Jupiter: Jurnal Pendidikan Terapan
Homepage : https://journal.diginus.id/jupiter/index
Email: jurnalpendidikanterapan@gmail.com

p-ISSN : 2985-3214; e-ISSN : 2964-3171
Jupiter, Vol. 4, No. 4, September 2026
Page 510-521

Development and Preliminary Evaluation of an Articulate Storyline-Based Food Chain Edugame for Supporting Fourth-Grade Students' Critical Thinking Skills

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ARTICLE INFO

Article history:
Submitted: September 16, 2026
Final Revised: Sept. 21, 2026
Accepted: September 29, 2026
Published: September 30, 2026

Keywords:
Articulate Storyline; Educational Game; Food Chain; Critical Thinking; Elementary Science Education.

ABSTRACT

Purpose: Development and preliminary evaluation of an Articulate Storyline-based food chain edugame were conducted to support fourth-grade students' critical thinking skills in elementary science learning. **Methods:** Research and Development (R&D) employed the ADDIE model. Research was conducted at SDN 1 Bogorejo, Blora Regency, Indonesia, during the second semester of 2025/2026. Participants comprised 31 fourth-grade students, with 15 students in the experimental group and 16 in the control group. A non-equivalent control group pretest–posttest design was used to evaluate effectiveness. Data were collected through expert validation and critical thinking tests. Pearson Product–Moment correlation and Cronbach's Alpha assessed instrument validity and reliability. Normality and homogeneity tests preceded hypothesis testing. Effectiveness was analyzed using N-Gain and an independent-samples *t*-test. **Findings:** Ten of 12 essay items met validity criteria, with a Cronbach's Alpha coefficient of 0.877. Expert validation produced an average score of 85%, indicating valid media. Mean pretest and posttest scores reached 22.33 and 34.27 in the experimental group and 22.13 and 26.94 in the control group. Mean N-Gain scores were 0.680 and 0.273, respectively. An independent-samples *t*-test indicated a significant difference in N-Gain scores ($t = -19.515$, $p < .001$). **Research Implications:** Articulate Storyline-based food chain edugames provide interactive media for supporting critical thinking development in elementary science education. **Originality:** Integration of food chain simulations, gamification, interactive challenges, quizzes, and immediate feedback constitutes the primary contribution.

Doi: https://doi.org/10.61255/jupiter.v4i4.2113

INTRODUCTION

Rapid advancements in digital technology have expanded opportunities for integrating innovative learning media into elementary education, particularly for supporting active learning and higher-order thinking skills (Cenita & De Guzman, 2023; Ahzari et al., 2024). Nevertheless, technology-based learning remains limited in some elementary classrooms. Needs analysis and classroom observations at SDN 1 Bogorejo, Blora Regency, indicated that science instruction was predominantly teacher-centered and relied heavily on textbooks and conventional teaching methods. Students consequently had limited opportunities to analyze relationships among scientific phenomena. Difficulties were particularly evident in food chain learning, including identifying ecological interactions, explaining energy flow, and evaluating environmental changes. Similar conditions have been reported in previous studies, which found that teacher-dominated instruction and limited use of interactive digital media can constrain the development of students' critical thinking skills in science learning (Wahyuni & Fitria, 2023; Moriska & Hanif, 2024).

Critical thinking represents an essential competency in twenty-first-century education because learners need to analyze information, evaluate evidence, formulate logical conclusions, and solve problems systematically. Science learning provides meaningful contexts for developing such competencies through interpretation of natural phenomena, construction of scientific explanations, and application of concepts to real-world situations (García-Carmona, 2024). Problem-based learning and collaborative inquiry have also been associated with higher-order thinking because students investigate authentic problems and evaluate alternative solutions (Loyens et al., 2023). Food chain topics provide particular opportunities for critical-thinking development because learners can examine ecological relationships, analyze energy transfer, predict environmental consequences, and evaluate interactions among ecosystem components. However, learning activities that emphasize factual recall may provide insufficient opportunities for analytical reasoning and problem-solving. Educational games offer an alternative learning approach by combining instructional content with interactive challenges, game mechanics, and immediate feedback. Digital game-based learning has demonstrated positive effects on cognitive, metacognitive, and affective-motivational

outcomes (Barz et al., 2024). A systematic review also indicated that game-based learning can support higher-order thinking through active engagement and decision-making (Wang et al., 2023). Gamification has additionally been associated with increased motivation and participation among elementary school students (Mohammed et al., 2024). Interactive learning experiences can encourage learners to construct knowledge through active engagement with problems, feedback, and the consequences of their decisions. Such characteristics are consistent with constructivist learning principles, which emphasize active knowledge construction through meaningful experiences and interaction.

Articulate Storyline provides technical features suitable for implementing interactive learning experiences, including animations, simulations, quizzes, branching scenarios, and gamification components. Previous research has demonstrated the potential of Articulate Storyline-based media for improving learning outcomes, problem-solving, conceptual understanding, and critical-thinking performance (Daryanes et al., 2023; Mulyawati et al., 2024). Game-based problem-solving environments have likewise supported reasoning, engagement, and complex problem-solving processes (Ke et al., 2024), while technology-supported interactive learning activities have demonstrated benefits for higher-order thinking, including critical thinking, reasoning, and reflective thinking (Zhan et al., 2023).

The existing literature indicates that Articulate Storyline and interactive digital media have already been investigated in relation to students' learning outcomes and critical thinking. Consequently, the research gap is not the use of Articulate Storyline itself, but the limited integration of food chain content, game mechanics, critical-thinking-oriented activities, and immediate feedback within a single interactive learning medium for elementary science. Previous studies have examined game-based features, collaborative problem-solving, and interactive learning environments as approaches for supporting critical thinking (Sun et al., 2023; Xu et al., 2023; Song & Cai, 2024). However, limited attention has been given to combining ecological food chain simulations with interactive game activities and critical-thinking tasks within an Articulate Storyline-based edugame for elementary students.

The developed edugame addresses this gap by integrating food chain simulations, interactive challenges, quizzes, gamification, contextual problem-solving, and immediate feedback. Each feature serves a specific instructional function. Food chain simulations allow students to examine ecological relationships and energy transfer; interactive challenges encourage analysis and decision-making; contextual problems facilitate application of scientific concepts; and immediate feedback provides opportunities for students to reconsider responses and refine their understanding. The design is also consistent with the Cognitive Theory of Multimedia Learning, which emphasizes meaningful processing of information presented through complementary verbal and visual representations. The combination of visual representations, narration, interactive tasks, and feedback is therefore intended to support active cognitive processing rather than passive information reception.

The integration of game-based activities with critical-thinking tasks also provides opportunities for learners to engage in analysis, inference, evaluation, and explanation during science learning. Gamification can support critical thinking and reflective reasoning through interactive learning experiences (Angelelli et al., 2023), while engagement in digital learning environments has been associated with higher-order thinking and problem-solving (J. Chen et al., 2023). The present study therefore emphasizes the instructional integration of these elements rather than claiming that individual components are novel.

Accordingly, the present study focuses on the development and preliminary evaluation of an Articulate Storyline-based food chain edugame for fourth-grade elementary students. The study aims to develop and preliminarily evaluate the validity and effectiveness of an Articulate Storyline-based food chain edugame in supporting fourth-grade students' critical thinking skills in science learning. The study contributes a digital learning medium that integrates food chain content, game-based activities, critical-thinking-oriented tasks, and immediate feedback within an interactive elementary science learning environment.

METHOD

Research Design

Research and Development (R&D) was employed using the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. The model was selected to provide a systematic framework for developing and evaluating an Articulate Storyline-based food chain edugame. The development process focused on identifying learning needs, designing the learning media, developing and validating the product, implementing the product in classroom learning, and evaluating its validity and effectiveness.

The effectiveness of the developed edugame was evaluated during the implementation stage using a quasi-experimental approach with a non-equivalent control group pretest–posttest design. The experimental and control groups completed a pretest before the learning intervention and a posttest after the learning activities. Changes in students' critical thinking scores were analyzed using normalized gain (N-gain), followed by a comparison of N-gain scores between the two groups.

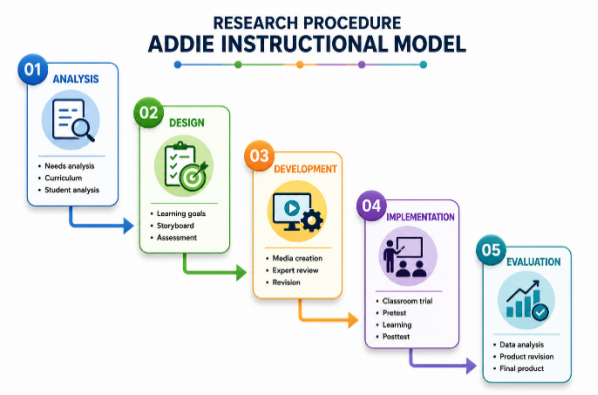


Figure 1. Research Procedure Based on the ADDIE Model

Figure 1 illustrates the research procedure based on the ADDIE instructional design model. The Analysis stage identified students' learning needs, curriculum requirements, learner characteristics, and learning problems related to food chain instruction. The Design stage involved formulating learning objectives, preparing storyboards and assessment instruments, designing navigation structures, and developing the interface layout of the Articulate Storyline-based edugame.

During the Development stage, the edugame was created by integrating food chain learning materials, visual representations, animations, interactive activities, quizzes, and feedback. The developed product was subsequently reviewed by a material expert and a media expert, and revisions were made based on their recommendations. The Implementation stage involved classroom trials with an experimental group (n = 15) and a control group (n = 16). The experimental group received instruction using the developed edugame, whereas the control group received conventional science instruction. The Evaluation stage examined product validity and effectiveness based on expert validation and students' critical thinking outcomes.

Research Participants

The research was conducted at SDN 1 Bogorejo, Blora Regency, Indonesia, during the second semester of the 2025/2026 academic year. The participants were 31 fourth-grade elementary school students, consisting of 15 students in the experimental group and 16 students in the control group. Both groups completed the pretest and posttest using the critical thinking instrument.

The experimental group received science instruction using the Articulate Storyline-based food chain edugame, whereas the control group received conventional science instruction. Both groups were assessed using the same critical thinking instrument before and after the learning activities. Before classroom implementation, the developed product was evaluated by one material expert and one media expert. The material expert assessed the appropriateness of the learning content, while the media expert evaluated the design and technical aspects of the developed edugame.

Development Procedure

Product development followed the ADDIE model. During the Analysis stage, learning needs were identified through classroom observations, teacher interviews, and student questionnaires. Curriculum requirements, learner characteristics, instructional objectives, and difficulties related to food chain learning were also examined. The Design stage focused on preparing learning objectives, storyboards, navigation structures, assessment instruments, and user interface designs. Learning activities and assessment tasks were aligned with the intended critical thinking indicators.

During the Development stage, the edugame was developed using Articulate Storyline by integrating learning materials, images, animations, interactive activities, quizzes, and feedback. The initial product was subsequently evaluated by a material expert and a media expert. Revisions were made based on the feedback obtained during the validation process.

During the Implementation stage, the revised edugame was implemented in the experimental group, while the control group received conventional science instruction. Both groups completed the critical thinking pretest before the learning activities and the posttest after the intervention. During the Evaluation stage, the results of expert validation and students' critical thinking scores were analyzed. Evaluation of the product focused on its validity and effectiveness in supporting students' critical thinking skills.

Research Instruments

The research instruments consisted of teacher interview guidelines, a student needs analysis questionnaire, material and media expert validation sheets, and a critical thinking test. The instruments were used at different stages of the research to identify learning needs, evaluate the developed product, and measure students' critical thinking skills. The critical thinking test initially consisted of 12 essay items. The items were developed based on the critical thinking indicators used in the study. Before implementation, the instrument was tested with 30 respondents to examine its empirical validity and reliability.

Instrument Validity and Reliability

The critical thinking test initially consisted of 12 essay items. Instrument validity was examined using the Pearson Product–Moment correlation. The analysis showed that 10 items met the validity criterion, whereas Items 7 and 11 did not meet the criterion and were excluded from the final instrument. The critical value used was r=0.361r = 0.361.

Reliability analysis was conducted using Cronbach's Alpha. The resulting coefficient was 0.877, indicating high internal consistency of the critical thinking instrument. The empirical validity and reliability analysis provided evidence concerning the consistency and item performance of the test. Expert validation of the developed edugame was conducted separately to assess the quality and appropriateness of the learning media.

Data Collection

Data collection was conducted in three main stages. First, a needs analysis was conducted through classroom observation, teacher interviews, and student questionnaires to identify learning problems and requirements for developing the edugame. Second, the developed edugame was evaluated by a material expert and a media expert. Expert validation was used to assess the suitability of the learning content and the quality of the developed media.

Third, classroom implementation was conducted using a pretest–posttest procedure. Students in both the experimental and control groups completed the critical thinking pretest before the learning activities. The experimental group then received instruction using the Articulate Storyline-based food chain edugame, while the control group received conventional science instruction. Following the learning activities, both groups completed the critical thinking posttest.

Data Analysis

Descriptive and inferential statistical analyses were conducted to evaluate the developed edugame and students' critical thinking outcomes. Percentage scores from the material and media expert validation were used to determine the validity of the developed product. The interpretation of validation scores followed the criteria presented in Table 1.

Table 1. Validity Criteria

Percentage	Category
81–100%	Very Valid
61–80%	Valid
41–60%	Fair
21–40%	Poor
0–20%	Very Poor

The effectiveness of the developed edugame was evaluated based on changes in students' critical thinking scores between the pretest and posttest. Normalized gain (N-gain) was calculated using the following formula:

$$N - gain = \frac{Posttes - Pretest}{Maximum\ Score - Pretes}$$

N-gain values were classified as high (≥ 0.70), moderate (0.30–0.69), and low (< 0.30).

Before inferential analysis, the normality and homogeneity assumptions were examined using the Shapiro–Wilk and Levene's tests, respectively. The paired-samples t-test was used to examine changes in critical thinking scores within each group, whereas the independent-samples t-test was used to compare N-gain scores between the experimental and control groups. Statistical significance was determined at the 0.05 level.

Because the study employed a non-equivalent control group design, the pretest scores were considered when interpreting differences in post-intervention outcomes. N-gain analysis was retained as the primary measure of score improvement because it quantified the relative change from pretest to posttest. Normalized gain (N-gain) values were classified as high (≥ 0.70), moderate (0.30–0.69), and low (< 0.30). Prior to hypothesis testing, the assumptions of normality and homogeneity were examined using the Kolmogorov–Smirnov, Shapiro–Wilk, and Levene's tests. If the data satisfied the assumptions for parametric analysis, improvements in students' critical thinking skills were analyzed

using a paired-samples t-test, whereas differences between the experimental and control groups were examined using an independent-samples t-test. Statistical significance was established at the 0.05 level.

Ethical Considerations

The study was conducted in accordance with the procedures and permissions applicable to classroom-based educational research. Participation was limited to students involved in the selected classes, and the data were used for research purposes. Student identities were kept confidential in reporting the research findings.

RESULTS

The Articulate Storyline-based food chain edugame was developed using the ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation stages (Sun et al., 2024). The analysis stage identified learning needs, curriculum requirements, learner characteristics, and learning difficulties related to food chain concepts. The development process resulted in an interactive learning medium integrating food chain materials, simulations, game-based activities, quizzes, and immediate feedback (Agbo et al., 2023). The developed edugame consisted of several interactive components. The main interface provided access to the learning and game sections, while the learning section presented food chain materials through written explanations and audio narration. The game section included four activities: Pick Many, Matching, Pick One, and Puzzle. An interactive quiz provided immediate feedback after students submitted their responses (de Freitas et al., 2023).

Development of the Articulate Storyline-Based Food Chain Edugame

Development of the Articulate Storyline-based food chain edugame was carried out using the ADDIE model. Following the needs analysis and instructional design stages, the learning media was developed by integrating interactive multimedia, gamification, food chain simulations, quizzes, and immediate feedback into a single digital learning environment. Several interfaces of the developed edugame are presented in Figures 2.



Figure 2. Main Interface of the Articulate Storyline-Based Edugame

Figure 2 shows the main interface of the developed Articulate Storyline-based food chain edugame. The interface includes the title page, visual illustrations, and a navigation button that allows students to begin the interactive learning activities.



Figure 3. Storyboard Design of the Articulate Storyline-based Edugame

Figure 3 illustrates the storyboard design of the developed Articulate Storyline-based edugame. The storyboard presents the main navigation menu, including the Learning (Belajar) and Game (Bermain) sections, which guide students to learning materials and interactive game activities. The visual layout and navigation were designed to create an engaging learning environment while ensuring that students could easily access each learning component.



Figure 4. Main Interface of the Articulate Storyline-based Edugame

Figure 4 shows the learning materials interface of the developed edugame. The content is presented through written explanations accompanied by audio narration, allowing students to learn by reading and listening simultaneously. This feature supports independent learning and enhances students' understanding of food chain concepts.



Figure 5. Interactive Food Chain Game

Figure 5 shows the game menu of the developed edugame, which consists of four interactive activities: Pick Many, Matching, Pick One, and Puzzle. These educational games are designed to strengthen students' understanding of food chain concepts while promoting active engagement and critical thinking through game-based learning.

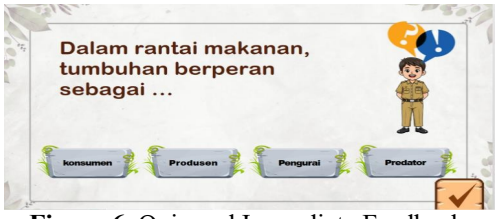


Figure 6. Quiz and Immediate Feedback

Figure 6 shows the interactive quiz interface of the developed edugame. Students answer multiple-choice questions related to food chain concepts and receive immediate feedback on their responses, allowing them to monitor their understanding and strengthen their critical thinking skills throughout the learning process.

Instrument Validity and Reliability

Before classroom implementation, the critical thinking instrument was examined for validity and reliability. The initial instrument consisted of 12 essay items. Pearson Product–Moment analysis showed that 10 items met the validity criterion, whereas Items 7 and 11 did not meet the required criterion and were excluded from further analysis.

Table 2. Item Validity of the Critical Thinking Instrument

Item	r-value	Decision
1	0.635	Valid
2	0.719	Valid
3	0.628	Valid
4	0.572	Valid
5	0.712	Valid
6	0.681	Valid
7	0.313	Invalid
8	0.747	Valid
9	0.600	Valid
10	0.747	Valid
11	0.170	Invalid
12	0.723	Valid

The validity analysis resulted in 10 valid items that were retained for subsequent analysis. The two invalid items, Items 7 and 11, were excluded from the final instrument. Reliability analysis produced a Cronbach's Alpha coefficient of 0.877, indicating high internal consistency of the critical thinking instrument.

Table 3. Reliability of the Critical Thinking Instrument

Instrument	Cronbach's Alpha	Category
Critical Thinking Test	0.877	Highly Reliable

Expert Validation of the Learning Media

Expert validation was conducted before classroom implementation by one material expert and one media expert. The validation instrument assessed content, language, learning design, interface design, and navigation. The material expert provided scores of 86% for content, 82% for language, and 85% for learning design. The media expert provided scores of 87% for interface design and 84% for navigation.

Table 4. Results of Expert Validation of the Developed Learning Media

Assessment Aspect	Material Expert (%)	Media Expert (%)	Category
Content	86	–	Valid
Language	82	–	Valid
Learning Design	85	–	Valid
Interface Design	–	87	Valid
Navigation	–	84	Valid
Average	84	86	Valid

The average validation score was 84% from the material expert and 86% from the media expert. The combined average was 85%, which was categorized as valid according to the predetermined criteria. The validators also provided recommendations concerning instructional clarity, visual elements, and interface consistency. The recommendations were incorporated into the final version of the edugame before classroom implementation.

Storyboard Validation

The storyboard was reviewed before the final Articulate Storyline product was implemented. The review examined the instructional sequence, game mechanics, navigation, quizzes, and assessment activities. Minor revisions concerning navigation and visual consistency were incorporated before the storyboard was developed into the final application. Because no quantitative storyboard-validation score is reported in the available results, no additional percentage or numerical validity value is presented for the storyboard.

Students' Critical Thinking Skills

Before hypothesis testing, normality and homogeneity tests were conducted for the pretest and posttest scores. The Shapiro–Wilk results indicated that all pretest and posttest datasets were normally distributed because all significance values exceeded 0.05. Levene's tests also indicated homogeneous variances for both pretest and posttest scores.

Table 5. Results of Normality and Homogeneity Tests

Test	Statistic	Sig.	Decision
Shapiro–Wilk (Pretest Control)	0.963	0.707	Normal
Shapiro–Wilk (Pretest Experimental)	0.945	0.445	Normal
Shapiro–Wilk (Posttest Control)	0.949	0.478	Normal
Shapiro–Wilk (Posttest Experimental)	0.951	0.540	Normal
Levene's Test (Pretest)	0.109	0.743	Homogeneous
Levene's Test (Posttest)	0.447	0.509	Homogeneous

The results indicated that the assumptions for subsequent parametric analyses were satisfied.

Table 6. Descriptive Statistics of Critical Thinking Scores

Group	N	Pretest Mean	Posttest Mean	Gain
Experimental	15	22.33	34.27	11.94
Control	16	22.13	26.94	4.81

The experimental group had a pretest mean of 22.33 and a posttest mean of 34.27, resulting in a gain of 11.94. The control group had a pretest mean of 22.13 and a posttest mean of 26.94, resulting in a gain of 4.81. The pretest means were relatively similar between groups, while the experimental group showed a larger increase in the posttest mean.

N-Gain Analysis
Normalized gain analysis was conducted to determine the relative improvement in students' critical thinking scores from pretest to posttest.

Table 7. Normalized Gain (N-Gain) of Students' Critical Thinking Skills

Group	N	Mean N-Gain	Category
Experimental	15	0.680	Moderate
Control	16	0.273	Low

The experimental group obtained a mean N-Gain of 0.680, categorized as moderate, whereas the control group obtained a mean N-Gain of 0.273, categorized as low. Thus, the experimental group showed a higher normalized improvement in critical thinking scores than the control group.

Hypothesis Testing
The difference in N-Gain scores between the experimental and control groups was examined using an independent-samples *t*-test.

Table 8. Independent-Samples *t*-Test of N-Gain Scores

Variable	*t*	Sig. (2-tailed)	Interpretation
N-Gain	−19.515	< .001	Significant difference

The independent-samples *t*-test showed a statistically significant difference in N-Gain scores between the experimental and control groups ($t = -19.515$, $p < .001$). The result indicates that the improvement in critical thinking scores differed significantly between students who received instruction using the Articulate Storyline-based food chain edugame and those who received conventional instruction.

DISCUSSION

Development and preliminary evaluation of the Articulate Storyline-based food chain edugame produced a learning medium that met the established validity criteria and showed promising preliminary evidence for supporting fourth-grade students' critical thinking skills. Expert validation resulted in an average score of 85%, while the critical-thinking instrument demonstrated high internal consistency with a Cronbach's Alpha coefficient of 0.877. Mean N-Gain reached 0.680 in the experimental group and 0.273 in the control group. An independent-samples *t*-test indicated a statistically significant difference in N-Gain scores between the groups ($t = -19.515$, $p < .001$). Such findings provide preliminary evidence concerning the potential of the developed edugame to support critical-thinking development in food chain learning. Interpretation should nevertheless consider the non-equivalent group design and relatively small sample size.

Previous research provides a relevant foundation for understanding the contribution of the present study. Sari & Hanif, (2023) investigated Articulate Storyline-based interactive multimedia among fourth-grade elementary students and reported improved IPAS learning outcomes following its implementation. The study demonstrates the potential of Articulate Storyline as an interactive learning medium, although the focus was primarily on learning outcomes rather than critical-thinking-oriented educational game activities. Gamage et al., (2023) emphasized the importance of valid and reliable assessment in technology-enhanced learning, highlighting the need for appropriate measurement when evaluating technology-supported instruction. Wen et al., (2024) further reported the potential of well-designed digital learning environments to support inquiry processes and cognitive engagement. J. Chen et al., (2023) examined computer-supported collaborative learning and peer feedback and reported potential benefits for aspects of students' critical-thinking development. Differences in learning context, instructional approach, and target outcomes, however, distinguish those studies from the present investigation.

Integration of food chain content, educational game mechanics, interactive activities, contextual problem-solving tasks, and immediate feedback represents the main contribution of the present study. Articulate Storyline functions not merely as a platform for presenting multimedia content but also as an environment for implementing interactive food chain activities. Activities such as Pick Many, Matching, Pick One, and Puzzle require students to identify relationships among organisms, select appropriate responses, and solve food chain-related problems. Drag-and-drop activities, animations, quizzes, and immediate feedback further provide opportunities for active interaction with learning materials. Previous research has established the relevance of interactive digital media, assessment quality, inquiry-oriented environments, and feedback, whereas the present study brings several of these elements together within a food chain edugame designed for elementary science learning.

Several instructional features may have contributed to the greater improvement observed in the experimental group. Interactive tasks can provide opportunities for students to engage directly with representations of food chains rather than relying exclusively on conventional content presentation. Matching and puzzle activities, for example, require students to establish relationships among organisms, while quiz activities require students to select or evaluate possible responses. Immediate feedback may help students recognize incorrect responses and reconsider their understanding during learning. Because all features were implemented as an integrated learning package, however, the available data do not permit determination of which individual component contributed most to the observed difference.

Constructivist learning principles offer a relevant perspective for interpreting the instructional design. Active interaction with learning tasks may encourage students to construct understanding through direct engagement with food chain concepts. Visual representations, interactive activities, and contextual problems require students to connect organisms and ecological relationships. Cognitive Theory of Multimedia Learning also provides a theoretical basis for combining verbal and visual representations within the edugame. Written explanations, narration, visual materials, interactive activities, and feedback may support active cognitive processing during learning. Student engagement and cognitive processing were not directly measured, however, so these mechanisms should be regarded as plausible theoretical explanations rather than empirically established mechanisms.

The moderate N-Gain obtained by the experimental group provides an important qualification to the interpretation of the findings. A mean N-Gain of 0.680 indicates meaningful improvement but remains within the moderate category rather than the high category. Differences in prior knowledge, familiarity with digital learning environments, individual learning characteristics, and intervention duration or intensity may have contributed to the level of improvement. Such factors were not directly examined in the present study, preventing determination of their respective contributions to the learning outcomes.

The statistically significant difference between the groups also requires cautious interpretation. Group assignment was non-random, and the study involved only 31 fourth-grade students from a single elementary school. Pre-existing differences and other uncontrolled variables may therefore have influenced the observed outcomes. Experimental and control groups showed relatively similar pretest means, 22.33 and 22.13, respectively, but comparable group means do not eliminate individual differences or other potential confounding factors. Consequently, the statistical result indicates a difference in improvement under the conditions of the study rather than definitive evidence that the edugame alone caused the observed gains.

Novelty and testing effects also warrant consideration. Exposure to an interactive digital learning format may have influenced students' engagement because the learning experience differed from conventional instruction. Familiarity with the assessment format may likewise have contributed to changes between pretest and posttest performance. Student motivation, engagement, perceptions of novelty, and testing effects were not directly measured. Longer intervention periods, repeated measurements, and additional measures of student engagement could provide stronger evidence concerning the mechanisms associated with learning improvement.

Several limitations should be acknowledged. First, the sample consisted of only 31 students from one elementary school, limiting transferability to other educational contexts and student populations. Second, the non-randomized design limits causal inference and leaves the possibility of selection bias and uncontrolled group differences. Third, validation involved one material expert and one media expert, providing preliminary rather than extensive validation evidence. Fourth, the analysis focused on overall critical-thinking performance and did not separately examine dimensions such as interpretation, analysis, inference, evaluation, and explanation. Fifth, engagement and cognitive processing were proposed as possible mechanisms but were not directly measured. Finally, quantitative evidence regarding teacher and student practicality was not reported. Consequently, conclusions should remain focused on product validity and preliminary effectiveness rather than practicality.

Future research should involve larger and more diverse samples across multiple educational settings and employ stronger experimental or quasi-experimental designs. Baseline-adjusted analyses such as ANCOVA could provide additional information regarding posttest differences while accounting for pretest scores, provided that the relevant statistical assumptions are satisfied. Reporting effect sizes and confidence intervals would further strengthen interpretation of the magnitude and precision of the findings. Further investigation could examine individual critical-thinking dimensions alongside student engagement, motivation, usability, and learning experience. Comparative research involving specific edugame components could also clarify the contribution of matching activities, puzzle solving, simulations, and immediate feedback to critical-thinking outcomes.

Overall, the Articulate Storyline-based food chain edugame met the predetermined validity criteria and was associated with greater improvement in critical-thinking scores in the experimental group than in the control group. Previous studies have established the relevance of Articulate Storyline, technology-enhanced assessment, inquiry-oriented digital learning, and interactive feedback, while the present study extends those applications to an integrated

food chain edugame for elementary science learning. The moderate N-Gain and methodological limitations indicate that the findings should be interpreted as preliminary evidence rather than definitive proof of causal effectiveness. Further research involving larger samples, stronger designs, longer intervention periods, and more comprehensive outcome measures is needed to examine the consistency and broader applicability of the findings.

CONCLUSION

Development of an Articulate Storyline-based food chain edugame produced a learning medium that met the established validity criteria and showed promising preliminary evidence for supporting fourth-grade students' critical thinking skills. Expert validation yielded an overall validity score of 85%, while the critical-thinking instrument demonstrated high internal consistency with a Cronbach's Alpha coefficient of 0.877. Mean N-Gain reached 0.680 in the experimental group and 0.273 in the control group, with an independent-samples *t*-test indicating a statistically significant difference between groups ($t = -19.515$, $p < .001$).

Integration of interactive multimedia, game-based activities, contextual food chain tasks, quizzes, and immediate feedback created an interactive learning environment for elementary science instruction. Such features provided opportunities for students to engage with food chain concepts through activities oriented toward critical thinking. Nevertheless, interpretation of the findings requires caution because the study involved only 31 students from a single school and employed a non-equivalent control group design. Consequently, the findings provide preliminary evidence rather than definitive causal evidence regarding the effectiveness of the edugame. Quantitative practicality was not evaluated in the reported results; therefore, no conclusion regarding product practicality is drawn.

Future studies should involve larger and more diverse student populations across multiple educational settings and employ stronger experimental or quasi-experimental designs. Further investigation could examine learning retention through delayed posttests, student engagement, usability, motivation, and specific dimensions of critical thinking. Research involving different science topics and comparisons of individual edugame components could also provide additional evidence regarding the applicability and instructional contribution of Articulate Storyline-based educational games.

REFERENCE

Agbo, F. J., Olaleye, S. A., Bower, M., & Oyelere, S. S. (2023). Examining the relationships between students' perceptions of technology, pedagogy, and cognition: The case of immersive virtual reality mini games to foster computational thinking in higher education. *Smart Learning Environments, 10*, 16. https://doi.org/10.1186/s40561-023-00233-1

Ahzari, S., Asrizal, & Usmeldi. (2024). Effects of physics teaching materials on student critical thinking and creative thinking skills: A meta-analysis. *Jurnal Penelitian Pembelajaran Fisika, 10*(2), 150–160. https://doi.org/10.24036/jppf.v10i2.129627

Angelelli, C. V., Ribeiro, G. M. C., & Severino, M. R. (2023). Developing critical thinking skills through gamification. *Thinking Skills and Creativity, 49*, 101354. https://doi.org/10.1016/j.tsc.2023.101354

Barz, N., Benick, M., Dörrenbächer-Ulrich, L., & Perels, F. (2024). The effect of digital game-based learning interventions on cognitive, metacognitive, and affective-motivational learning outcomes in school: A meta-analysis. *Review of Educational Research, 94*(2), 247–289. https://doi.org/10.3102/00346543231167795

Cenita, J. A. S., & De Guzman, Z. R. (2023). Education in the digital world: From the lens of millennial learners. *International Journal of Computing Sciences Research*, 1816–1829. https://doi.org/10.25147/ijcsr.2017.001.1.132

Chen, J., Hwang, G. J., & Chang, C. Y. (2023). A study on the relationship between students' learning engagements and higher-order thinking skills in programming learning. *Thinking Skills and Creativity, 49*, 101369. https://doi.org/10.1016/j.tsc.2023.101369

Daryanes, F., Darmadi, D., Fikri, K., Sayuti, I., Rusandi, M. A., & Situmorang, D. D. B. (2023). The development of Articulate Storyline interactive learning media based on case methods to train students' problem-solving ability. *Heliyon, 9*(4), e15082. https://doi.org/10.1016/j.heliyon.2023.e15082

de Freitas, S., Uren, V., Kiili, K., Ninaus, M., Petridis, P., Lameras, P., Dunwell, I., Arnab, S., Jarvis, S., & Star, K. (2023). Efficacy of the 4F feedback model: A game-based assessment in university education. *Information, 14*(2), 99. https://doi.org/10.3390/info14020099

Febliza, A., Afdal, Z., & Copriady, J. (2023). Improving students' critical thinking skills: Is interactive video and interactive web module beneficial? *International Journal of Interactive Mobile Technologies, 17*(3), 70–86. https://doi.org/10.3991/ijim.v17i03.34699

García-Carmona, A. (2024). Scientific thinking and critical thinking in science education: Two distinct but symbiotically related intellectual processes. *Science & Education, 34*(1), 227–245. https://doi.org/10.1007/s11191-023-00460-5

Hwang, G.-J., Tu, Y.-F., & Chu, H.-C. (2024). Using peer feedback to improve critical thinking in computer-supported collaborative argumentation: An exploratory study. *Journal of Computer Assisted Learning, 40*(6), 3390–3405. https://doi.org/10.1111/jcal.13078

Ke, F., Dai, C.-P., & West, L. (2024). Mathematical experience in game-based problem-solving. *Journal of Computer Assisted Learning, 40*(3), 845–861. https://doi.org/10.1111/jcal.12938

Loyens, S. M. M., van Meerten, J. E., Schaap, L., & Wijnia, L. (2023). Situating higher-order, critical, and critical-analytic thinking in problem- and project-based learning environments: A systematic review. *Educational Psychology Review, 35*, 39. https://doi.org/10.1007/s10648-023-09757-x

Mohammed, M., Fatemah, A., & Hassan, L. (2024). Effects of gamification on motivations of elementary school students: An action research field experiment. *Simulation & Gaming, 55*(4), 467–489. https://doi.org/10.1177/10468781241237389

Moriska, A., & Hanif, M. (2024). Interactive learning multimedia Articulate Storyline as an alternative media to improve elementary students' critical thinking skills. *Jurnal Ilmiah Sekolah Dasar, 8*(2), 258–269. https://doi.org/10.23887/jisd.v8i2.65310

Mulyawati, Y., Sukmanasa, E., Rostikawati, R. T., Maharani, N. D., & Azizah, A. N. (2024). A new approach to elementary learning: An interactive digital module for critical thinking with Articulate Storyline. *Pedagogia: Jurnal Ilmiah Pendidikan, 16*(2), 97–102. https://doi.org/10.55215/pedagogia.v16i2.23

Ninaus, M., Cortez, R., Hazin, I., Kiili, K., Wortha, S. M., Klein, E., Weiss, E. M., & Moeller, K. (2023). The added value of game elements: Better training performance but comparable learning gains. *Educational Technology Research and Development, 71*, 1917–1939. https://doi.org/10.1007/s11423-023-10263-8

Patiño, A., Ramírez-Montoya, M. S., & Buenestado-Fernández, M. (2023). Active learning and Education 4.0 for complex thinking training: Analysis of two case studies in open education. *Smart Learning Environments, 10*, 8. https://doi.org/10.1186/s40561-023-00229-x

Rifayanti, Z. E. T., Mustaji, Mariana, N., & Suryanti. (2024). Enhancing critical thinking and problem-solving skills in upper elementary students through game-based learning. *Perspectives of Science and Education, 70*(4), 396–420. https://doi.org/10.32744/pse.2024.4.25

Sari, P. K., & Hanif, M. (2023). Pengaruh penggunaan multimedia interaktif berbasis Articulate Storyline terhadap hasil belajar IPAS siswa kelas IV SDN Tambakrejo Magetan. *Journal of Scientech Research and Development, 5*(2), 153–161. https://doi.org/10.56670/jsrd.v5i2.175

Simonovic, B., Correa Vione, K., Stupple, E., & Doherty, A. (2023). It is not what you think it is how you think: A critical thinking intervention enhances argumentation, analytic thinking and metacognitive sensitivity. *Thinking Skills and Creativity, 49*, 101362. https://doi.org/10.1016/j.tsc.2023.101362

Song, H., & Cai, L. (2024). Interactive learning environment as a source of critical thinking skills for college students. *BMC Medical Education, 24*, 270. https://doi.org/10.1186/s12909-024-05247-y

Sun, L., Kangas, M., & Ruokamo, H. (2024). Game-based features in intelligent game-based learning environments: A systematic literature review. *Interactive Learning Environments, 32*(7), 3431–3447. https://doi.org/10.1080/10494820.2023.2179638

Wahyuni, E., & Fitria, Y. (2023). Media digital dalam meningkatkan kemampuan berpikir kritis pembelajaran IPA siswa sekolah dasar. *Pendas: Jurnal Ilmiah Pendidikan Dasar, 8*(1), 5116–5126. https://doi.org/10.23969/jp.v8i1.8615

Wang, X., Cheng, M., & Li, X. (2023). Teaching and learning computational thinking through game-based learning: A systematic review. *Journal of Educational Computing Research, 61*(7), 1505–1536. https://doi.org/10.1177/07356331231180951

Wen, Y., Lai, C., He, S., Cai, Y., Looi, C.-K., & Wu, L. (2024). Investigating primary school students' epistemic beliefs in augmented reality-based inquiry learning. *Interactive Learning Environments, 32*(9), 5355–5372. https://doi.org/10.1080/10494820.2023.2214182

Xu, E., Wang, W., & Wang, Q. (2023). The effectiveness of collaborative problem solving in promoting students' critical thinking: A meta-analysis based on empirical literature. *Humanities and Social Sciences Communications, 10*, 16. https://doi.org/10.1057/s41599-023-01508-1

Zhan, Y., Yan, Z., Wan, Z. H., Wang, X., Zeng, Y., Yang, M., & Yang, L. (2023). Effects of online peer assessment on higher-order thinking: A meta-analysis. *British Journal of Educational Technology, 54*(4), 817–835. https://doi.org/10.1111/bjet.13310

ACKNOWLEDGEMENT
The authors would like to express their sincere gratitude to all individuals and institutions who contributed to the completion of this study. Special appreciation is extended to the material and media experts for their valuable feedback during the validation process, the participating elementary school, teachers, and students for their cooperation during the implementation stage, and all colleagues who provided constructive suggestions throughout the development of the Articulate Storyline-based food chain edugame. Their support and contributions were invaluable to the successful completion of this research.

AUTHOR CONTRIBUTION STATEMENT
Conceptualization, T.A.A, I.P., and J.S.; methodology, T.A.A.P. and M.M.; software, T.A.A..; validation, T.A.A., I.M., and J.S.; formal analysis, T.A.A. and I.S.; investigation, T.A.A.; resources, T.A.A.; data curation, T.A.A.; writing original draft preparation, T.A.A.; writing, review and editing, I.P. and J.S.; visualization, T.A.R.; supervision, I.P. and J.S.; project administration, T.A.R. All authors have read and agreed to the published version of the manuscript.

AI DISCLOSURE STATEMENT
The authors used ChatGPT by OpenAI during the preparation of this manuscript to assist with language refinement, organization, and clarity of presentation. The tool was not used to generate, modify, or analyze the research data. After using the tool, the authors thoroughly reviewed, verified, and edited the content and take full responsibility for the accuracy and integrity of the publication.

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