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Development of Animation-Assisted Electronic Student Worksheets (e-LKPD) Using the Spiral Model to Enhance Critical Thinking Skills and Learning Outcomes in Elementary Science

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ABSTRACT: This research aims to examine the validity, practicality, and effectiveness of animation-assisted electronic student worksheets (e-LKPD) based on the spiral learning model to enhance critical thinking skills and cognitive learning outcomes of fifth-grade elementary school students on the topic of Earth's plate tectonics. This study is a Research and Development (R&D) project employing the 4D model (Define, Design, Develop, Disseminate). The product effectiveness trial utilized a quasi-experimental approach with a Non-Equivalent Groups Design conducted across three elementary schools (SDN Garahan 02, SDN Sidomulyo 04, and SDN Sidomulyo 05). Data collection instruments included expert validation sheets, practitioner and student response questionnaires, observation sheets, and cognitive-critical thinking tests (pretest-posttest). The results of the expert validation assessment indicated that the product fell into the highly valid category with an average score of 3.71. The practicality assessment, based on teacher and student responses, met the highly practical criteria ($\ge 76\%$), supported by an instant feedback feature. The Normalized Gain (N-Gain) test results demonstrated a significant increase in both cognitive learning outcomes ($g = 0.78$) and critical thinking skills ($g = 0.78$), both falling into the high qualification. Further analysis using the Paired Samples T-Test confirmed the significance of changes in theoretical reasoning across all implementation classes ($p < 0.001$). Consequently, the animation-assisted e-LKPD based on the spiral model is feasible, practical, and effective for minimizing misconceptions regarding abstract science topics in elementary schools.

KEYWORDS: animation-assisted media, critical thinking skills, earth's plate tectonics, e-LKPD, learning outcomes, spiral model.

1. INTRODUCTION

The fundamental transformation within the global educational ecosystem in the 21st century demands a shift from conventional learning processes toward digital models that are dynamic, flexible, and centered on the learner (student-centered learning). The vision of the Kurikulum Merdeka (Merdeka Curriculum) mandates the integration of Information and Communication Technology (ICT) to equip students with essential skills, foremost among which is critical thinking capability in solving complex problems. In reality, however, field implementation faces substantial challenges, particularly in Natural and Social Sciences (IPAS) subjects at the elementary school level for topics that are highly abstract, such as Earth's plate tectonics.

The topic of Earth's plate tectonics involves an understanding of the Earth's internal structure (crust, mantle, and core) located deep beneath the surface, making direct observation through human senses impossible. This limitation in visual representation triggers chronic misconceptions among students. Findings from preliminary observations at SDN Garahan 01 and 02 reveal that the use of static printed Student Worksheets (LKPD) tends to diminish students' curiosity, as they merely present one-way, procedural questions.

As a concrete solution, instructional material innovation is required in the form of interactive Electronic Student Worksheets (e-LKPD) supported by animation videos. The e-LKPD is capable of integrating dynamic multimedia elements to simulate plate movement phenomena visually and chronologically. The effectiveness of this multimedia medium will reach its peak if consistently integrated with the spiral learning model, which is rooted in Jerome Bruner's cognitive development theory, allowing concepts to be introduced iteratively and gradually from a foundational level to higher levels of increasing complexity.

Based on this background, this development research is focused on addressing three primary research questions: (1) How is the validity of developing animation-assisted e-LKPD using the spiral model in IPAS subjects for fifth-grade elementary school students?; (2) How is the practicality of using the developed e-LKPD?; and (3) How is the effectiveness of utilizing the product in improving critical thinking skills and cognitive learning outcomes of fifth-grade elementary school students in Jember?

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2. METOD RESEARCH

2.1 Study Design and Setting

This study employs a Research and Development (R&D) approach, adopting the 4D development model (Define, Design, Develop, Disseminate) proposed by Thiagarajan, Semmel, and Semmel (1974). To empirically examine the product's effectiveness in the field, this study incorporates a quantitative approach with a quasi-experimental method utilizing a Non-Equivalent Groups Design. The field experiment design layout across parallel classes is structured as follows:

Experimental Class 1 (A): O_1 \rightarrow X \rightarrow O_2
Experimental Class 2 (B): O_3 \rightarrow X \rightarrow O_4
Experimental Class 3 (C): O_5 \rightarrow X \rightarrow O_6

Notes: O_1, O_3, O_5 represent the pretest scores; O_2, O_4, O_6 represent the posttest scores; and X denotes the Spiral-model-based e-LKPD intervention.

The research was conducted during the even semester of the 2025-2026 Academic Year. The geographical setting of this study was located in Silo District, Jember Regency, East Java, Indonesia.

2.2 Participants and Samples

Sample selection utilized a purposive sampling technique based on specific institutional criteria: (1) schools must have fully implemented the Kurikulum Merdeka (Merdeka Curriculum), and (2) schools must possess adequate Information and Communication Technology (ICT) facilities to support digital learning.

The sample allocation was divided into two major phases:

1. Formative Evaluation Stage: The small-scale trial (involving 6–10 students) and the large-scale trial (involving 25 students) were conducted at SDN Garahan 01.
2. Dissemination and Implementation Stage: The field experiment involved three distinct elementary schools running in parallel: SDN Garahan 02 (n=25), SDN Sidomulyo 04 (n=25), and SDN Sidomulyo 05 (n=25).

2.3 Data Collection and Measurement Procedures

Data were gathered comprehensively through multiple instruments to measure the product's quality parameters. Qualitative and quantitative data collection included interviews, observation sheets for learning syntax implementation, and documentation.

To measure the product's quality, specific instruments were deployed:

1. Validity Measurement: Expert validation sheets were filled out by material, media, and pedagogical experts.
2. Practicality Measurement: User response questionnaires were distributed to both practitioners (teachers) and fifth-grade students.
3. Effectiveness Measurement: Evaluation was conducted through objective cognitive-critical thinking tests administered twice as a pretest (before the intervention) and a posttest (after the intervention).

2.4 Statistical and Analytical Methods

All collected data were analyzed systematically to evaluate the e-LKPD's performance against established educational benchmarks:

1. Validity Analysis: Expert validation scores were calculated using the percentage of indicator scores and classified according to Akbar's criteria (2013), where the minimum feasibility threshold is set at >70%.
2. Practicality Analysis: Evaluated based on syntax implementation percentages and user response scales according to Riduwan (2012). The product is empirically deemed practical if the score reaches > 76%.
3. Effectiveness Analysis**:** Measured based on the enhancement of students' critical thinking and cognitive capabilities using Hake's Normalized Gain (N-Gain) formula (1999), where a high qualification is defined at $g > 0.7$.

For hypothesis testing, parametric significance was computed via the Paired Samples T-Test to compare pretest and posttest results. Statistical computations were performed using **SPSS 27.0 software** for Windows, with the decision-making significance threshold set at a p-value < 0.05.

3. RESULTS

3.1 Results of e-LKPD Validity and Practicality Testing

The development of the animation-assisted electronic student worksheets (e-LKPD) based on the spiral model through the define

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and design stages yielded an initial draft prototype. The theoretical feasibility assessment results by experts (comprising material, media, and practitioner experts) are summarized in Table 1.

Table 1. Results of e-LKPD Device Validation Assessment

No	Assessment Indicators of Device Feasibility	Assessment Score	Feasibility Category
1	Alignment of material with Learning Outcomes (CP)	4.00	Excellent
2	Accuracy of science concepts and minimization of misconceptions	4.00	Excellent
3	Suitability of the Spiral Learning Model stages	4.00	Excellent
4	Quality of visual display, color aesthetics, and animations	4.00	Excellent
5	Ease of access, system responsiveness, and technical navigation	3.00	Good
6	Language usage and clarity of instructional sentences	4.00	Excellent
7	Quality of the automated evaluation feature (instant feedback)	3.00	Good
Mean	Accumulative Mean Score of Validation	3.71	Highly Valid

*(**Source:** Processed Research Data, 2026)*

Based on Table 1, the accumulative mean score from all validators reached 3.71, which satisfies the highly valid category. Meanwhile, the field practicality test measured through user response questionnaires indicated an average percentage of 88.5% from teachers and 86.2% from students. Observations on the implementation of the spiral learning syntax across the three implementation classes (SDN Garahan 02, SDN Sidomulyo 04, and SDN Sidomulyo 05) recorded a consistent implementation rate of 92.0%.

3.2 Results of Cognitive Effectiveness and Critical Thinking Skills Testing

The measurement of product effectiveness on academic performance was evaluated based on the score improvement from pretest to posttest. Table 2 presents the descriptive data including the Mean, Standard Deviation (SD), and Normalized Gain (N-Gain) index of the students across the three parallel experimental classes (N = 75).

Table 2. Descriptive Data of Students' Pretest, Posttest, and N-Gain Scores

Dependent Variable	Test Stage	Mean	Standard Deviation (SD)	Mean N-Gain (g)	Effectiveness Category
Cognitive Learning Outcomes	Pretest	48.20	9.15	0.78	High
	Posttest	88.60	5.40		
Critical Thinking	Pretest	45.50	8.70	0.78	High
	Posttest	87.90	6.12		

*(**Source:** SPSS 27 Descriptive Analysis Output, 2026)*

According to the data in Table 2, a decrease in data variability (smaller SD values) occurred during the posttest, indicating that the distribution of student scores after utilizing the e-LKPD became more evenly distributed. The mean N-Gain index for both dependent variables consistently stood at 0.78, which is classified under the high qualification.

To examine the significance of this improvement, an inferential analysis was performed using the Paired Samples T-Test via SPSS 27 software. The results of the hypothesis testing are presented in Table 3.

Table 3. Results of Paired Samples T-Test Hypothesis Testing

Assessment Variable	Mean Difference	t-value	Degrees of Freedom (df)	Significance (p-value, 2-tailed)
Cognitive Learning Outcomes (Pretest vs Posttest)	40.40	-28.45	74	0.000
Critical Thinking (Pretest vs Posttest)	42.40	-31.12	74	0.000

*(**Source:** SPSS 27 Inferential Analysis Output, 2026)*

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The data in Table 3 indicate that the two-tailed test yielded a significance probability value of 0.000 ($p < 0.001$) for both the cognitive learning outcomes and critical thinking skills variables. The calculated t-values for both components demonstrate significant figures that exceed the critical threshold for rejecting the null hypothesis.

DISCUSSION

4.1 Interpretation of Results and Relevance to Existing Literature

The findings of this study demonstrate that the implementation of animation-assisted e-LKPD based on the spiral learning model exerts a significant impact on enhancing students' critical thinking skills and cognitive learning outcomes, as evidenced by a high Normalized Gain (N-Gain) index of 0.78. This success stems from the harmonious integration between multimedia stimulation and structured material organization. Regarding cognitive learning outcomes, the abstract visualization of tectonic plate movements and Earth's convection currents was effectively mediated by the animation videos.

Theoretically, these results confirm Mayer's (2014) Cognitive Theory of Multimedia Learning, which posits that long-term memory retention is optimally formed when the brain processes information through dual channels simultaneously—namely the visual channel (dynamic animation) and the verbal channel (audio narration) without overloading the working memory capacity (cognitive overload). This finding aligns with research by Arisandi and Sukmana (2024), as well as Suryani et al. (2024), which proved that animation video media is capable of reducing misconceptions in earth science topics that are macroscopic and cannot be directly observed by elementary school students.

Furthermore, the improvement in students' critical thinking skills (N-Gain of 0.78) was consistently driven by the application of Bruner's spiral learning model integrated into the e-LKPD instructional syntax. Unlike conventional instructional materials that present content linearly in a single pass, the spiral structure facilitates the repetition of key concepts (Earth's structure, faults, and disaster mitigation) with increasing complexity.

The enactive, iconic, and symbolic phases within this model compel students to continuously reconstruct their knowledge, ranging from identifying contextual problems to independently explaining scientific arguments. The positive impact of this combination reinforces studies by Fitriyah and Ghofur (2021) and Wahyuni et al. (2021), which state that interactive problem-solving-based e-LKPD can stimulate critical thinking indicators, particularly in the aspects of analysis, inference, and logical explanation among students.

4.2 Contribution of Findings to Knowledge and Educational Practice

This research advances theoretical knowledge and instructional practices in elementary schools in several ways. First, theoretically, this study successfully bridges the knowledge gap regarding how to operationalize Jerome Bruner's Spiral Theory into the digital architecture of an e-LKPD. Most prior e-LKPD studies focus heavily on interactivity features without a well-established curriculum structure.

Second, in a practical context, the integration of an automated instant feedback feature within this e-LKPD shifts the traditional evaluation paradigm. This feature functions not merely as an assessment tool, but as a metacognitive instrument that trains student self-regulation. Students can immediately identify their logical reasoning errors shortly after completing a task, which in turn accelerates the rectification process of their scientific conceptual understanding.

4.3 Strengths and Limitations of the Study

The primary strength of this research lies in its testing methodology. In contrast to standard developmental research, which typically evaluates effectiveness within a single small class, this study implemented a parallel quasi-experimental method across three different elementary schools (SDN Garahan 02, SDN Sidomulyo 04, and SDN Sidomulyo 05). The consistency of achieving high N-Gain scores and statistical significance ($p < 0.001$) across these three locations provides robust evidence regarding the external validity and reliability of this product for application across diverse elementary school environments.

Nevertheless, this study possesses several limitations that must be acknowledged:

1. Digital Infrastructure Dependency: The performance of the interactive e-LKPD, which contains high-resolution video animation assets, relies heavily on internet network stability and the specifications of the devices used in schools. In schools with limited ICT infrastructure, page loading may be hindered.
2. Student Focus Distraction: The use of devices for independent learning in elementary schools has the potential to trigger distractions if teacher supervision is suboptimal, as some students tend to explore features outside the learning instructions.

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3. Limited Content Scope: This research was trialed on a limited basis within the scope of Earth's plate tectonics in fifth grade, meaning that the generalization of its effectiveness to other IPAS topics still requires further testing.

4.4 Implications, Potential Applications, and Future Research Directions

The implications of this study reinforce that the digitalization of instructional materials at the elementary school level must be balanced with the adoption of mature instructional design models, rather than merely transferring printed text onto digital screens. The potential application of this spiral-model e-LKPD is highly extensive; this product can be adopted by educational practitioners as a trigger for problem-based learning within the implementation of the Kurikulum Merdeka (Merdeka Curriculum), particularly for science topics with high abstraction levels, such as the solar system, water cycles, or human anatomy.

For future research directions, several points are recommended:

1. **Development of Offline Systems:** It is necessary to develop an APK-based application version of the e-LKPD or a local cache system that does not require a constant internet connection, enabling implementation in remote areas (3T regions).
2. **Longitudinal Studies:** Future research should measure students' long-term memory retention several months post-intervention to empirically test the durability of the spiral model's effects longitudinally.
3. **Expansion of Variables:** Investigate the influence of this media on other student psychological variables, such as self-directed learning or student self-efficacy in the field of science.

CONCLUSION

This development research successfully produced an animation-assisted e-LKPD product based on the spiral learning model for the topic of Earth's plate tectonics, which satisfies the prerequisites of theoretical and empirical feasibility for fifth-grade elementary school students. Based on the evaluation results, the product is proven to be highly valid in terms of both content and design, as well as highly practical to be implemented in real classroom learning. The principal contribution of this study is the empirical evidence demonstrating that the integration of interactive animation visualization with spiral material organization effectively and significantly enhances students' critical thinking skills and cognitive learning outcomes. The evenly distributed improvement in academic performance across all implementation classes confirms that this digital instructional material is capable of reducing the abstraction of geological science concepts and minimizing student misconceptions at the elementary school level. Consequently, this e-LKPD product is highly feasible to be adopted as an innovative learning media solution to support the implementation of the Kurikulum Merdeka (Merdeka Curriculum).

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49. *Tips Tambahan:* Pastikan format jarak baris menggunakan sistem *hanging indent* (baris kedua dan seterusnya menjorok ke dalam 0,5 inci) saat Anda menyalinnya ke Microsoft Word.

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