles remain relevant, particularly in establishing meaningful learning experiences from an early age.

Active student involvement in learning also has a positive impact on motivation and learning satisfaction, as noted by Kassab (2020). Children in this study showed high enthusiasm during the exploration of the media, indicating an intrinsic drive to understand scientific phenomena in a way that is enjoyable and aligned with their world. Thus, the experimental learning approach implemented through digital comics is not only effective in stimulating cognitive aspects but also contributes to fostering a positive attitude toward science learning from an early age.

Beyond cognitive aspects, the media also integrates positive character values, such as curiosity, cooperation, and courage to try new things, as highlighted by Rachmasari, (2023). However, some challenges emerged, including children's difficulty in interpreting combinations of text and images, as noted by Oktaviana & Ramadhani, (2023). Another notable constraint is the limited access to technological infrastructure and digital literacy among teachers, which remains a significant barrier in the implementation of digital media in early childhood education (Lestari & Hanesman, 2023; Wahyunisari et al., 2023)

Therefore, teacher training and technological infrastructure development are crucial to maximizing the potential of this instructional media. Overall, the experimental-based digital comic media demonstrates substantial potential as an innovative tool for early childhood science learning, combining engaging visualizations, high interactivity, and authentic exploratory experiences that holistically develop science process skills (Fananta et al., 2019; Radeswandri et al., 2021). Further development and broader application are expected to contribute to equitable and sustainable improvements in the quality of early childhood education.

Conclusion

Based on the findings and discussion presented, it can be concluded that the experimental-based digital comic instructional media developed in this study meets the criteria of validity, practicality, and effectiveness as a learning tool for kindergarten children aged 5–6 years. Validation by content and media experts confirmed that the media is highly feasible, both in terms of instructional content and technical and aesthetic aspects. Field trials demonstrated that the media is user-friendly for both teachers and children, and successfully captured learners' interest and active engagement throughout the learning process.

Furthermore, statistical analysis using the Paired Sample t-Test revealed a significant improvement in

children's science process skills after using the media, particularly in the abilities to observe, classify, predict, measure, and communicate.

This experimental-based digital comic media not only presents content in an engaging and interactive way but also integrates experimental activities that provide concrete learning experiences for young children. Thus, the media has proven effective in stimulating the development of science process skills, which serve as a critical foundation for early science education.

Therefore, this instructional media is highly recommended as an innovative learning resource for science instruction in early childhood education (PAUD). Further development and teacher support in utilizing the media are expected to enhance the quality and effectiveness of early science education in a sustainable manner.

In addition to being effective in enhancing the science process skills of early childhood learners, this experimental-based digital comic learning media holds significant potential for broader adoption, including in 3T areas (underdeveloped, frontier, and outermost regions). Its flexible, visually oriented design—tailored to local contexts—enables it to serve as an innovative and inclusive alternative for science learning across diverse geographical and social conditions. Nevertheless, implementation in 3T regions presents specific challenges, particularly the limited access to internet connectivity and digital devices such as smartphones or tablets. Therefore, adaptation through printed comic formats and strengthened educational infrastructure is essential to ensure equitable utilization of the media across all regions.

Acknowledgments

The researcher would like to express sincere gratitude to all parties who have supported the completion of this study. Special thanks are extended to the lecturers and experts from Universitas Pendidikan Ganesha who provided valuable guidance and constructive feedback throughout the research process. Appreciation is also given to the teachers and staff at PAUD 3 Serangkai, Lombok Barat, for their cooperation and assistance during data collection and implementation phases. Furthermore, heartfelt thanks to the children who participated enthusiastically in this study. Finally, the researcher acknowledges the support of family and friends for their encouragement and motivation. Without these contributions, this research would not have been possible

Author Contributions

The first author (student) was fully responsible for the conception and design of the study, data collection, data analysis, and initial manuscript drafting. The second and third authors (lecturers) provided academic guidance, methodological supervision, and contributed to substantive revisions and the refinement of the manuscript. All authors participated in the discussion of the research findings and approved the final version of the manuscript for publication.

Funding

This research received no external funding

Conflicts of Interest

The authors declare no conflict of interest

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