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Development of ESD-Based StoryJumper Digital Teaching Materials to Enhance Elementary School Students' Critical Thinking Skills

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ABSTRACT

This study aimed to develop Education for Sustainable Development (ESD)-based StoryJumper teaching materials to enhance the critical thinking skills of fourth-grade elementary school students. The research employed a Research and Development (R&D) approach using the ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation stages. The study was conducted in elementary schools involving 16 fourth-grade students. Data were collected through observations, interviews, validation sheets, questionnaires, and critical thinking tests. The developed digital teaching materials were validated by four experts, comprising one media expert, one language expert, and two subject-matter experts.he instruments of critical thinking test also developed. These instrument and learning materials are revised based on expert feedback before being implemented in classroom learning. The data analysis used RASCH model to perform improvement of students' critical thinking skills. The results showed that the teaching materials achieved a very high validity, indicating that they were highly suitable for classroom use. Practicality evaluation revealed highly positive responses from students and the teacher. The effectiveness analysis demonstrated significant improvement in students' critical thinking skills. These findings suggest that ESD-based StoryJumper teaching materials are valid, practical, and highly effective in promoting critical thinking skills through meaningful, contextual, and interactive learning experiences.

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INTRODUCTION

Critical thinking is one of the essential competencies that students need to develop in the twenty-first century. The ability to analyze information, evaluate arguments, solve problems, and make reasoned decisions enables learners to respond effectively to increasingly complex social, environmental, and technological challenges (Facione, 2015; Ennis, 2018; OECD, 2020). In elementary education, critical thinking serves as a fundamental skill that supports students in understanding concepts, interpreting information, and connecting classroom learning with real-life situations (Abrami et al., 2015; Zhang & Liu, 2022; Rahayu et al., 2026). Therefore, developing critical thinking skills has become a major objective of contemporary educational practices worldwide. Despite its importance, empirical studies indicate that elementary school students still demonstrate relatively low levels of critical thinking skills. Many students rely heavily on memorization and experience difficulties in analyzing problems, providing logical explanations, and justifying their answers (Li et al., 2026; Palayukan et al., 2025; Pratiwi et al., 2023; Reynders et al., 2020). Learning activities often emphasize the acquisition of factual knowledge rather than engaging students in inquiry, evaluation, and problem-solving processes. Consequently, students may struggle when confronted with contextual issues that require higher-order thinking skills (Facione, 2015; Ennis, 2018). This condition highlights the need for innovative instructional strategies and learning resources that can facilitate the development of critical thinking from an early age.

The urgency of enhancing critical thinking skills is increasingly relevant within the framework of Education for Sustainable Development (ESD). ESD aims to equip learners with the knowledge, skills, values, and attitudes necessary to contribute to sustainable development and address global challenges responsibly (UNESCO, 2017; UNESCO, 2020). Through ESD-oriented learning, students are encouraged to critically examine environmental, social, and economic issues, evaluate alternative perspectives, and make informed decisions for sustainable futures (Rieckmann, 2018; Brundiers et al., 2021). Critical thinking is therefore recognized as one of the key competencies required to achieve sustainability-oriented education. In Indonesia, the implementation of ESD principles is increasingly aligned with the objectives of the Merdeka Curriculum, which emphasizes meaningful learning, contextual understanding, and character development (Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi, 2022). Learning experiences are expected to connect students with authentic issues from their surrounding environments while fostering competencies needed to face future challenges (Nurramadhani et al., 2022). However, the integration of ESD principles into elementary school teaching materials remains limited, particularly in resources specifically designed to improve students' critical thinking skills through contextual and engaging learning experiences (Mulyani et al., 2023; Perdamaian et al., 2021).

One instructional approach that has the potential to support ESD implementation and critical thinking development is digital storytelling. Digital storytelling combines narrative structures with multimedia elements such as text, images, audio, and interactive features to create meaningful learning experiences (Robin, 2016; Yang & Wu, 2012). Previous studies have demonstrated that digital storytelling can enhance student engagement, learning motivation, creativity, conceptual understanding, and higher-order thinking skills (Puspitasari et al., 2025; Robin, 2016). Through narrative-based learning, students are encouraged to interpret situations, analyze problems, and propose solutions, all of which are closely associated with critical thinking processes. Among the various digital storytelling platforms available, StoryJumper offers a practical and interactive environment for developing digital learning materials. StoryJumper enables educators to integrate stories, illustrations, audio narration, and interactive activities into a single digital platform. Research has shown that StoryJumper can improve students' literacy skills, motivation, and classroom participation (Listia et al., 2022; Hariyani et al., 2023). Furthermore, its storytelling features provide opportunities for students to explore real-world problems and reflect on possible solutions, thereby supporting the development of critical thinking skills (Facione, 2015).

Another important consideration in elementary education is the integration of local cultural values into learning materials. Learning becomes more meaningful when instructional content reflects students' social and cultural contexts (Gay, 2018). Local cultural norms contain values that guide social interaction, responsibility, and community participation. Incorporating these norms into ESD-oriented

learning materials allows students to understand the relationship between cultural practices, social responsibility, and sustainable living. Such integration also supports culturally responsive teaching by connecting classroom learning with students' everyday experiences (Gay, 2018; Santrock, 2021). Although previous studies have investigated ESD-oriented learning, digital storytelling, and the us of digital tools education, futher investigation is needed to clarify how these approaches can be integrated with local cultural content to support elementary students critical thinking skills. In particular, the integration of ESD principles, local customary norms, and Storyjumper into a single digital teaching resource for fourth-grade students requires futher examination. Therefore, the present study develops ESD-based StoryJumper digital teaching materials on local customary norms and evaluates their validity, practicality, and potential to support students critical thinking skills. This study contributes a context-specific digital teaching resource that connects sustainability-related values, local cultural knowledge, and interactive digital storytelling in elementary education. Existing studies generally focus on sustainability education or digital storytelling independently, without examining how ESD principles, StoryJumper technology, and local cultural contexts can be combined to enhance elementary students' critical thinking skills (Ekamilasari et al., 2021; Puspitasari et al., 2025). This gap indicates the need for the development of innovative teaching materials that simultaneously promote sustainability awareness, cultural relevance, and critical thinking competencies.

To address this gap, the present study adopts a development approach by designing ESD-based StoryJumper teaching materials on the topic of local cultural norms for fourth-grade elementary school students. The conceptual framework underlying this study assumes that the integration of ESD principles, digital storytelling, and local cultural contexts can provide meaningful and contextual learning experiences that stimulate students' critical thinking processes. Through interactive narratives and sustainability-related issues embedded in local cultural settings, students are expected to analyze information, evaluate situations, and formulate reasoned conclusions. Therefore, this study aimed to develop ESD-based StoryJumper teaching materials and evaluate their validity, practicality, and effectiveness in improving the critical thinking skills of fourth-grade elementary school students. The findings are expected to contribute to the development of innovative instructional resources that support sustainability-oriented education and foster critical thinking competencies among elementary learners. Because this study employed a Research and Development (R&D) design, no statistical hypothesis was formulated; instead, the study focused on determining whether the developed teaching materials met the criteria of validity, practicality, and effectiveness.

METHOD

This study employed a Research and Development (R&D) (Cresswell & Creswell, 2022) approach using both qualitative and quantitative data to develop Education for Sustainable Development (ESD)-based StoryJumper teaching materials aimed at enhancing fourth-grade students' critical thinking skills. The development process adopted the ADDIE model, consisting of five stages: Analysis, Design, Development, Implementation, and Evaluation. The R&D approach was selected because it enables researchers not only to develop an educational product but also to evaluate its validity, practicality, and effectiveness before implementation in classroom learning. The study was conducted at SDN Bubulak Bogor, Indonesia. Purposive sampling was employed to select participants who were directly involved in the development and implementation process. The developed digital teaching materials were evaluated by four expert validators selected based on their relevant expertise in educational media, language, and subject-matter content. The validators comprised one media expert, one language expert, and two subject-matter experts. Their roles were to assess the quality and suitability of the developed materials from their respective areas of expertise and to provide feedback for product improvement before classroom implementation.The product trial involved all 16 students of Grade IV-A, consisting of seven male students and nine female students aged approximately 9–10 years. The students participated in the implementation stage to evaluate the practicality and effectiveness of the developed teaching materials.

Several instruments were utilized to collect research data. Observation sheets were used to identify classroom conditions, learning resources, and students' critical thinking characteristics during

the needs analysis stage. Interview guidelines were employed to obtain information from the classroom teacher regarding learning challenges and instructional needs. Expert validation sheets were used to assess the quality of the developed materials from content, language, media, and instructional perspectives. Teacher and student response questionnaires were administered to evaluate the practicality of the teaching materials. Critical thinking tests consisting of five essay items were used to assess students' critical thinking skills before and after implementation. The test focused on two critical thinking indicators, namely interpretation and explanation, adapted from the critical thinking framework proposed by Facione (2015). The developed teaching materials were created using the StoryJumper digital storytelling platform and integrated Education for Sustainable Development (ESD) principles with local cultural norms. Content validity of the instruments was examined through expert judgment involving media, language, and content experts. Instrument revisions were conducted based on expert feedback before implementation.

The development process followed the five stages of the ADDIE model as research procedure. The analysis stage was conducted to identify learning needs, student characteristics, and curriculum requirements. Data were collected through classroom observations and interviews with the classroom teacher. The analysis focused on identifying existing learning resources, students' critical thinking abilities, and opportunities to integrate Education for Sustainable Development (ESD) principles into the topic of local cultural norms in my region. Curriculum analysis was also conducted to ensure alignment between the developed materials and the intended learning objectives. Based on the results of the needs analysis, the design stage involved the preparation of learning objectives, instructional content, storylines, learning activities, and assessment strategies. The materials were designed to present local cultural norms through contextual stories that encourage students to interpret information, analyze situations, evaluate problems, and explain their reasoning. At this stage, research instruments were also developed, including expert validation sheets, teacher and student response questionnaires, observation sheets, interview guidelines, and critical thinking tests.

During the development stage, the teaching materials were created using the StoryJumper platform. The materials incorporated contextual stories, illustrations, and learning activities related to local cultural norms and ESD values, especially carbon emission footprints. After the initial product was completed, validation was conducted by one media expert, one language expert, and two content experts. The validators assessed the materials in terms of content quality, language appropriateness, visual design, and instructional aspects. Feedback and recommendations from the validators were used to revise and improve the product before implementation. The implementation stage involved a limited trial with fourth-grade students. The revised teaching materials were integrated into classroom learning activities. Students used the StoryJumper materials during the learning process and completed critical thinking assessments before and after the intervention. Teacher and student responses were also collected to evaluate the practicality of the developed product. Rasch analysis was employed to evaluate the measurement quality of the critical thinking test and estimate students' critical thinking ability based on their test responses. The evaluation stage was conducted to determine the validity, practicality, and effectiveness of the developed materials. Evaluation was carried out continuously throughout the development process based on expert judgments, user responses, and students' learning outcomes. The results of the evaluation were used to assess the overall quality of the product and its potential for classroom use.

This study employed both qualitative and quantitative data collection techniques. Qualitative data were obtained from classroom observations, teacher interviews, and expert feedback during the validation process. These data were used to identify weaknesses in the product and provide a basis for revisions and improvements. Quantitative data were collected from expert validation scores, empirical data of students validation, teacher and student response questionnaires, and students' pretest and posttest scores. These data were used to evaluate the validity, practicality, and effectiveness of the developed teaching materials. The effectiveness of the developed teaching materials and empirical data of the instruments was evaluated using Rasch Model analysis, and effect size analysis. Pretest and posttest responses were analyzed using Ministep software based on the Rasch model. Person measures, expressed in logits, were examined to describe changes in students' estimated critical thinking ability between the pretest and posttest. Rasch fit statistics and reliability indices were also examined to evaluate the measurement quality of the instrument. The difference between the pretest and posttest

person measures was interpreted descriptively. The effect size was reported separately, with its calculation method specified to ensure transparency and reproducibility. In addition, effect size analysis was conducted to determine the magnitude of the impact of the developed StoryJumper materials on students' critical thinking skills.

Ethical Considerations

Prior to data collection, permission to conduct the research was obtained from the school principal and classroom teacher. Participation was voluntary, and students' identities were kept confidential. All collected data were used exclusively for research purposes and reported anonymously to protect participants' privacy.

RESULTS AND DISCUSSION

Validity of the Developed Teaching Materials and Instruments

The validity of the ESD-based StoryJumper teaching materials was evaluated through two complementary stages of validation to ensure the quality and appropriateness of the developed product. The first stage involved expert validation, which was conducted by four experts with expertise in science education, educational technology, language, and learning media. The experts assessed various aspects of the teaching materials, including content accuracy, alignment with Education for Sustainable Development (ESD) principles, language clarity, presentation, and graphical design. Feedback and suggestions from the experts were used to revise and improve the product before further testing. The results of this expert validation are presented in Table 1. The second stage consisted of empirical validation, which was conducted through a pilot test involving elementary school students prior to the implementation phase. This empirical validation aimed to examine the practicality, readability, comprehensibility, and suitability of the teaching materials from the learners' perspective. Data obtained from student responses were analyzed to determine whether each component of the teaching materials functioned effectively in actual learning situations. The combination of expert and empirical validation provided comprehensive evidence regarding the validity and feasibility of the ESD-based StoryJumper teaching materials for classroom use.

Table 1. Expert Validation Results

Validator	First Validation (%)	Second Validation (%)
Media Expert	88	96
Language Expert	88	100
Content Expert 1	88	94
Content Expert 2	92	N/A
Average	89.00	96.97

As shown in Table 1, the average validation score increased from 89.00% in the first round to 96.67% in the second round. The second-round average was calculated using the scores of three validators: the media expert, language expert, and Content Expert 1. Content Expert 2 did not participate in the second validation round because the first-round evaluation had already met the established acceptance criteria. Therefore, the second-round average was calculated based on the three available scores rather than all four validators. Indicating that the developed materials achieved a highly valid category. This improvement reflects the effectiveness of the revision process, including the enhancement of content explanations, language accuracy, supporting references, and visual illustrations. These findings support the notion that effective teaching materials should provide accurate content, clear language, attractive design, and meaningful learning experiences (Prastowo, 2021; Qona et al., 2024). Furthermore, the integration of ESD principles and local cultural contexts aligns with UNESCO's recommendation that learning resources should connect knowledge with real-world sustainability challenges and foster competencies for sustainable development (UNESCO, 2017; Rieckmann, 2018; Brundiers et al., 2021). The increase in validity scores demonstrates that the revision process successfully improved the quality of the teaching materials. The addition of real-life examples,

clearer explanations, supporting references, and contextual illustrations strengthened both the content quality and instructional relevance of the product. These findings suggest that the developed StoryJumper materials are appropriate for supporting elementary students' learning experiences.

The empirical validation was conducted to examine the quality of the critical thinking test instrument developed within the ESD-based learning context. This stage involved a trial implementation of the instrument to students to ensure that each item functioned effectively in measuring the intended construct. The validation focused on assessing the validity and reliability of the test items in relation to students' critical thinking skills. In addition, the alignment of each item with ESD content, particularly topics related to carbon footprint, was carefully evaluated. The results of the empirical validation are presented in Table 2.

Table 2. Item Test Results (Empirical Validity)

Aspect	Value (Logit)
Infit MNSQ	0.99
Outfit MNSQ	0.98
Infit ZSTD	-0.03
Outfit ZSTD	-0.04
Item Reliability	0.71
Item Separation	1.58

As shown in Table 2, the Rasch analysis yielded an Infit MNSQ of 0.99 and an Outfit MNSQ of 0.98, with corresponding ZSTD values of −0.03 and −0.04. These fit statistics suggest that the overall response pattern was reasonably consistent with the Rasch model expectations. The item reliability coefficient was 0.71, while the item separation index was 1.58, indicating a limited level of differentiation among item difficulty estimates. However, these aggregate statistics do not establish that every test item individually meets the relevant fit criteria. Therefore, conclusions regarding individual item quality should be based on item-level fit statistics and the applicable evaluation criteria. Each test item demonstrated appropriate levels of validity, showing that the items were able to accurately measure students' critical thinking skills within the ESD framework. Furthermore, the reliability analysis confirmed the consistency of the instrument in assessing student performance across different items. This also the item test could separate the difficulty level of content. All test items were found to effectively represent critical thinking indicators embedded in ESD-based learning, particularly in the context of carbon footprint issues. This suggests that the instrument is suitable for use in evaluating students' higher-order thinking skills in sustainability-related topics. The strong validity and reliability evidence also support the feasibility of the instrument for broader implementation in science education contexts.

Practicality of the Developed Teaching Materials

The practicality of the developed materials was assessed through student and teacher response questionnaires. The results are presented in Table 3.

Table 3. Practicality Results

Respondent	Percentage (%)	Category
Students	94.63	Highly Practical
Teacher	92.00	Highly Practical

As shown in Table 3, the developed teaching materials received practicality scores of 94.63% from students and 92.00% from the teacher. Both scores were categorized as highly practical based on the evaluation criteria used in this study. These results indicate that the materials were perceived as practical for classroom use by both groups of respondents. The student responses reflect their evaluation of the learning materials, while the teacher's response provides a perspective on their practicality in instructional implementation. However, these findings represent respondents' evaluations of practicality and should not be interpreted as direct evidence of learning effectiveness. The student response score of 94.63% and teacher response score of 92.00% indicate that the materials were easy

to use, engaging, and supportive of classroom learning. These findings may be attributed to the characteristics of StoryJumper as a digital storytelling platform that integrates text, images, and interactive narratives to create meaningful learning experiences (Listia et al., 2022; Hariyani et al., 2023). Previous studies have also reported that digital storytelling enhances student engagement, motivation, and participation in learning activities (Robin, 2016; Yang & Wu, 2012). The classroom observations further revealed that students actively participated in discussions and demonstrated enthusiasm when interacting with the digital stories, which is consistent with the learning characteristics of elementary school students who benefit from concrete and visual learning experiences (Santrock, 2021).

Effectiveness of the Developed Teaching Materials

The effectiveness of the developed materials was examined using Rasch Model analysis and effect size analysis to determine the improvement in students' performance after the implementation of the ESD-based StoryJumper learning materials. The Rasch Model was employed to evaluate the consistency and quality of the measurement before and after the intervention, particularly in terms of item fit and response patterns. This analysis provides a more robust interpretation of learning outcomes by converting raw scores into logit values. The comparison between pretest and posttest results using the Rasch Model is presented in Table 4.

Table 4. Comparison of Pretest and Posttest Results

Aspect	Value (Logit)
Infit MNSQ	0.99
Outfit MNSQ	0.98
Infit ZSTD	-0.12
Outfit ZSTD	-0.12
Person Mean Measure (Logit) (Pretest)	0.34
Person Mean Measure (Logit) (Posttest)	1.12
Person Reliability	0.83

The results presented in Table 4 indicate that the pretest and posttest data fit the Rasch Model requirements, as shown by the Infit and Outfit Mean Square (MNSQ) values that are close to the ideal value of 1.00. The Infit MNSQ (0.99) and Outfit MNSQ (0.98) suggest that the data are well within the acceptable range, indicating good item and person fit. Similarly, the Infit and Outfit ZSTD values (-0.12 and -0.12) are close to zero, confirming that there is no significant distortion in the measurement model. These findings demonstrate that the instrument functioned consistently across both testing phases. Overall, the Rasch analysis supports the stability of the measurement and confirms that the data are reliable for further interpretation of learning effectiveness.

The mean Person Measure increased from 0.34 logits in the pretest to 1.12 logits in the posttest, representing a descriptive increase of 0.78 logits. The Person Reliability value reported in Table 4 was 0.83. However, the posttest Person Reliability value could not be independently verified; therefore, no claim is made regarding an increase in Person Reliability. The higher posttest Person Measure indicates an increase in students'estimated critical thinking ability following the implementation of the ESD-based StoryJumper digital teaching materials. Nevertheless, this difference should be interpreted descriptively and does not, by itself, establish statistical significance or demonstrate a causal effect of the intervention. These results indicate that the developed materials effectively supported students' critical thinking development The increase in Person Mean Measure from 0.34 logits to 1.12 logits indicates that students critical thinking skills are improves after receive the lesson. In the Rasch measurement framework, higher logit values reflect higher ability levels. Therefore, the observed increase suggests meaningful improvement in students' critical thinking skills.

Effect Size Analysis

To determine the magnitude of the intervention effect, a Cohen's d effect size analysis was conducted based on students' pretest and posttest scores obtained from the implementation of the ESD-based learning materials. This analysis was used to measure the practical significance of the instructional intervention beyond statistical significance. The pretest and posttest scores were first converted into logit values to ensure consistency with the Rasch measurement scale. The results of the effect size analysis are presented in Table 5.

Table 5. Cohen's *d* Results

Analysis	Value
Mean Pretest	0,34
Mean Posttest	1,12
Cohen's *d*	2.78
Cohen's *d*	Large Effect

According to Cohen's criteria, an effect size greater than 0.80 indicates a large effect. Therefore, the obtained value of 2.78 demonstrates that the developed teaching materials had a very strong impact on improving students' critical thinking skills. This finding suggests that the ESD-based StoryJumper materials were highly effective in facilitating meaningful learning and supporting students' higher-order thinking development. This finding suggests that the developed ESD-based learning materials had a strong and meaningful impact on students' learning outcomes. The large effect size indicates that the instructional intervention was highly effective in enhancing students' understanding and skills. Therefore, the results provide robust evidence that the implementation of the developed materials significantly improved student achievement in the learning process.

Discussions

The findings indicate that the ESD-based StoryJumper teaching materials are valid, practical, and effective in enhancing the critical thinking skills of fourth-grade elementary school students. The high validity results suggest that the materials meet the characteristics of quality teaching resources, including accurate content, clear language, attractive visual design, and alignment with curriculum objectives and students' needs (Prastowo, 2021; Qona et al., 2024). The integration of Education for Sustainable Development (ESD) principles and local cultural norms strengthened the relevance of the materials by connecting learning content with real-life social and sustainability issues, which is consistent with the objectives of ESD in fostering competencies for sustainable development (UNESCO, 2017; Rieckmann, 2018; Brundiers et al., 2021). In addition, the highly positive responses from students and teachers indicate that the materials were practical and engaging. These findings can be attributed to the interactive features of StoryJumper, which combines text, images, and digital storytelling to promote student participation, motivation, and meaningful learning experiences (Yang & Wu, 2012; Robin, 2016; Listia et al., 2022; Hariyani et al., 2023). The contextual presentation of local cultural norms also aligns with the learning characteristics of elementary school students, who learn more effectively through concrete and relevant experiences (Santrock, 2021).

A closer examination of individual student performance also revealed meaningful differences in learning outcomes. One student, identified by the initials ASP, demonstrated a substantial improvement in critical thinking performance. ASP's pretest score was below the class average, whereas the posttest score exceeded the class average after the implementation of the ESD-based StoryJumper materials. This improvement may be associated with the student's active participation during the learning process. Classroom observations indicated that ASP frequently asked questions related to the learning materials and actively sought clarification when encountering difficulties. Questioning is widely recognized as an important component of critical thinking because it reflects students' efforts to explore information, examine ideas, and construct understanding through inquiry (Facione, 2015; Ennis, 2018). In contrast, another student identified by the initials SANA showed only limited improvement between the pretest and posttest. Observational data suggested that SANA tended to be shy and less active during classroom discussions and learning activities. The student rarely asked questions or expressed opinions, which may have reduced opportunities to engage in deeper cognitive

processing and critical reflection. These findings suggest that active participation and inquiry behaviors play an important role in maximizing the benefits of ESD-based digital storytelling materials for the development of critical thinking skills. Motivation and inquiry-based learning may support the development of students' critical thinking skills by encouraging them to ask questions, explore information, and reflect on their learning experiences. (Presnillo & Aliazas, 2024; Schöpfer & Hernandez, 2026)

The effectiveness analysis demonstrated that the developed materials significantly improved students' critical thinking skills, as evidenced by the increase in Rasch ability measures and the very large effect size (Cohen's d = 2.78). Through digital storytelling activities, students were encouraged to interpret information, analyze problems, evaluate solutions, and explain their reasoning, which are fundamental aspects of critical thinking (Facione, 2015; Ennis, 2018). The integration of ESD principles further supported these outcomes by encouraging learners to critically examine real-world challenges and engage in responsible decision-making related to sustainability (UNESCO, 2017; UNESCO, 2020; Rieckmann, 2018). By linking sustainability concepts with local cultural contexts, the materials promoted higher-order thinking and meaningful problem-solving skills (Ekamilasari et al., 2021; Brundiers et al., 2021; Suryani et al., 2025). These findings are consistent with previous studies reporting that ESD-oriented learning can significantly enhance critical thinking, sustainability awareness, and responsible decision-making among students (Ekamilasari et al., 2021; Badruttamam et al., 2025; Nurramadhani et al., 2022). Consequently, the integration of ESD principles with digital storytelling through StoryJumper offers an effective and innovative approach to supporting student-centered learning in elementary education (Gay, 2018).

Despite the positive findings, this study has several limitations. First, the study involved only 16 fourth-grade students from one elementary school, limiting the generalizability of the findings. Second, the study employed a single-group design without a comparison group. Therefore, the observed changes in students' critical thinking ability cannot be attributed solely to the intervention. Third, the implementation period was relatively short, so the long-term effects of the ESD-based StoryJumper digital teaching materials could not be examined. Fourth, the study primarily focused on students' critical thinking skills, while other dimensions of ESD competencies, such as sustainability awareness and responsible decision-making, were not extensively explored. Finally, the use of digital learning tools such as StoryJumper may require adequate technological infrastructure and digital literacy, which may not be equally available in all educational settings. Future research should involve larger and more diverse samples, comparison groups, longer intervention periods, and a more comprehensive assessment of ESD competencies. Second, the implementation period was relatively short, so long-term effects of the ESD-based learning materials on students' critical thinking development were not fully examined. Third, the study primarily focused on cognitive aspects of learning outcomes, particularly critical thinking skills, while affective and behavioral dimensions of ESD competencies were not extensively explored. Fourth, the use of digital learning tools such as StoryJumper may require adequate technological infrastructure and digital literacy, which may not be equally available in all educational settings. Therefore, future research is recommended to address these limitations by involving broader samples, longer intervention periods, and more comprehensive assessment of ESD competencies.

The findings of this study have several important implications for science education, particularly in integrating Education for Sustainable Development (ESD) into classroom instruction. First, the developed ESD-based StoryJumper teaching materials can serve as an effective alternative learning resource to enhance students' critical thinking skills, especially in understanding real-world environmental issues such as carbon footprint. Second, the strong effect size indicates that integrating digital storytelling with ESD content can significantly improve learning outcomes, suggesting that teachers should consider adopting similar approaches in classroom practice. Third, the validated and reliable assessment instrument provides educators with a practical tool to measure students' higher-order thinking skills in a more contextualized and meaningful way. Finally, this study supports the broader implementation of technology-enhanced learning materials in fostering sustainability awareness and 21st-century skills among elementary school students.

CONCLUSION AND SUGGESTION

This study developed ESD-based StoryJumper digital teaching materials on local customary norms for fourth-grade elementary school students. The findings indicate that the developed materials were considered valid and practical based on expert validation and user assessments. The mean Person Measure increased from 0.34 logits in the pretest to 1.12 logits in the posttest, suggesting a higher estimated level of students' critical thinking ability following implementation. However, because the study involved only 16 students in a limited trial and did not include a comparison group, the observed increase cannot be attributed solely to the intervention. Therefore, the findings should be interpreted as preliminary evidence of the potential of the developed materials to support students' critical thinking skills rather than definitive proof of their effectiveness. Future research should involve larger samples, comparison groups, and longer implementation periods to examine the effectiveness and broader applicability of these materials. Further studies may also investigate their contribution to students' sustainability awareness and responsible decision-making.

CONFLICTS OF INTEREST

The authors declare that we have no conflicts of interest to report regarding the publication of this article.

AUTHOR CONTRIBUTIONS STATEMENT

The authors contributed to this research as follows: conceptualization was carried out by M.A.P., E.S. and A.N.; methodology was developed by M.A.P., E.S., and A.N.; formal analysis was conducted by M.A.P. and A.N.; investigation and data collection were performed by M.A.P and E.S.; writing—original draft preparation was completed by M.A.P. and A.N.; writing—review and editing were carried out by M.A.P., A.N., and P.I.; and supervision was provided by E.S. and A.N. All authors have read and agreed to the published version of the manuscript. Authorship is limited to those who have made substantial contributions to the conception, design, execution, or interpretation of the reported study.

DECLARATION OF GENERATIVE AI SOURCES

During the preparation of this manuscript, the author(s) used ChatGPT (OpenAI) and Quilbot for language improvement, grammar checking, and refinement of academic writing structure. The tool was utilized solely as an assistive instrument to enhance clarity and readability of the text, while maintaining the scientific integrity of the manuscript. All generated suggestions and outputs were carefully reviewed, critically revised, and verified by the author(s). The author(s) take full responsibility for the accuracy, validity, and originality of the final content of the manuscript.

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