



## Empowering ecology learning with digital storytelling: A pathway to critical and computational thinking skills

Khalida Zia\*, Diana Vivanti Sigit, Hanum Isfaeni

Magister of Biology Education, Faculty of Mathematics and Natural Science, Universitas Negeri Jakarta, Indonesia

\*Corresponding author: [dianav@unj.ac.id](mailto:dianav@unj.ac.id)

### ARTICLE INFO

#### Article history

Received: 25 July 2025

Revised: 19 October 2025

Accepted: 28 November 2025

#### Keywords:

Higher-order thinking

Multimedia learning

Science education

### ABSTRACT

Ecology learning presents complex challenges due to its interdisciplinary nature, requiring students to develop both critical and computational thinking skills. However, these higher-order cognitive abilities must be intentionally cultivated through innovative pedagogical strategies. This study developed and evaluated a digital storytelling-based learning medium designed to enhance students' critical and computational thinking skills in ecology. The research involved 120 seventh-grade students from a public Islamic junior high school in Bekasi, Indonesia, and employed a quasi-experimental pre-test-post-test control group design. The control group received instruction through interactive PowerPoint presentations, while the experimental group used the digital storytelling medium; both groups followed a guided inquiry model. The developed media were validated by experts, yielding average scores of 74.28% (language), 77% (content), and 80% (design), indicating strong validity and feasibility. Instruments measuring critical and computational thinking were also validated and demonstrated high reliability ( $\alpha = 0.83$ ; KR-20 = 0.89). Data were analyzed using descriptive statistics and MANOVA. Results revealed significant improvements in both skills across groups, with the experimental group exhibiting greater consistency and higher final performance. Evaluation and decomposition emerged as the strongest indicators of critical and computational thinking, respectively. MANOVA confirmed a statistically significant multivariate effect ( $p = 0.033$ ) of digital storytelling. These findings demonstrate that digital storytelling is a valid, feasible, and effective medium for fostering higher-order thinking in ecology learning and should be integrated into 21st-century science education.

© 2026 Universitas Negeri Jakarta. This is an open-access article under the CC-BY license (<https://creativecommons.org/licenses/by/4.0>)

## INTRODUCTION

Ecology is a fundamental branch of biological science that investigates the complex interactions between organisms and their environments. As a discipline central to addressing urgent environmental challenges such as biodiversity loss, climate change, and ecosystem degradation, ecology requires not only a solid grounding in biological principles but also the cultivation of advanced cognitive skills (Hardanie et al., 2021). Owing to its inherently interdisciplinary nature, the field increasingly relies on computational tools and mathematical models to analyze and simulate ecological processes (Husodo et al., 2020). However, existing educational practices often fail to adequately equip students with the critical and computational thinking skills necessary to navigate these complex systems effectively (Putra & Fitrihidajati, 2022). Despite the gradual integration of digital technologies into education, traditional approaches such as lectures and textbook-based instruction remain predominant. These methods typically emphasize rote memorization rather than analytical reasoning, problem-solving, or digital literacy (OECD, 2021). Consequently, students frequently struggle to engage deeply with ecological content or to apply their knowledge in real-world contexts. This situation underscores a clear research problem: how can educators effectively foster students' critical and computational thinking skills in ecology through innovative, technology-enhanced pedagogies? To address this gap, the present study proposes the development and implementation of a digital storytelling-based learning tool as a pedagogical strategy (Mayarni & Yulianti, 2020). Digital storytelling integrates multimedia elements, including text, audio, images, video, and animation, into coherent narratives that promote active, reflective, and student-centered learning. This approach not only cultivates critical thinking by requiring students to analyze and synthesize ecological information but also enhances computational thinking through the use of digital tools, logical sequencing, and problem-solving frameworks (Haşlamani et al., 2024; Wing, 2017). Aligned with contemporary pedagogical frameworks such as TPACK (Technological Pedagogical Content Knowledge), digital storytelling supports the meaningful integration of content knowledge, pedagogy, and technology to improve learning outcomes. Therefore, this study aims to design and evaluate a digital storytelling-based learning tool intended to strengthen students' critical and computational thinking skills within the context of ecology learning (Abdullah & Mahmud, 2024; Lim & Md Noor, 2019; Mishra & Koehler, 2016).

The theoretical foundation of this study is grounded in constructivist learning theory, which posits that learners acquire knowledge most effectively through active engagement and personal meaning-making. Digital storytelling aligns closely with this perspective, as it fosters student agency, encourages reflective thinking, and supports the development of contextual understanding. The study also draws on the computational thinking framework proposed by Wing (2006), which encompasses core competencies such as abstraction, decomposition, and algorithmic design skills increasingly essential in contemporary scientific learning. Furthermore, it incorporates critical thinking frameworks that emphasize interpretation, analysis, inference, and evaluation, all of which are integral to ecological inquiry. Numerous studies have underscored the importance of critical and computational thinking in science education (Rosyid et al., 2025). Csizmadia et al (2015) highlighted computational thinking as a key competency for effective problem-solving in STEM disciplines. However, Uribe-Enciso et al (2017) observed that traditional instructional methods rarely provide structured opportunities to systematically develop these skills. Although digital storytelling has been shown to enhance student engagement, digital literacy, and self-reflection, few studies have explicitly explored its potential to cultivate both critical and computational thinking within the context of ecology learning. Moreover, much of the existing research lacks a rigorous integration of storytelling approaches with domain-specific biological content, particularly in areas such as ecosystem dynamics, biodiversity, and environmental modeling. This gap highlights both the originality and urgency of the present study (Kortegast & Davis, 2017).

The subject matter selected for this study is ecology, with a particular focus on core topics such as ecosystem dynamics, energy flow, biogeochemical cycles, and species interactions. Mastery of these concepts requires students to comprehend systemic relationships, evaluate anthropogenic impacts, and predict ecological outcomes tasks that inherently demand both critical analysis and computational reasoning. Engaging with this content through digital storytelling enables learners to examine real-world scenarios (e.g., climate change, deforestation, pollution) within a narrative framework that fosters empathy, contextual understanding, and digital competence (Darwis et al., 2025). This research is situated at the intersection of digital pedagogy, cognitive skill development, and biological learning, representing an innovative response to the evolving demands of science education in the digital era

(Husamah et al., 2025). The proposed learning tool adopts a state-of-the-art approach by combining the immersive and affective dimensions of storytelling with the analytical rigor of ecological science. Its novelty lies in the deliberate integration of multimedia narratives with targeted objectives for developing critical and computational thinking in a scientifically grounded and pedagogically robust manner (Andriopoulou et al., 2022; Putri, 2018). The anticipated outcomes include heightened student engagement with ecological content, enhanced problem-solving abilities, improved digital literacy, and a deeper conceptual understanding of complex ecological systems. Ultimately, this research seeks to contribute a validated, scalable educational model that can be adapted across STEM disciplines to support the development of essential 21st-century skills (Juanda et al., 2024; Siddique & Khan, 2024).

## METHODS

### Research Design

A quasi-experimental method employing a pre-test–post-test control group design was used in this study. The research was conducted at a public Islamic junior high school in Bekasi, Indonesia, during the 2024/2025 academic year. This design consisted of two groups: the control group, which was taught using interactive PowerPoint presentations, and the experimental group, which engaged with a digital storytelling–based learning medium. Both groups were instructed through a guided inquiry learning model over three sessions, each lasting 40 minutes. Within this model, students were guided to formulate questions, collect data, analyze findings, and draw conclusions, while the teacher acted as a facilitator (Nurfauziah et al., 2015). The primary objective of the study was to examine the effect of digital storytelling on students’ critical and computational thinking skills. Foundational frameworks proposed by Facione (2015) and Wing (2008) were adopted to underpin the conceptualization of these thinking skills.

### Population and Samples

The study population comprised 120 seventh-grade students from a public Islamic junior high school in Bekasi, Indonesia. The broader regional selection process employed a combination of purposive and cluster sampling techniques. West Java Province and Bekasi City were selected purposively, while East Bekasi District was chosen using cluster sampling. The participating school was selected purposively based on its identified need for enhanced learning media in ecology learning. Within the school, four classes were randomly selected through simple random sampling and assigned to either the control or experimental group, with 60 students in each group. The demographic characteristics of the sample are presented in Table 1.

**Table 1**  
Demographic Characteristics of the Sample

Group	Class	Gender	N	%
Control	2 (VII-1 and VII-2)	Male	30	50.0%
		Female	30	50.0%
Experiment	2 (VII-3 and VII-4)	Male	29	48.3%
		Female	31	51.7%
Total	4		120	100%

### Instrument

Two assessment instruments were developed to evaluate students’ critical and computational thinking skills. Critical thinking was assessed using an essay test designed according to the six indicators proposed by Facione (2015) interpretation, analysis, inference, evaluation, explanation, and self-regulation. Student responses were scored on a four-point scale, following the guidelines of the California Critical Thinking Skills Test (CCTST). An example of an essay item used to assess critical thinking is presented in Table 2 (Alkharusi et al., 2019). Computational thinking was measured using a multiple-choice test developed based on the four indicators proposed by Wing (2008) decomposition, pattern recognition, abstraction, and algorithm design. Each item consisted of five options with a single correct answer. Correct responses were awarded one point, while incorrect responses received zero points. An example of a multiple-choice item used to assess computational thinking is provided in Table 3 (Román-González et al., 2016). Both instruments were reviewed by three experts to ensure content accuracy and alignment with the intended constructs. Construct validation was conducted with a sample

of 34 eighth-grade students who had previously studied ecology. The content validity of the essay test was examined using the Pearson product-moment correlation, while the multiple-choice test was validated using the point-biserial correlation. Reliability was assessed using Cronbach's alpha for the critical thinking test and the Kuder-Richardson Formula 20 (KR-20) for the computational thinking test (Choirunnisya' & Sudira, 2021; Hidayati et al., 2023; Ramadhan et al., 2024; Setyaedhi, 2024; Sutrimah et al., 2019).

**Table 2**  
Critical Thinking Skills Instrument

Component	Description
Topic	Ecology
Sub-topic	Biodiversity and energy flow in forest ecosystems (food chains, ecological pyramids, and food webs in forest ecosystems)
Prior Competency	Analyzing interactions among components of an ecosystem
Learning Objective	Students will be able to analyze the relationships among organisms within food chains and food webs in forest ecosystems and construct ecological pyramids (numbers, biomass, energy) based on one of the identified food chains.
Indicators of Learning Achievement	<ol style="list-style-type: none"> <li>Identify trophic levels within a food chain in a forest ecosystem</li> <li>Construct pyramids of numbers, biomass, and energy based on the selected food chain</li> <li>Develop a food web by integrating multiple interacting food chains</li> <li>Explain the roles of producers, consumers, and decomposers in maintaining ecological balance</li> </ol>
Cognitive Level (Bloom's Taxonomy)	<ol style="list-style-type: none"> <li>Analyze (C4): Analyze food chains and relationships among organisms</li> <li>Create (C6): Construct food webs from multiple food chains</li> </ol>
Critical Thinking Skills Indicators (Facione, 2015)	<ol style="list-style-type: none"> <li>Analysis</li> <li>Explanation</li> </ol>
Sub-indicators of Critical Thinking Skills (Facione, 2015)	<ol style="list-style-type: none"> <li>Identify relationships among information (organisms in the food chain)</li> <li>Explain the processes and reasoning underlying the formation of ecological pyramids and food webs</li> </ol>
Question	<p>Biodiversity in forests is exceptionally high, leading to numerous complex food chains. This is particularly evident in tropical rainforests, where interactions are both diverse and dynamic. Below are examples of food chains commonly found in forest environments:</p> <p>Food Chain 1: Sunlight → Grass → Goat → Tiger → Decomposer            Food Chain 2: Sunlight → Forest Plants → Deer → Tiger → Decomposer            Food Chain 3: Sunlight → Grass → Grasshopper → Frog → Snake → Decomposer</p> <p>Tasks:</p> <ol style="list-style-type: none"> <li>Based on one of the food chains above, construct diagrams of the following: a pyramid of numbers, a pyramid of biomass, and a pyramid of energy.</li> <li>Using the organisms provided in the food chains, develop a comprehensive food web representing their interactions.</li> </ol>

**Table 3**  
Computational Thinking Skills Instrument

Component	Description
Topic	Ecology
Sub-topic	Ecosystems and population dynamics (predator-prey relationships and competition among species)
Prior Competency	Understanding basic concepts of reproduction, predator-prey dynamics, and ecological interactions such as competition and mutualism.
Learning Objective	Students will be able to analyze population interactions between species and predict ecological outcomes based on reproduction rates and resource availability.
Indicators of Learning Achievement	<ol style="list-style-type: none"> <li>Explain and predict population dynamics based on reproduction rate and competition</li> <li>Identify and evaluate types of interspecies interactions</li> </ol>
Cognitive Level (Bloom's Taxonomy)	Analyze (C4): Students interpret the relationship between reproduction rates and ecological outcomes.

**Table 3**

## Computational Thinking Skills Instrument

Component	Description
Computational Thinking Skills Indicators (Wing, 2008)	Pattern recognition
Sub-indicators of Computational Thinking Skills (Wing, 2008)	Identify patterns in species reproduction rates and their influence on population dynamics.
Question	<p>A culture of algae is inoculated with a small number of two different species of ciliated protozoa, Protozoa A and Protozoa C, both of which feed on the algae. Protozoa A reproduces asexually every hour, while Protozoa C reproduces asexually every 1.5 hours, assuming an unlimited supply of algae. Which of the following statements is most likely to be observed?</p> <p>a. The protozoa will develop a mutualistic relationship with the algae</p> <p>b. Both protozoa populations will increase in number, then Protozoa C will disappear from the culture</p> <p>c. The algae will evolve quickly to develop mechanisms to avoid predation</p> <p>d. The algae will disappear from the culture due to over predation</p> <p>e. The protozoa will evolve the ability to reproduce more quickly</p>

**Procedure**

The research was conducted in two main phases: the development and validation of the learning media and instruments, and the implementation of the learning intervention. In the first phase, the digital storytelling media and assessment instruments were designed and validated through expert review. Subsequently, empirical validation was conducted with a sample of 34 eighth-grade students to ensure that the instruments were suitable for measuring the targeted thinking skills. During the implementation phase, 120 seventh-grade students were divided into two groups. The control group received instruction through interactive PowerPoint presentations, whereas the experimental group was taught using digital storytelling media. Both groups followed a guided inquiry model that involved structured questioning, exploration of ecological concepts, data interpretation, and guided conclusion formulation (Román-González et al., 2016). The lessons were delivered over three sessions, each lasting 40 minutes. A pre-test was administered before the intervention, and a post-test was conducted after the final session to assess changes in students' critical and computational thinking skills (Jannah et al., 2024).

**Data Analysis Techniques**

The study employed both descriptive statistics and Multivariate Analysis of Variance (MANOVA) to provide a comprehensive understanding of the data and to test the research hypotheses. Descriptive statistics served as a crucial preliminary step, summarizing students' performance levels before and after the introduction of the digital storytelling media. By examining measures of central tendency (mean) and dispersion (range, standard deviation, and variance), along with frequency distributions, the analysis offered a clear depiction of how students' skills were distributed across conditions. These descriptive insights identified general trends and potential differences in learning outcomes, thereby setting the foundation for inferential testing (Hasim et al., 2024). The use of MANOVA was particularly appropriate for this study, as it involved multiple dependent variables representing various aspects of students' skills. This multivariate approach provided a more holistic assessment of the impact of digital storytelling, determining whether the learning media exerted a collective influence on students' skill dimensions rather than producing isolated effects. Prior to conducting the MANOVA, the researchers verified nine key assumptions, including multivariate normality, linearity, homogeneity of variance-covariance matrices, absence of multicollinearity, and independence of observations. All assumptions were satisfactorily met, thereby enhancing the credibility and robustness of the analysis, as any violations could have resulted in biased estimates or misleading conclusions. Meeting these conditions ensured that the MANOVA results could be interpreted with confidence and that any significant effects reflected genuine group differences attributable to the implementation of digital storytelling media rather than statistical artifacts. Overall, the combined use of descriptive and multivariate analyses enabled both a comprehensive summary of student performance and a rigorous inferential test of the intervention's effectiveness. This methodological rigor strengthens the study's conclusions regarding

the educational benefits of digital storytelling and supports its potential for broader application in instructional contexts (De Santis et al., 2024).

## RESULTS AND DISCUSSION

This study resulted in the development of digital storytelling-based learning media, accompanied by evaluation tools that include assessments of critical and computational thinking skills. These components were meticulously designed to align with ecology learning objectives and to effectively measure students' competencies, which are essential for meeting educational standards (York et al., 2015). The digital storytelling media integrates multiple elements that support students' holistic skill development, including learning content, summaries, ecologist profiles, research articles, case studies, virtual laboratories with interactive worksheets, question banks, glossaries, and references. The learning content consists of two main components: learning information and learning materials. Learning information includes learning outcomes, learning objectives, and concept maps, whereas the learning materials are presented through a combination of storytelling and interactive multimedia that integrates text, digital graphics, animated videos, voice narration, and music. These elements are cohesively designed to convey ecological concepts within a structured and time-efficient framework (Mayer, 2021). The summary section simplifies complex ecological concepts without diminishing their scientific integrity, thereby making them more accessible to students (Tarigan et al., 2023). Ecologist profiles highlight key contributors to the field of ecology, while research articles present contemporary issues related to ecosystems. By engaging with and analyzing these articles, students enhance their critical and computational thinking skills, particularly in evaluating arguments, analyzing data, and interpreting scientific evidence on ecosystem-related issues (Musah & Wangila, 2024; Palop et al., 2025). In the case study section, students examine real-world ecological problems and develop evidence-based solutions, which they subsequently present through digital storytelling (Dibia, 2023).

The virtual laboratories are supported by interactive worksheets hosted on the Liveworksheets application, which include tasks such as observing environmental components, analyzing organism interactions, and studying population dynamics. These worksheets follow a guided inquiry model structured through stages of orientation, problem formulation, hypothesis development, experimentation, data analysis, and conclusion, an approach specifically designed to foster both critical and computational thinking (Riskayanti, 2023). Additionally, educational games are incorporated to promote abstract thinking and reinforce computational concepts within ecological contexts (Saidin et al., 2021). Students' responses are automatically submitted to the teacher's account and assessed by the system, thereby reducing the burden of manual grading (Widodo, 2021). The question bank comprises multiple-choice questions covering cognitive domains from C1 to C6, designed to assess critical and computational thinking skills such as prediction, inference, and experimental or model design. These questions are completed individually and graded automatically. The glossary provides definitions of key ecological terms, while the references section lists all sources used in developing the digital storytelling-based learning media (Javed et al., 2025).

A high-quality learning product must satisfy two key criteria: validity (the alignment of content with measurement objectives) and reliability (the consistency of measurement results). When instruments demonstrate both, they can be effectively employed to assess critical and computational thinking skills (Putri et al., 2023). To ensure quality, the instruments and digital storytelling-based media were validated by three expert evaluators. The average validation scores for the digital storytelling media were 74.28% for language, 77% for content, and 80% for design. Meanwhile, the assessment instruments for critical and computational thinking skills obtained an average score of 77%, indicating that both the media and instruments were valid (Mawarni et al., 2022), feasible (Athifah et al., 2022), and practical for classroom implementation (Hodiyanto et al., 2020). Content validity testing revealed that 18 out of 36 items in the critical thinking test were valid, while the remaining 18 were invalid. For the computational thinking test, 40 out of 60 items were valid and 20 were invalid. Reliability analysis produced coefficients of 0.83 for critical thinking and 0.89 for computational thinking, both classified as very high, signifying strong internal consistency. Overall, the digital storytelling media and associated assessment instruments met the quality standards required for both research and instructional purposes (Putrawan, 2022).

Evaluation in ecology learning was conducted using pre-tests and post-tests to assess students' critical and computational thinking skills. The pre-test established a baseline of students' abilities before the learning intervention, whereas the post-test measured the development of these competencies

afterward. The results for both the control and experimental groups are presented in Table 4, with a detailed analysis of each skill indicator provided in Tables 5 and 6 (Mukti & Istiyono, 2018).

**Table 4**  
Students' Critical and Computational Thinking Skills Results

Description	Class Group	Critical Thinking Skills		Computational Thinking Skills	
		Pre-test	Post-test	Pre-test	Post-test
Total	Control	2272	5320	1,287.50	5,087.50
	Experimental	2537	5325	1,637.50	5,122.50
Average	Control	38	89	21.45	84.79
	Experimental	42	89	27.29	85.37
Range	Control	31-46	78-99	5-35	72.5-100
	Experimental	36-50	79-100	7.5-65	72.5-100
Standard Deviation	Control	3	4	8.15	7.38
	Experimental	3	4	11.77	7.75
Variance	Control	12	17	66.49	54.51
	Experimental	12	15	138.64	60.10

The results presented in Table 4 indicate a substantial improvement in both critical and computational thinking skills among students in the control and experimental groups. In the control group, critical thinking scores increased from 38 to 89, while in the experimental group, they rose from 42 to 89, demonstrating that the learning process effectively enhanced students' ability to analyze, evaluate, and reflect on ecological concepts (Alshaye, 2021). Similarly, computational thinking scores improved from 21.45 to 84.79 in the control group and from 27.29 to 85.37 in the experimental group, suggesting that students became more proficient in problem-solving, logical reasoning, and engaging with complex material (Erwinsyah et al., 2025; Zhang & Savard, 2023). Although both groups achieved comparably high final scores, the experimental group demonstrated greater consistency. Their lower standard deviation and variance indicate that most students improved at a similar rate, suggesting that the digital storytelling approach fostered a more uniform learning experience across varying ability levels. This consistency may be attributed to the multimodal and narrative-based nature of digital storytelling. Narratives provide a coherent storyline that enables learners to construct stable mental models for understanding complex ecological interactions. By integrating abstract concepts into meaningful sequences, this approach helps reduce cognitive overload. Moreover, its multimodal design combining visual, auditory, and textual elements addresses diverse learning styles and promotes more equitable comprehension (Chelghoum, 2017). While both instructional methods yielded positive learning outcomes, digital storytelling offered distinct cognitive and affective advantages. Unlike interactive PowerPoint presentations, which often fragment information into discrete bullet points, digital storytelling organizes content in a temporal and contextual sequence. Through a coherent narrative, students can trace cause-and-effect relationships, explore character motivations, and comprehend ecological processes more holistically. This approach supports situated cognition, wherein learning occurs within meaningful and authentic contexts (Anggeraini & Afifah, 2017; Hung et al., 2012; Parsazadeh et al., 2020; Smeda et al., 2014; Yang & Wu, 2012). In addition, the storytelling format requires students to actively interpret and reconstruct meaning, thereby fostering metacognitive engagement. The process of creating or evaluating stories enhances evaluative reasoning, reflective thinking, and the synthesis of information from multiple sources. Consequently, digital storytelling not only deepens conceptual understanding but also cultivates emotional engagement and higher-order thinking, surpassing the surface-level interaction typical of traditional multimedia lectures (Lai & Hwang, 2014; Lee, 2015; Quines, 2017; Sahibzada et al., 2020).

**Table 5**  
Students' Critical Thinking Skills by Indicator

Numb.	Indicator	Control Group		Experimental Group	
		Pre-test	Post-test	Pre-test	Post-test
1.	Interpretation	43.19	86.94	38.61	88.75
2.	Analysis	37.50	88.33	40.00	86.25
3.	Inference	37.63	87.50	44.02	88.47
4.	Evaluation	37.77	89.16	44.86	90.69
5.	Explanation	34.02	89.30	41.94	88.47
6.	Self-regulation	36.94	90.27	44.16	89.44
	<b>Average</b>	<b>37.84</b>	<b>88.58</b>	<b>42.26</b>	<b>88.68</b>

**Table 6**

Students' Computational Thinking Skills by Indicator

Numb.	Indicator	Control Group		Experimental Group	
		Pre-test	Post-test	Pre-test	Post-test
1.	Decomposition	22.22	85.83	25.14	89.72
2.	Pattern recognition	20.64	83.41	24.05	86.17
3.	Abstraction	21.03	85.58	22.58	83.14
4.	Algorithm	21.20	84.40	21.62	83.89
	Average	21.27	84.81	23.35	85.73

Tables 5 and 6 indicate a significant improvement in students' critical and computational thinking skills across both the control and experimental groups. Regarding critical thinking, both groups demonstrated substantial progress across all six indicators. The control group's mean score increased from 37.84 in the pre-test to 88.58 in the post-test, while the experimental group's mean rose from 42.26 to 88.68. Although both groups achieved nearly identical post-test scores, the experimental group's slightly higher pre-test performance suggests a stronger initial understanding. Among all aspects of critical thinking, the indicator of evaluation exhibited the most substantial improvement, reflecting a marked enhancement in students' higher-order cognitive processes. This skill entails the capacity to make reasoned judgments, appraise evidence, and justify decisions based on established criteria and standards. In an educational context, it transcends the mere recall or application of knowledge, requiring learners to analyze the validity, reliability, and relevance of information before concluding. The significant gains observed suggest that students not only became more proficient in understanding and analyzing concepts but also developed the intellectual maturity to critically assess arguments and construct informed judgments (Dewi et al., 2019; Mardiana et al., 2025). The pronounced improvement in evaluation can also be attributed to the interactive and reflective nature of digital storytelling. Unlike traditional teaching methods, digital storytelling actively engages students in creating and interpreting multimedia narratives, prompting them to continuously assess the quality and coherence of their own work. This process involves iterative decision-making, the selection of appropriate media, the logical organization of content, and ensuring that the narrative aligns with intended learning objectives. Each of these tasks requires evaluative thinking, as students must weigh alternatives, justify their choices, and consider the impact of their decisions on the final product (Hidayah et al., 2017; Putri et al., 2019). Furthermore, the findings suggest that evaluation serves as an integrative skill connecting other dimensions of critical thinking, such as analysis, inference, and interpretation, into a cohesive cognitive framework. As students synthesize knowledge from multiple sources and perspectives through storytelling, they become more adept at identifying inconsistencies, recognizing biases, and constructing coherent arguments. This integrative process reflects the transition from surface-level understanding to deep learning, whereby students internalize concepts and apply them both critically and creatively (Agnafia, 2019). The notable improvement in evaluation underscores digital storytelling's capacity to promote analytical judgment, reflective inquiry, and intellectual autonomy. By positioning students as creators and evaluators of knowledge rather than passive recipients, this approach cultivates the essence of higher-order thinking: critical discernment, logical reasoning, and the ability to make informed, evidence-based decisions (Papathanasiou et al., 2014; Smyrnaiou et al., 2020).

Similarly, students' computational thinking skills improved markedly in both groups. The control group's mean increased from 21.27 to 84.81, while the experimental group's mean rose from 23.35 to 85.73. The largest gain occurred in decomposition, particularly among students in the experimental group. These findings indicate that both instructional methods were effective in enhancing thinking skills; however, the digital storytelling approach facilitated more consistent and slightly higher improvements in several key dimensions. This suggests that digital storytelling enhances student engagement and promotes deeper conceptual understanding, particularly in tasks involving critical evaluation and problem-solving (Metin et al., 2025). Digital storytelling supports the development of decomposition skills the ability to break complex problems into smaller, more manageable components. Each sub-problem is analyzed, solved, and evaluated independently, enabling clearer understanding and more effective solution design. Through this process, students learn to adapt previous strategies to new contexts, improving flexibility and efficiency. Recognizing patterns, identifying relationships, and

discerning differences among problems become essential elements of this skill. By structuring problems into sequential steps, students cultivate both logical reasoning and creative problem-solving abilities (Shute et al., 2017). Computational thinking promotes systematic, structured, and innovative approaches to learning, encouraging learners to become active constructors of knowledge rather than passive recipients. Moreover, the integration of digital storytelling appears to bridge the cognitive and affective domains of learning. The narrative element inherent in storytelling provides context and meaning, making abstract computational concepts more accessible and relatable. When students design and narrate their own digital stories, they engage in a process that requires not only technical proficiency but also reflection, communication, and collaboration. This multimodal approach aligns with constructivist learning theories, wherein knowledge is built through active exploration and social interaction.

The collaborative and reflective dimensions of storytelling may therefore enhance metacognitive awareness, as students become more conscious of their problem-solving strategies and decision-making processes (Kearney, 2011). Additionally, digital storytelling fosters creativity and innovation qualities increasingly recognized as integral to computational thinking. By blending narrative composition with digital design, students are encouraged to think critically about how to represent problems and solutions both visually and conceptually. This process nurtures divergent thinking, whereby multiple solutions are explored and evaluated. Such experiences deepen students' understanding of algorithmic thinking and abstraction, two other essential dimensions of computational thinking. Another notable implication of these findings concerns the motivational aspect of storytelling-based learning. Students often perceive storytelling as a personally meaningful activity, which can enhance intrinsic motivation and sustained engagement. When learning tasks are contextualized within authentic narratives, students are more likely to perceive them as relevant and worthwhile. This emotional investment may partially explain the experimental group's higher and more consistent gains across dimensions (Corradini et al., 2017; Niemi et al., 2018). Overall, the findings underscore the pedagogical potential of digital storytelling as an effective approach to fostering both critical and computational thinking. By engaging students in reflective, creative, and problem-oriented learning experiences, digital storytelling bridges the cognitive, affective, and social dimensions of learning. This approach not only enhances students' analytical and evaluative abilities but also nurtures their capacity for systematic problem-solving and innovative thinking. For educators, these results highlight the importance of integrating narrative-based digital activities into instructional design to promote deeper learning and sustained engagement. Future implementations should emphasize collaboration, reflection, and iterative creation, enabling students to develop transferable thinking skills applicable across disciplines and real-world contexts (Bilici & Yilmaz, 2024; Maulana et al., 2021). Table 7 presents the results of multivariate tests used to examine the effect of the class variable on the dependent variables simultaneously.

**Table 7**  
Multivariate Tests Results

	Test Statistic	value	F	df1	df2	p
Control and experiment	Pillai's Trace	0.077	3.52	2	117	0.033
	Wilks' Lambda	0.923	3.52	2	117	0.033
	Hotelling's Trace	0.083	3.52	2	117	0.033
	Roy's Largest Root	0.077	3.52	2	117	0.033

Table 7 presents the results of four multivariate statistical tests (Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root) used to evaluate whether statistically significant differences existed between the control and experimental groups across multiple dependent variables (in this case, critical and computational thinking skills). All four tests yielded identical F-values of 3.52 and a p-value of 0.033. This consistency across the different statistical tests strengthens the reliability of the findings. Since the p-value is smaller than the commonly accepted significance level of 0.05, it can be concluded that a statistically significant difference exists between the two groups when the dependent variables are considered jointly. In practical terms, this finding indicates that the learning approach applied to the experimental group had a measurable and meaningful impact compared with the approach used for the control group. The use of multivariate testing is particularly important in this context because it enables the simultaneous analysis of multiple outcomes rather than examining each dependent variable in isolation. This method captures the combined effects of the intervention on interrelated cognitive skills (Tabachnick & Fidell, 2025). The results show that, although both groups experienced improvement

following the learning activities, the experimental group which received the digital storytelling intervention demonstrated a significantly greater increase in both critical and computational thinking skills. The study therefore provides strong evidence that digital storytelling-based media are effective in enhancing students' critical and computational thinking skills in ecology learning. The improvement observed is not only quantitative (reflected in higher scores) but also qualitative, encompassing more consistent performance, deeper conceptual understanding, and stronger engagement (Pituch & Stevens, 2015). The narrative coherence and multimodal features of digital storytelling help bridge abstract ecological concepts with students' lived experiences, leading to both cognitive and affective learning gains. These findings reinforce prior research demonstrating that storytelling enhances higher-order thinking and conceptual understanding. Consequently, digital storytelling can be regarded as an innovative, equitable, and theory-grounded instructional approach that supports the goals of contemporary education, cultivating learners who can think critically, reason computationally, and engage meaningfully with real-world ecological challenges (Hair et al., 2018).

## CONCLUSION

This study demonstrates that digital storytelling-based learning media are valid, feasible, practical, and highly effective in enhancing students' critical and computational thinking skills in ecology learning. Compared with interactive PowerPoint presentations, the digital storytelling approach produced significantly greater gains in higher-order cognitive processes, particularly in evaluation and decomposition, thereby confirming its value as an innovative pedagogical strategy aligned with the demands of twenty-first-century education. From a practical perspective, the findings suggest that teachers and curriculum designers can integrate digital storytelling into science instruction by developing narrative-driven multimedia materials that combine ecological content with guided inquiry-based activities. Successful implementation requires access to appropriate digital tools (e.g., video editing software, animation platforms, and interactive worksheet applications) as well as targeted professional development to strengthen teachers' Technological Pedagogical Content Knowledge (TPACK) and their capacity to design and facilitate digital narratives effectively. Moreover, schools should ensure adequate technological infrastructure, including computers, reliable internet connectivity, and multimedia equipment to support seamless integration. Despite these promising outcomes, the study is limited by its relatively small sample size, confinement to a single school, short intervention duration, and the specific cultural and curricular context in which it was conducted. These factors may constrain the generalizability of the findings. Future research should therefore examine the long-term effects of digital storytelling on learning outcomes, its applicability across diverse subjects and educational levels, and students' affective responses and perceptions of this approach. Broadening such investigations will provide a more comprehensive understanding of how narrative-based digital pedagogy can be scaled and adapted to foster critical and computational thinking across varied learning environments.

## ACKNOWLEDGMENT

My deepest gratitude and highest appreciation are extended to the expert validators for their willingness to serve as respondents in evaluating and providing valuable feedback on the developed product. We would also like to express my sincere thanks to the principal and science teachers of a public Islamic junior high school in Bekasi, Indonesia, for granting permission to conduct this research, as well as to all the students who participated in the product implementation.

## REFERENCES

- Abdullah, A., & Mahmud, S. N. D. (2024). Applying TPACK in STEM education towards 21-st century: Systematic literature review. *International Journal of Academic Research in Progressive Education and Development*, 13(1), 1014-1032. <https://doi.org/10.6007/IJARPED/v13-i1/20667>
- Agnafia, D. N. (2019). Analisis kemampuan berpikir kritis siswa dalam pembelajaran ekologi. *Florea (Jurnal Biologi Dan Pembelajarannya)*, 6(1), 45-53. <https://doi.org/10.25273/florea.v6i1.4369>
- Alkharusi, H. A., Sulaimani, H. A., & Neisler, O. (2019). Predicting critical thinking ability of Sultan Qaboos University Students. *International Journal of Instruction*, 12(2), 491-504. <https://doi.org/10.29333/iji.2019.12231a>
- Alshaye, S. (2021). Digital storytelling for improving critical reading skills, critical thinking skills, and self-regulated learning skills. *Cypriot Journal of Educational Sciences*, 16(4), 2049-2069.

<https://doi.org/10.18844/cjes.v16i4.6074>

- Andriopoulou, A., Giakoumi, S., Kouvarda, T., Tsabaris, C., Pavlatou, E., & Scoullou, M. (2022). Digital storytelling as an educational tool for scientific, environmental and sustainable development literacy on marine litter in informal education environments (Case study: Hellenic Center for Marine Research). *Mediterranean Marine Science*, 23(2), 327-337. <https://doi.org/10.12681/mms.26942>
- Anggeraini, Y., & Afifah, N. (2017). Digital storytelling as a teaching medium in reading classroom. *Journal of Language and Literature*, 12(1), 83-89. <https://doi.org/10.15294/lc.v12i1.11472>
- Athifah, N., Zain, M. I., & Ermiana, I. (2022). Pengembangan media pembelajaran pop-up book pada pembelajaran Bahasa Indonesia materi pantun. *Journal of Classroom Action Research*, 4(3), 187-195. <https://doi.org/10.29303/jcar.v4i3.2063>
- Bilici, S., & Yilmaz, R. M. (2024). The effects of using collaborative digital storytelling on academic achievement and skill development in biology education. *Educ Inf Technol*, 29, 20243-20266. <https://doi.org/10.1007/s10639-024-12638-7>
- Chelghoum, A. (2017). Promoting students' self-regulated learning through digital platforms: New horizon in educational psychology. *American Journal of Applied Psychology*, 6(5), 123-131. <https://doi.org/10.11648/j.ajap.20170605.17>
- Choirunnisya', L. R., & Sudira, P. (2021). Developing an e-module of making Edmodo-based Hosanna Moda system bustier to improve learning independence and learning achievement. *Jurnal Pendidikan Vokasi*, 11(3), 275-293. <https://doi.org/10.21831/jpv.v11i3.40196>
- Corradini, I., Lodi, M., & Nardelli, E. (2017). Conceptions and misconceptions about computational thinking among Italian primary school teachers. *Proceedings of ICER '17*, 9. <https://doi.org/10.1145/3105726.3106194>
- Csizmadia, A., Curzon, P., Dorling, M., Humphreys, S., Ng, T., Selby, C., & Woollard, J. (2015). *Computational thinking - a guide for teachers Swindon. Computing at School 18pp.* <http://eprints.soton.ac.uk/id/eprint/424545>
- Darwis, M., Lufri, L., Arnawa, I. M., Nasirsah, N., & Ritonga, E. N. (2025). Worldwide trends of ICT integration in ecology higher education: A bibliometric analysis of Scopus. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 11(3), 874-894. <https://doi.org/10.22219/jpbi.v11i3.42020>
- De Santis, A., Sannicandro, K., Bellini, C., & Minerva, T. (2024). Trends in the use of Multivariate Analysis in Educational Research: A review of methods and applications in 2018-2022. *Journal of E-Learning and Knowledge Society*, 20(1), 47-55. <https://doi.org/10.20368/1971-8829/1135946>
- Dewi, N. R., Maghfiroh, L., Nurkhalisa, L., & Dwijayanti, I. (2019). The development of contextual-based science digital storytelling teaching materials to improve students' critical thinking on classification theme. *Journal of Turkish Science Education*, 16(3), 364-378. <https://files.eric.ed.gov/fulltext/EJ1264925.pdf>
- Dibia, I. N. (2023). Penerapan model pembelajaran kooperatif jigsaw dengan metode diskusi interaktif untuk meningkatkan prestasi belajar biologi. *Jurnal Nalar: Pendidikan Dan Pembelajaran*, 2(1), 36-42. <https://doi.org/10.52232/jnalar.v2i1.26>
- Erwinsyah, A., Yusuf, F. M., Laliyo, L. A., Mursalin, & Riumkina, I. (2025). Research trends of computational thinking for advancing Sustainable Development Goals (SDGs) in science learning: Bibliometric analysis. *Jurnal Pendidikan IPA Indonesia*, 14(2). <https://doi.org/10.15294/jpii.v14i2.23645>
- Facione, P. A. (2015). *Critical thinking: What it is and why it counts. Insight Assessment.* Insight Assessment.
- Hair, J. F., Babin, B. J., Anderson, R., & Black, W. (2018). *Multivariate Data Analysis* (edition un). Cengage Learning EMEA. <https://www.perlego.com/book/2754480/multivariate-data-analysis-pdf>
- Hardanie, B. D., Inabuy, V., Sutia, C., Maryana, O. F. T., & Lestari, S. H. (2021). *Buku panduan guru ilmu pengetahuan alam untuk SMP kelas VII.* Pusat Kurikulum dan Perbukuan.
- Hasim, S. M., Rosli, R., & Halim, L. (2024). A quantitative case study of secondary school students' level of statistical thinking. *Eurasia Journal of Mathematics, Science and Technology Education*, 20(4), em2421. <https://doi.org/10.29333/ejmste/14358>
- Haşlamam, T., Mumcu, F. K., & Uslu, N. A. (2024). Fostering computational thinking through digital storytelling: A distinctive approach to promoting computational thinking skills of pre-service teachers. *Educ Inf Technol*, 29, 18121-18147. <https://doi.org/10.1007/s10639-024-12583-5>

- Hidayah, R., Salimi, M., & Susiani, T. S. (2017). Critical thinking skill: Konsep dan indikator penilaian. *Taman Cendekia: Jurnal Pendidikan Ke-SD-An*, 1(2), 127-133. <https://doi.org/10.30738/tc.v1i2.1945>
- Hidayati, R., Kusmanto, A. S., & Kiswanto, A. (2023). Development and construct validation of Indonesian students self-confidence scale using Pearson Product Moment. *Pegem Journal of Education and Instruction*, 13(3), 94-103. <https://doi.org/10.47750/pegegog.13.03.11>
- Hodiyanto., Darma, Y., & Putra, S. R. S. (2020). Pengembangan media pembelajaran berbasis macromedia flash bermuatan problem posing terhadap kemampuan pemecahan masalah matematis. *Mosharafa: Jurnal Pendidikan Matematika*, 9(2), 323-334. <https://doi.org/10.31980/mosharafa.v9i2.614>
- Husamah, H., Rahardjanto, A., Permana, T. I., & Lestari, N. (2025). Learning media for environmental education, what can the scopus database tell us? A review. *Al Jahiz: Journal of Biology Education Research*, 6(1), 93-114. <https://doi.org/10.32332/al-jahiz.v6i1.10401>
- Hung, C-M., Hwang, G-J., & Huang, I. (2012). A Project-based digital storytelling approach for improving students' learning motivation, problem-solving competence and learning achievement. *Journal of Educational Technology & Society*, 15(4), 368-379. <https://eric.ed.gov/?id=EJ992969>
- Husodo, T., Rosada, K. K., Fitriani, N., & Hewindati, Y. T. (2020). *Ekologi*. Universitas Terbuka.
- Jannah, N. D. K., Riandi, R., & Surtikanti, H. K. (2024). Studi literatur: Kajian pengembangan computational thinking dan critical thinking pada materi sains dan biologi untuk meningkatkan prestasi belajar. *Jurnal Penelitian Pendidikan*, 24(2), 238-246. <https://doi.org/10.17509/jpp.v24i2.73379>
- Javed, M. S., Aslam, M., & Khurshid, S. K. (2025). An intelligent model for parametric cognitive assessment of e-learning-based students. *Information*, 16(2), 93. <https://doi.org/10.3390/info16020093>
- Juanda, J., Djumingin, S., R, M., Afandi, I., & Intang, D. (2024). Ecoliteracy digital short stories among students in Indonesia. *Journal of Turkish Science Education*, 21(2), 254-270. <https://doi.org/10.36681/tused.2024.014>
- Kearney, M. (2011). A learning design for student-generated digital storytelling. *Learning, Media and Technology*, 36(2), 169-188. <https://doi.org/10.1080/17439884.2011.553623>
- Kortegast, C., & Davis, J. (2017). Theorizing the self: Digital storytelling, applying theory, and multimodal learning. *College Teaching*, 65(3), 106-114. <https://doi.org/10.1080/87567555.2016.1255584>
- Lai, C-L., & Hwang, G-J. (2014). Effects of mobile learning time on students' conception of collaboration, communication, complex problem-solving, meta-cognitive awareness and creativity. *International Journal of Mobile Learning and Organisation (IJMLO)*, 8(3/4). <https://doi.org/10.1504/IJMLO.2014.067029>
- Lee, Y. H. (2015). Facilitating critical thinking using the C-QRAC collaboration script: enhancing science reading literacy in a computer-supported collaborative learning environment. *Computers & Education*, 88, 182-191. <https://doi.org/10.1016/j.compedu.2015.05.004>
- Lim, P. R., & Md Noor, N. (2019). Digital storytelling as a creative teaching method in promoting secondary school students' writing skills. *International Journal of Interactive Mobile Technologies (ijim)*, 13(07), 117-128. <https://doi.org/10.3991/ijim.v13i07.10798>
- Mardiana, W., Alivi, J. S., Krisdiana, A., & Susanti, I. (2025). Cultivating Students' Critical Thinking and Collaboration: Literacy Practice in Digital Storytelling Project. *EBONY: Journal of English Language Teaching, Linguistics, and Literature*, 5(2), 289-302. <https://doi.org/10.37304/ebony.v5i2.21842>
- Maulana, C., Setyarini, S., & Wirza, Y. (2021). Implementation of digital storytelling in an online classroom to help promoting students' critical thinking. *Jurnal Pendidikan Bahasa*, 21(2), 263-270. [https://doi.org/10.17509/bs\\_jpbbsp.v21i2.44638](https://doi.org/10.17509/bs_jpbbsp.v21i2.44638)
- Mawarni, H., Sholahuddin, A., & Badruzsaufari, B. (2022). Validitas modul interaktif pembelajaran IPA untuk meningkatkan kemampuan berpikir kreatif. *Wahana-Bio: Jurnal Biologi Dan Pembelajarannya*, 14(1), 54-64. <https://doi.org/10.20527/wb.v14i1.13662>
- Mayarni, M., & Yulianti, Y. (2020). Hubungan antara kemampuan berpikir kritis dengan kemampuan berpikir kreatif siswa pada materi ekologi. *PENDIPA Journal of Science Education*, 4(3), 39-45. <https://doi.org/10.33369/pendipa.4.3.39-45>
- Mayer, R. E. (2021). *Multimedia learning* (2nd ed.). Cambridge University Press. <https://doi.org/10.1017/CBO9780511811678>
- Metin, Ş., Kalyenci, D., & Başaran, M. (2025). Design-based digital story program: Enhancing coding and

- computational thinking skills in early childhood education. *Early Childhood Educ J*, 53, 2255-2274. <https://doi.org/10.1007/s10643-024-01728-3>
- Mishra, P., & Koehler, M. J. (2016). *Handbook of Technological Pedagogical Content Knowledge (TPACK) for educators* (2nd ed.). <https://doi.org/10.4324/9781315771328>
- Mukti, T. S., & Istiyono, E. (2018). Instrumen penilaian kemampuan berpikir kritis peserta didik SMA Negeri mata pelajaran biologi kelas X. *BIOEDUKASI: Jurnal Pendidikan Biologi*, 11(2), 107-112. <https://doi.org/10.20961/bioedukasi-uns.v11i2.21624>
- Musah, E., & Wangila, C. (2024). Inquiry-based ethnoecological conservation approach to improve students' critical thinking skills. *International Journal of Ethnoscience and Technology in Education*, 1(2), 97-115. <https://doi.org/10.33394/ijete.v1i2.11240>
- Niemi, H., Niu, S., Vivitsou, M., & Li, B. (2018). Digital storytelling for twenty-first-century competencies with math literacy and student engagement in China and Finland. *Contemporary Educational Technology*, 9(4), 331-353. <https://doi.org/10.30935/cet.470999>
- Nurfauziyah, S., Marjono, M., & Sugiharto, B. (2015). Implementing guided inquiry to improve curiosity of student learning in biology of class XI IPA SMA Al Muayyad academic year 2014/2015. *Seminar Nasional XII Pendidikan Biologi FKIP Universitas Sebelas Maret*, 12(1), 235-239. <https://jurnal.uns.ac.id/prosbi/article/view/6752>
- OECD. (2021). *21st-century readers: Developing literacy skills in a digital world*. OECD Publishing. <https://doi.org/10.1787/a83d84cb-en>
- Palop, B., Díaz, I., & Rodríguez-Muñiz, L. J. (2025). Redefining computational thinking: A holistic framework and its implications for K-12 education. *Education and Information Technologies*, 30, 13385-13410. <https://doi.org/10.1007/s10639-024-13297-4>
- Papathanasiou, I. V., Kleisariis, C. F., Fradelos, E. C., Kakou, K., & Kourkouta, L. (2014). Critical thinking: The development of an essential skill for nursing students. *ACTA INFORM MED*, 22(4), 283-286. <https://doi.org/10.5455/aim.2014.22.283-286>
- Parsazadeh, N., Cheng, P., Wu, T., & Huang, Y. (2020). Integrating Computational Thinking Concept into Digital Storytelling to Improve Learners' Motivation and Performance. *Journal of Educational Computing Research*, 59(3), 470-495. <https://doi.org/10.1177/0735633120967315>
- Pituch, K. A., & Stevens, J. P. (2015). *Applied multivariate statistics for the social sciences: Analyses with SAS and IBM's SPSS* (Sixth Edit). <https://doi.org/10.4324/9781315814919>
- Putra, R. R., & Fitrihidajati, H. (2022). Validitas e-book terintegrasi hands on (homo) pada materi ekologi untuk melatih keterampilan berpikir kritis siswa kelas X SMA. *Berkala Ilmiah Pendidikan Biologi (BioEdu)*, 11(1), 116-126. <https://doi.org/10.26740/bioedu.v11n1.p116-126>
- Putrawan, I. M. (2022). *Prinsip prinsip logis metodologi penelitian kuantitatif*. CV.
- Putri, I. G. A. P. E. (2018). Critical environmental education in tertiary English language teaching (ELT): A collaborative digital storytelling project. *Indonesian Journal of Applied Linguistics*, 8(2), 336-344. <https://doi.org/10.17509/ijal.v8i2.13280>
- Putri, O. D., Nevrita, N., & Hindrasti, N. E. K. (2019). Pengembangan instrumen penilaian keterampilan berpikir kritis siswa SMA pada materi sistem pencernaan. *BIOEDUKASI: Jurnal Pendidikan Biologi*, 10(1), 14-27. <https://doi.org/10.24127/bioedukasi.v10i1.2004>
- Putri, Z. F., & Fauza, N. (2023). Validitas dan reliabilitas butir soal berbasis kemampuan berpikir kritis. *Jurnal Pendidikan Fisika*, 12(1), 28-34. <https://doi.org/10.24114/jpf.v12i1.42833>
- Quines, E. (2017). Effectiveness of Cooperative Learning Approach in Developing Critical Thinking Skills of Secondary Students. In T. G. & C. S (Eds.), *Empowering 21st Century Learners Through Holistic and Enterprising Learning*. Springer. [https://doi.org/10.1007/978-981-10-4241-6\\_12](https://doi.org/10.1007/978-981-10-4241-6_12)
- Ramadhan, M. F., Siroj, R. A., & Afgani, M. W. (2024). Validitas and Reliabilitas. *Journal on Education*, 6(2), 10967-10975. <https://doi.org/10.31004/joe.v6i2.4885>
- Riskayanti, D. (2023). Pengaruh model pembelajaran inkuiri terbimbing terhadap kemampuan pemecahan masalah dan hasil belajar kognitif siswa biologi kelas XI SMA. *Biocaster: Jurnal Kajian Biologi*, 3(1), 20-39. <https://doi.org/10.36312/bjkb.v3i1.156>
- Román-González, M., Pérez-González, J., & Jiménez-Fernández, C. (2016). Which cognitive abilities underlie computational thinking? Criterion validity of the computational thinking test. *Computers in Human Behavior*. <https://doi.org/10.1016/j.chb.2016.08.047>
- Rosyid, A., Fauzia, N., Darma, D. B., Abida, F. I. N., & Iye, R. (2025). The impact of digital storytelling applications on enhancing critical thinking abilities in higher education students. *Room of Civil Society Development*, 4(1), 79-89. <https://doi.org/10.59110/rcsd.497>

- Sahibzada, J., Ahmadzai, Y. M. B., Niaz, A., & Laftah, S. H. (2020). Effects of Storytelling on Improving EFL Students' Critical Thinking and Reading Comprehension. *American International Journal of Social Science Research*, 5(1), 33–47. <https://doi.org/10.46281/aijssr.v5i1.485>
- Saidin, N. D., Khalid, F., Martin, R., Kuppasamy, Y., & Munusamy, N. A. P. (2021). Benefits and challenges of applying computational thinking in education. *International Journal of Information and Education Technology*, 11(5), 248–254. <https://doi.org/10.18178/ijiet.2021.11.5.1519>
- Setyaedhi, H. S. (2024). Comparative Test of Cronbach's Alpha Reliability Coefficient, Kr-20, Kr-21, And Split-Half Method. *Journal of Education Research and Evaluation*, 8(1), 47–57. <https://doi.org/10.23887/jere.v8i1.68164>
- Siddique, M. Q. & Khan, W. N. (2024). Digital storytelling and interactive media as tools for environmental education. *Journal of Jurivox*, 1(1), 53–63. <https://researchcorridor.org/index.php/jj/article/view/168>
- Shute, V. J., Sun, C., & Asbell-Clarke, J. (2017). Demystifying computational thinking. *Educational Research Review*, 22, 142–158. <https://doi.org/10.1016/J.EDUREV.2017.09.003>
- Smeda, N., Dakich, E., & Sharda, N. (2014). The effectiveness of digital storytelling in the classrooms: a comprehensive study. *Smart Learning Environments*, 1, 6. <https://doi.org/10.1186/s40561-014-0006-3>
- Smyrnaiou, Z., Georgakopoulou, E., & Sotiriou, S. (2020). Promoting a mixed-design model of scientific creativity through digital storytelling—the CCQ model for creativity. In *IJ STEM* (7th ed., Vol. 7). <https://doi.org/10.1186/s40594-020-00223-6>
- Sutrimah, W., R., W., E., N., & Ngadiso. (2019). Evaluating the Use of Modern Indonesian Literary History Textbook (Poetry in East Java) in Teaching Literary History Course. *International Journal of Instruction*, 12(3), 1–16. <https://doi.org/10.29333/iji.2019.1231a>
- Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed.). Pearson International. <https://elibrary.pearson.de/book/99.150005/9781292034546>
- Tabachnick, B. G., & Fidell, L. S. (2025). Multivariate Analysis of Variance (MANOVA. In M. Lovric (Ed.), *International Encyclopedia of Statistical Science*. Springer. [https://doi.org/10.1007/978-3-662-69359-9\\_398](https://doi.org/10.1007/978-3-662-69359-9_398)
- Tarigan, W. P. L., Sipahutar, H., & Harahap, F. (2023). The impact of an interactive digital learning module on students' academic performance and memory retention. *Computers and Children*, 2(2), 4. <https://doi.org/10.29333/cac/13654>
- Uribe-Enciso, O. L., Uribe-Enciso, D. S., & Vargas-Daza, M. D. P. (2017). Critical thinking and its importance in education: Some reflections. *Rastros Rostros*, 19(34), 78–88. <https://doi.org/10.16925/ra.v19i34.2144>
- Widodo, A. (2021). *Pembelajaran ilmu pengetahuan alam: Dasar-dasar untuk praktik*. UPI Press.
- Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, 49(3), 33–35. <https://doi.org/10.1145/1118178.1118215>
- Wing, J. M. (2008). Computational thinking and thinking about computing. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 366(1881), 3717–3725. <https://doi.org/10.1098/rsta.2008.0118>
- Wing, J. M. (2017). Computational thinking's influence on education. *Communications of the ACM*, 60(4), 33–35. <https://doi.org/10.1145/2998438>
- Yang, Y. C., & Wu, W. I. (2012). Digital storytelling for enhancing student academic achievement, critical thinking, and learning motivation: A year-long experimental study. *Computers & Education*, 59(2012), 339–352. <https://doi.org/10.1016/j.compedu.2011.12.012>
- York, T. T., Gibson, C., & Rankin, S. (2015). Defining and measuring academic succes. *Practical Assessment, Research & Evaluation*, 20(5), 1–20. <https://doi.org/10.7275/HZ5X-TX03>
- Zhang, Y., & Savard, A. (2023). Defining Computational Thinking as an Evident Tool in Problem Solving: Comparative Research on Chinese and Canadian Mathematics Textbooks. *ECNU Review of Education*, 6(4), 677–699. <https://doi.org/10.1177/20965311231158393>