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Interactive Articulate Storyline Food Chain Edugame to Improve Fifth-Grade Students Critical Thinking Skills

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Abstract: Developing an effective game-based learning environment to improve elementary students' critical thinking skills remains a challenge in science education, particularly for food chain learning. This study aimed to develop and evaluate an Interactive Articulate Storyline-based Food Chain Edugame using a Research and Development (R&D) approach with the ADDIE model. Product quality was evaluated through expert validation, teacher and student practicality assessments, instrument testing, and effectiveness analysis using a quasi-experimental pretest–posttest control group design. The critical thinking instrument consisted of 12 essay items, of which 10 were valid and demonstrated high reliability (Cronbach's Alpha = 0.877). The developed learning environment met the criteria for validity, practicality, and effectiveness. No significant difference was found between the experimental and control groups in the pretest ($p = 0.725$), whereas the posttest showed a significant difference ($p < 0.001$). The experimental group achieved a higher mean posttest score (85.63) and normalized gain (0.680) than the control group (67.34; 0.273). These findings demonstrate that integrating game-based learning activities, formative assessment, and immediate feedback within a meaningful learning design effectively enhances elementary students' critical thinking skills.

Keywords: ADDIE model; Critical thinking skills; Elementary science; Food chain; Game-based learning; Interactive learning media

Introduction

Preliminary classroom observations and an analysis of students' learning outcomes conducted at SDN 1 Bogorejo, Blora Regency, Indonesia, revealed that elementary science instruction had not yet effectively fostered students' critical thinking skills, particularly in the food chain topic. Learning achievement records showed that 12 of 15 fifth-grade students (80%) failed to achieve the Minimum Mastery Criterion, indicating substantial learning difficulties prior to the intervention. Classroom observations further revealed that teacher explanations dominated most learning sessions, whereas students had limited opportunities to investigate ecological problems, discuss alternative explanations, analyze relationships among organisms, or justify their answers using scientific evidence. Consequently, most students were able to recall factual information but experienced considerable difficulty explaining energy transfer, predicting ecological changes, and constructing logical arguments based on evidence. Such findings reflect a broader challenge in elementary science education, where classroom practices continue to prioritize factual recall over scientific reasoning despite curriculum expectations that emphasize inquiry, evidence-based thinking, and higher-order cognitive skills (García-Carmona, 2024; Wahyuni & Fitria, 2023). Consequently, developing innovative learning media that actively engage students in analyzing ecological phenomena and constructing evidence-based explanations has become an urgent priority for strengthening critical thinking and improving the quality of elementary science learning (Barz et al., 2024; Febliza et al., 2023; Rifayanti et al., 2024).

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Learning difficulties observed among fifth-grade students at SDN 1 Bogorejo indicate that developing critical thinking in elementary science remains a significant challenge. Classroom observations showed that many students were able to recall factual information about food chains but experienced difficulty analyzing ecological relationships, explaining cause-and-effect interactions, and formulating evidence-based conclusions. Such conditions are closely associated with the cognitive characteristics of elementary learners. According to Piaget's cognitive development theory, fifth-grade students generally remain in the concrete operational stage, in which logical reasoning and critical thinking develop through direct experiences, visual representations, and manipulation of concrete objects rather than through abstract verbal instruction alone (Aini et al., 2025). Consequently, learning topics such as food chains become particularly demanding because students must mentally visualize invisible ecological processes, including energy transfer, organism interdependence, and ecosystem dynamics, all of which require analytical reasoning beyond simple memorization. Reliance on teacher explanations and static textbook illustrations, as observed in the classroom, provides limited opportunities for students to investigate scientific phenomena, compare evidence, and justify their reasoning, thereby restricting the development of critical thinking skills (Wen et al., 2024). Therefore, elementary science learning requires interactive digital learning environments that integrate visualization, inquiry, and meaningful learner engagement to transform abstract ecological concepts into concrete learning experiences and better support the development of fifth-grade students' critical thinking skills (Song & Cai, 2024).

Addressing the learning challenges identified at SDN 1 Bogorejo requires instructional media that not only accommodate the cognitive characteristics of fifth-grade students but also align with their learning preferences. Findings from the initial needs survey revealed that 12 of 15 fifth-grade students (80%) preferred smartphones or other digital technologies as learning media, indicating students' readiness to engage in technology-enhanced learning. Nevertheless, classroom observations showed that science instruction remained predominantly dependent on teacher explanations and printed textbooks, leaving the educational potential of digital technology largely underutilized. This mismatch is particularly critical in food chain learning, which requires students to visualize ecological interactions, analyze energy transfer, predict the consequences of population changes, and make evidence-based decisions—processes that are difficult to support through static learning resources alone. Consequently, effective digital learning media should facilitate interactive visualization, inquiry-based exploration, immediate feedback, and active learner engagement (Sun et al., 2024; F. Zhang et al., 2024). Articulate Storyline provides these pedagogical affordances through integrated features such as drag-and-drop interactions, branching scenarios, variables, triggers, animations, and instant feedback, enabling abstract ecological concepts to be transformed into meaningful educational game experiences that effectively support the development of fifth-grade students' critical thinking skills (Daryanes et al., 2023; Fatih et al., 2024).

Recent studies have consistently highlighted the contribution of digital and game-based learning to improving the quality of elementary science education. Meta-analytic evidence indicates that digital game-based learning significantly improves cognitive, metacognitive, and affective learning outcomes across school settings. Likewise, systematic reviews have shown that game-based learning effectively promotes higher-order thinking, engagement, and problem-solving through meaningful learner interaction. Research has also demonstrated that Articulate Storyline-based learning media improve students' critical thinking and problem-solving abilities by integrating interactive exploration, multimedia, and immediate feedback (Moriska & Hanif, 2024). Furthermore, gamification has been reported to enhance elementary students' learning motivation while simultaneously supporting critical thinking development through inquiry-oriented activities (Angelelli et al., 2023; Mohammed et al., 2024). Consistent with these international findings, studies conducted in Indonesian elementary schools have shown that Articulate Storyline-based multimedia, interactive digital modules, and game-based learning significantly improve students' critical thinking skills, problem-solving abilities, and science learning outcomes (Mulyawati et al., 2024; Mustikawati & Isdaryanti, 2024). Collectively, these studies provide strong empirical evidence that interactive digital learning environments have considerable potential to improve science learning and foster higher-order thinking among elementary school students.

In addition, supporting evidence from Indonesian science education research further strengthens these findings. Farida et al. (2023) reported that the REACT learning strategy significantly enhances students' critical thinking abilities in elementary science learning contexts. Similarly, Widodo et al. (2023) found that argumentation-based teaching contributes to improved reasoning, decision-making, and scientific thinking skills. Moreover, Kholidah et al. (2023) developed HOTS-based game media for grade V science learning and demonstrated its effectiveness in fostering higher-

order thinking skills in elementary students. Collectively, these studies reinforce the importance of interactive, inquiry-based, and game-oriented learning environments in developing students' critical thinking skills in science education.

Although previous studies have consistently demonstrated the positive contributions of digital learning media, gamification, and Articulate Storyline to improving students' motivation, engagement, learning outcomes, and conceptual understanding (Barz et al., 2024a), the available literature has paid comparatively less attention to developing critical thinking skills through interactive educational games specifically designed for elementary science learning (Xu et al., 2023). Existing evidence also remains limited regarding the development of an Articulate Storyline-based food chain edugame that integrates inquiry activities, ecological problem-solving, and gamification while simultaneously evaluating its effectiveness using validated critical thinking assessment instruments. These limitations indicate the need for further research that provides stronger empirical evidence regarding the use of interactive digital game-based learning to improve fifth-grade students' critical thinking skills in elementary science education.

The novelty of this study lies not merely in developing an Articulate Storyline-based food chain edugame, but in proposing an integrated instructional framework that combines inquiry-based learning, gamification, ecological problem-solving, interactive visualization, and immediate feedback within a single digital learning environment specifically designed to foster fifth-grade students' critical thinking skills (Simonovic et al., 2023). This study contributes by demonstrating that effective digital game-based learning depends on meaningful instructional design rather than technology alone. The integrated evaluation of product quality and instructional effectiveness provides a replicable framework for developing interactive science learning media that promote elementary students' critical thinking.

Accordingly, this study aims to develop an Interactive Articulate Storyline-based Food Chain Edugame and evaluate its validity and effectiveness in improving the critical thinking skills of fifth-grade elementary school students. By integrating interactive visualization, inquiry-oriented learning, and gamification into a single digital learning environment, this study is expected to provide an empirically validated instructional innovation that supports the implementation of technology-enhanced science learning and contributes to the advancement of digital pedagogy for fostering critical thinking in elementary education.

Method

Research Design

This study employed Research and Development (R&D) using the ADDIE instructional design model, consisting of five systematic stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was selected because its systematic and iterative process facilitates the development, validation, revision, and evaluation of instructional media to ensure product quality and effectiveness before implementation in classrooms (Afina et al., 2022).

The product developed in this study was an interactive Articulate Storyline-based Food Chain Edugame designed to improve fifth-grade students' critical thinking skills in science learning. The instructional effectiveness of the developed product was examined using a quasi-experimental method with a non-equivalent control group pretest–posttest design. The experimental group received instruction using the developed Edugame, while the control group was taught using conventional learning methods. Learning improvement was measured using normalized gain (N-gain) analysis, and differences between groups were analyzed using inferential statistical tests. This research design is consistent with development studies in elementary education that combine product development with field implementation to evaluate validity, practicality, and instructional effectiveness (Samsudin et al., 2023).

Research Participants

The study was conducted at SDN 1 Bogorejo, Blora Regency, Indonesia, involving 31 fifth-grade students, consisting of 15 students in the experimental group and 16 students in the control group.

To ensure methodological rigor, an additional 30 fifth-grade students from another school who had previously studied the food chain topic were involved in the pilot testing of the research instrument. These students were not included in the main experimental sample to avoid contamination bias.

Sampling Technique, Research Variables, and Ethical Considerations

The population of this study consisted of all fifth-grade students enrolled at SDN 1 Bogorejo, Blora Regency, Indonesia, during the 2025/2026 academic year. Participants were selected using a purposive sampling technique because the existing classrooms possessed comparable academic characteristics and were considered appropriate for implementing the developed instructional media. Random assignment of individual students was not conducted due to administrative constraints and the use of intact

classroom groups, which is consistent with the non-equivalent control group design employed in quasi-experimental research. Consequently, one existing class consisting of 15 students was assigned as the experimental group, while another class consisting of 16 students served as the control group.

To evaluate instrument quality, a pilot test was conducted with 30 fifth-grade students from another elementary school who had previously studied food chain concepts. These students were excluded from the main experiment to avoid contamination bias. The independent variable was the implementation of the Interactive Articulate Storyline-based Food Chain Edugame, whereas the dependent variable was students' critical thinking skills. Learning objectives, instructional content, learning duration, classroom environment, and teacher were controlled to ensure comparable learning conditions across groups. The intervention was conducted over four 70-minute instructional sessions, with both groups completing identical pretest and posttest assessments. Ethical approval was obtained from the school principal, participation was voluntary, and all participant data were anonymized and used solely for research purposes.

Development Procedure

The development of the interactive Articulate Storyline-based Food Chain Edugame followed the ADDIE instructional design model, which consists of five systematic and interrelated stages: analysis, design, development, implementation, and evaluation. This model was applied in a structured and non-redundant sequence to ensure that the resulting learning media was pedagogically valid, technically feasible, and effective in improving students' critical thinking skills.

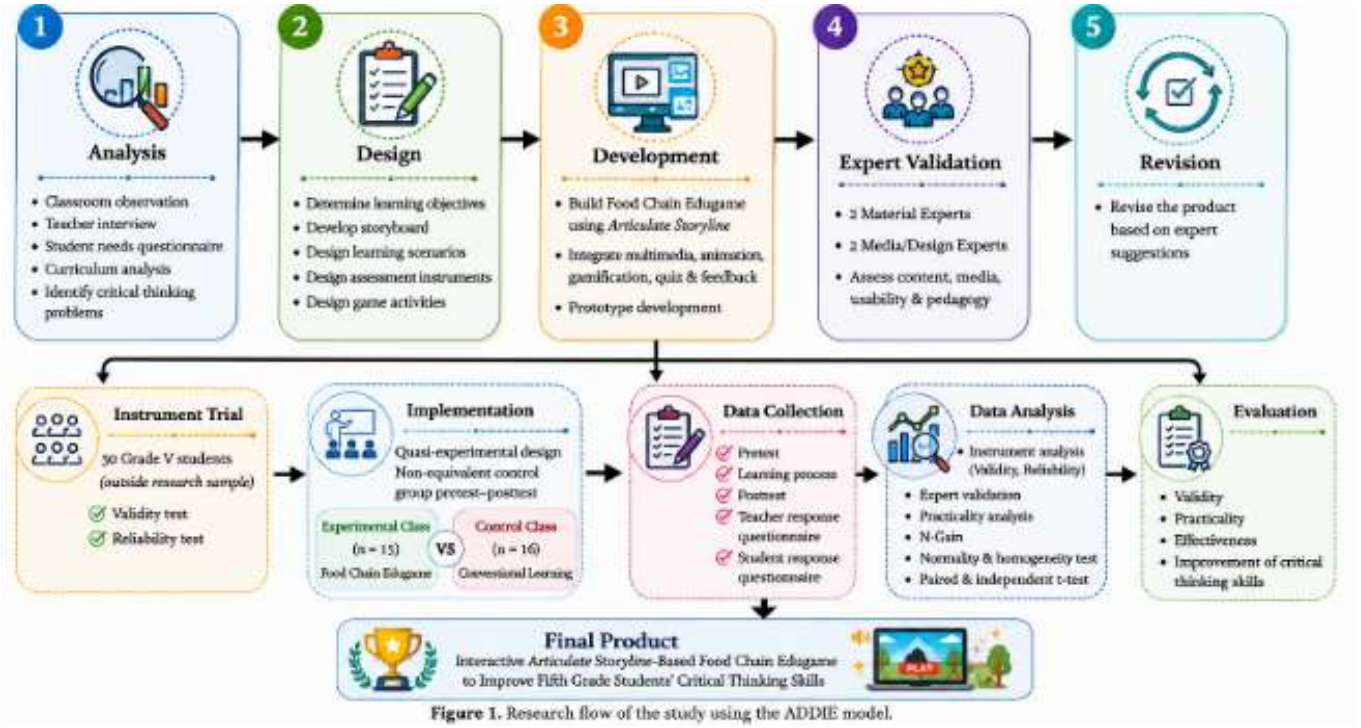

Figure 1. Research flow of the study using the ADDIE model.

Figure 1. Research flow of the study using the ADDIE development model

During the analysis phase, instructional problems were identified through classroom observations, teacher interviews, and student questionnaires. This stage focused on analyzing students' misconceptions regarding food chain concepts, identifying learner characteristics, reviewing curriculum requirements, and determining learning needs related to critical thinking skills. The results of this analysis became the basis for formulating instructional objectives and designing learning activities that were aligned with students' characteristics and curriculum demands (Fatoni & Bektiningsih, 2024).

In the design phase, learning objectives were formulated based on critical thinking indicators, including interpretation, analysis, inference, and evaluation. A comprehensive storyboard was then developed to describe the learning sequence, navigation flow, interface layout, assessment design, and interaction patterns within the Edugame. Learning scenarios, quizzes, feedback mechanisms, and game elements were designed to ensure consistency between instructional objectives, learning activities, and expected outcomes, as recommended in previous studies on

interactive multimedia development using Articulate Storyline (Dahlan & Sriyanto, 2024).

The development phase involved constructing the Edugame using Articulate Storyline by integrating multimedia components, including animations, illustrations, narration, interactive quizzes, feedback systems, and gamification features to create an engaging learning environment. After the prototype had been completed, product validation was conducted by two material experts and two media experts to evaluate the accuracy of the scientific content, instructional quality, interface design, and usability. The experts' suggestions were then used to revise the product to improve content clarity, visual appearance, navigation, and instructional quality before classroom implementation. Similar validation procedures have been widely applied in recent studies developing Articulate Storyline-based learning media.

Product validation was conducted by two material experts and two media experts. Each validator had at least five years of professional experience in elementary education, curriculum development, or instructional media evaluation. All validators had experience in evaluating educational media and provided both quantitative ratings and qualitative suggestions to improve the accuracy of scientific content, instructional quality, interface design, navigation, and usability before classroom implementation.

The implementation phase consisted of field testing using a quasi-experimental non-equivalent control group pretest-posttest design. Students in the experimental group learned using the developed Edugame, whereas students in the control group received conventional instruction. Both groups completed pretests before the intervention and posttests after the learning process to measure improvements in students' critical thinking skills. Previous studies have similarly reported that Articulate Storyline-based learning media significantly improve students' higher-order thinking skills when implemented in authentic classroom settings (Rea et al., 2024).

Finally, the evaluation phase assessed the quality of the developed product through three major dimensions: validity, practicality, and effectiveness. Product validity was determined through expert judgment, practicality was measured using teacher and student response questionnaires, and effectiveness was evaluated through students' learning outcomes using normalized gain (N-gain) analysis and inferential statistical tests. The evaluation results were used to determine the overall feasibility and instructional effectiveness of the developed Food Chain Edugame in improving elementary students' critical thinking skills. This evaluation framework is consistent with recent studies on the development of interactive learning media using the ADDIE model, which emphasize the importance of validating instructional products before large-scale implementation.

Research Instruments

The instruments used in this study were designed to comprehensively collect data related to students' learning needs, product feasibility, and learning outcomes. Specifically, the instruments consisted of teacher interview guidelines, a student needs analysis questionnaire, expert validation sheets, teacher and student response questionnaires, and a critical thinking test consisting of 12 items. Each instrument was developed based on the research objectives and aligned with indicators of critical thinking skills, product validity, and instructional practicality.

The teacher interview guidelines and student needs analysis questionnaire were employed during the initial analysis phase to identify instructional problems, students' difficulties in understanding food chain concepts, and their learning preferences. Expert validation sheets were used to assess the content validity and media quality of the developed Edugame, while teacher and student response questionnaires were used to measure the practicality of the learning media in classroom implementation. Furthermore, the critical thinking test was used as the main instrument to evaluate students' cognitive learning outcomes before and after the intervention (Febriyanti et al., 2023).

To provide a clearer overview of the research instruments, the details are presented in Table 1 below.

Table 1. Research Instruments

ıstrument	Purpose	Respondents	Measurement Aspect
ıterview Guidelines	Identify instructional problems and teacher perspectives	Teachers	Learning needs & classroom problems
:udent Needs Analysis uestionnaire	Identify students' learning difficulties and preferences	Grade V students	Learning needs & learning media preference
xpert Validation Sheets Aaterial & Media)	Evaluate content validity, instructional design, and interface quality	2 Material Experts, 2 Media Experts	Product validity (content & media quality)
eacher & Student Response uestionnaires	Measure practicality and user experience of Edugame	Teacher & Students	Practicality of learning media
ritical Thinking Test (12 ems)	Measure students' critical thinking skills before and after intervention	Experimental & Control Groups	Learning outcomes (pretest–posttest)

To ensure adequate representation of each critical thinking indicator, the test blueprint is presented in Table 2. As shown in Table 2, the critical thinking test consisted of twelve multiple-choice items distributed across six critical thinking indicators. This blueprint ensured that each critical thinking indicator was proportionally represented, thereby supporting the content validity of the instrument before empirical validation was conducted.

Table 2. Blueprint of the Critical Thinking Test

Critical Thinking Indicator	Description	Item Number	Total Items
Interpretation	Identifying and understanding scientific information related to food chain concepts	1, 2	2
Analysis	Analyzing relationships among organisms and energy flow within food chains	3, 4	2
Inference	Drawing logical conclusions from food chain phenomena	5, 6	2
Evaluation	Evaluating evidence and determining the accuracy of scientific statements	7, 8	2
Explanation	Providing scientific explanations for food chain interactions	9, 10	2
Self-regulation	Reflecting on and reviewing answers based on scientific reasoning	11, 12	2
Total		1–12	12

Instrument Validity and Reliability

The validity and reliability of the critical thinking test instrument were evaluated to ensure that the measurement tool was both accurate and consistent in assessing students' cognitive abilities. Prior to the main implementation of the study, the instrument consisting of 12 multiple-choice items was piloted with 30 fifth-grade students from a school outside the research sample. These students had previously studied the topic of food chains, ensuring that they possessed the required prior knowledge to respond meaningfully to the test items without influencing the main experimental data.

Instrument validity was analyzed using the Pearson Product–Moment correlation technique, which measures the degree of relationship between each item score and the total test score. The calculated correlation coefficients were then compared with the critical r-table value of 0.361 at a significance level of 0.05. The analysis results indicated that 10 items met the validity criteria, meaning they showed a strong and significant correlation with the overall construct of critical thinking skills. However, 2 items (Items 7 and 11) were found to be invalid because their correlation values were lower than the r-table threshold. These items were subsequently removed from the final instrument to improve measurement accuracy and ensure that only valid indicators of critical thinking were used in the study.

In addition to validity testing, the reliability of the instrument was examined using Cronbach's Alpha coefficient to determine the internal consistency of the test items. The analysis produced a reliability coefficient of 0.877, which is categorized as high reliability. This indicates that the instrument has strong internal consistency, meaning that the test items consistently measure the same construct, namely students' critical thinking skills in science learning. Therefore, the final instrument was considered reliable and appropriate for use in the pretest and posttest assessments in the experimental and control groups.

Data Collection Procedure

Data collection in this study was conducted through a systematic four-stage procedure to ensure comprehensive and structured data acquisition. The first stage involved a needs analysis, which was carried out through classroom observations, teacher interviews, and student questionnaires. This stage aimed to identify instructional problems, students' learning difficulties in understanding food chain concepts, and their preferences toward learning media, particularly in relation to the use of digital technology in science learning.

The second stage was expert validation of the developed Edugame, which involved material and media experts evaluating the instructional content, accuracy of scientific concepts, interface design, usability, and overall pedagogical appropriateness. Feedback obtained from this validation process was used to revise and improve the quality of the learning media before classroom implementation.

The third stage consisted of the experimental implementation phase, which was conducted using a quasi-experimental approach with a pretest–posttest control group design. In this stage, the developed Edugame was applied in the experimental class, while the control class received conventional instruction. Both groups were given pretest assessments before the intervention and posttest assessments after the learning process to measure differences in learning outcomes.

The final stage involved practicality and effectiveness evaluation, which was conducted through

teacher and student response questionnaires as well as analysis of students' pretest and posttest scores. This stage aimed to determine the usability, attractiveness, and instructional effectiveness of the Edugame in improving students' critical thinking skills in science learning. The combination of qualitative and quantitative data ensured that the evaluation results reflected both user experience and learning achievement outcomes.

Research Hypothesis

The effectiveness of the developed Articulate Storyline-based Food Chain Edugame was examined using the following statistical hypotheses:

H_0: There is no statistically significant difference in the critical thinking skills of fifth-grade students before and after learning using the Articulate Storyline-based Food Chain Edugame, nor between students receiving the Edugame and those receiving conventional instruction.

H_1: There is a statistically significant improvement in the critical thinking skills of fifth-grade students after learning using the Articulate Storyline-based Food Chain Edugame, and the improvement is significantly higher than that of students receiving conventional instruction.

Data Analysis

Data analysis employed both descriptive and inferential statistical techniques to evaluate the validity, reliability, practicality, and effectiveness of the developed Articulate Storyline-based Food Chain Edugame. Instrument validity was determined using the Pearson Product–Moment correlation coefficient, whereas instrument reliability was evaluated using Cronbach's Alpha coefficient. The validity and practicality of the developed Edugame were calculated using percentage-based scoring derived from expert validation sheets and teacher–student response questionnaires. The resulting percentages were interpreted according to predetermined validity and practicality criteria to determine the feasibility of the developed product.

The Pearson Product–Moment correlation coefficient was calculated using the following equation (Hair et al., 2023):

$$r_{\{xy\}} = \left\{ \frac{N\sum XY - \sum X \sum Y}{\sqrt{\{(N\sum X^2 - (\sum X)^2)(N\sum Y^2 - (\sum Y)^2)\}}} \right\} \quad (1)$$

where rxy is the correlation coefficient, N is the number of respondents, X is the item score, and Y is the total score.

The reliability coefficient was determined using Cronbach's Alpha as follows (Hair et al., 2023):

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum \sigma_i^2}{\sigma_t^2}\right) \quad (2)$$

where α is the reliability coefficient, kis the number of items, ∑σi2 is the sum of the item variances, and $\sum\sigma_t^2$ is the total score variance. The percentage score used to determine the validity and practicality (Fraenkel et al., 2024) of the developed Edugame was calculated using:

$$P = \frac{\sum X}{\sum X_i} \times 100\% \quad (3)$$

where P is the percentage score, ∑X is the obtained score, and ∑Xi is the maximum possible score. The percentage scores obtained from expert validation were interpreted using the product validity criteria presented in Table 3.

Table 3. Criteria for Product Validity

Percentage	Category
81–100%	Very Valid
61–80%	Valid
41–60%	Fairly Valid
21–40%	Less Valid
0–20%	Invalid

As shown in Table 2, higher percentage scores indicate a higher level of product validity, with scores of 81–100% categorized as very valid. The practicality scores obtained from teachers' and students' response questionnaires were interpreted according to the practicality criteria presented in Table 4.

Table 4 Criteria for Product Practicality

Percentage	Category
81–100%	Very Practical
61–80%	Practical
41–60%	Fairly Practical
21–40%	Less Practical
0–20%	Not Practical

As presented in Table 3, higher percentage scores indicate a higher level of practicality, with scores ranging from 81% to 100% classified as *very practical*. These criteria were used to determine the practicality of the developed Edugame based on teachers' and students' responses.

The effectiveness of the Edugame was evaluated using the normalized gain (N-gain) score, which remains one of the most widely accepted measures for assessing learning improvement in pretest–posttest educational research (Diaz et al., 2023). The N-gain score was calculated using the following equation:

$$N\text{-}gain = \frac{Posttest - Pretest}{Maximum\ core - Pretest} \quad (4)$$

where *Posttest* is the posttest score, *Pretest* is the pretest score, and *Maximum Score* is the maximum possible score. N-gain values were categorized as high (≥0.70, moderate (0.30−0.69), and low (<0.30).

Table 5. Criteria for Normalized Gain (N-gain)

N-gain	Category
≥ 0.70	High
0.30–0.69	Moderate
< 0.30	Low

The N-gain categories presented in Table 5 were used to interpret the magnitude of students' learning improvement following the implementation of the developed Edugame.

Prior to hypothesis testing, data were considered normally distributed and homogeneous when the significance value exceeded 0.05 ($p > 0.05$). After satisfying these assumptions, differences in students' critical thinking skills within each group were analyzed using the paired-samples t-test, whereas differences between the experimental and control groups were analyzed using the independent-samples t-test. Statistical significance was established at $\alpha = 0.05$.

Result and Discussion

Development of the Interactive Articulate Storyline-Based Food Chain Edugame

The Interactive Articulate Storyline Food Chain Edugame was successfully developed through the ADDIE instructional design model to facilitate fifth-grade students' understanding of food chain concepts while promoting critical thinking skills. The final product integrated learning materials, interactive simulations, educational games, quizzes, and immediate feedback within a user-friendly interface designed to support independent and classroom-based learning. Following expert validation and product revision, the Edugame was considered suitable for implementation in elementary science instruction. The overall appearance and main features of the developed Edugame are presented in Figures 2–6.

Figure 2. Main menu of the interactive articulate storyline food chain edugame

Figure 2 shows the main menu of the Interactive Articulate Storyline Food Chain Edugame. The interface provides access to the learning materials (*Belajar*) and interactive game activities (*Bermain*), enabling students to navigate the application easily.

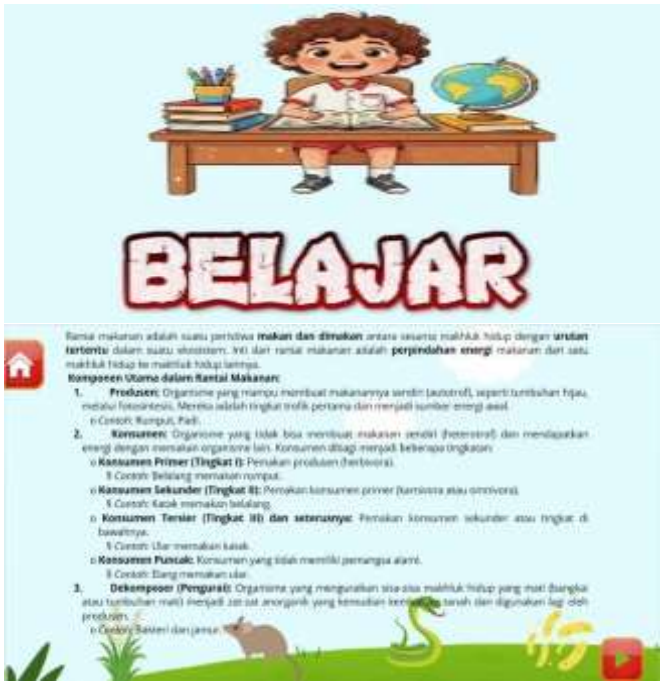

Figure 3. Learning materials on food chain concepts

Figure 3 shows the learning materials section of the Interactive Articulate Storyline Food Chain Edugame. The page presents structured content on food chain concepts and provides navigation buttons that enable students to access the instructional materials independently.

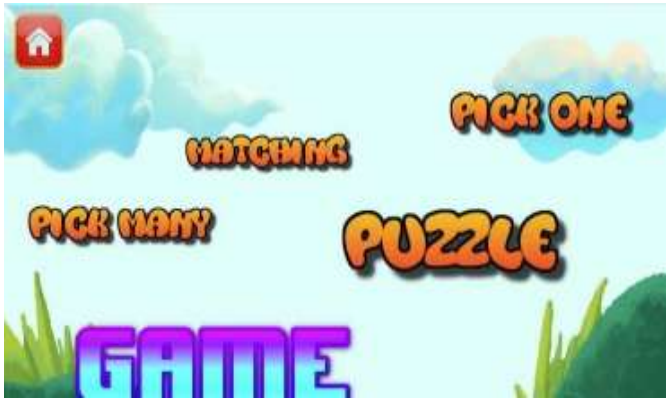

Figure 4. Interactive game menu of the interactive articulate storyline food chain edugame

Figure 4 shows the interactive game menu of the developed Edugame. The menu provides four game-based learning activities (*Pick Many*, *Matching*, *Pick One*, and *Puzzle*) that students can select during the learning process.

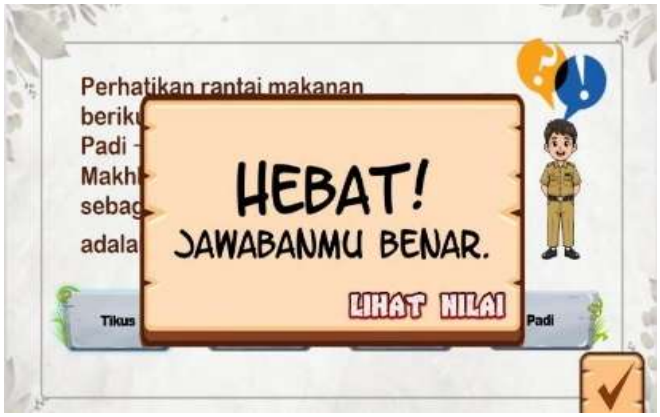

Figure 5. Immediate feedback on students' quiz responses

Figure 5 shows the immediate feedback feature provided after students complete a quiz item. The system displays the correctness of the answer and allows students to view their score before continuing the learning activity.

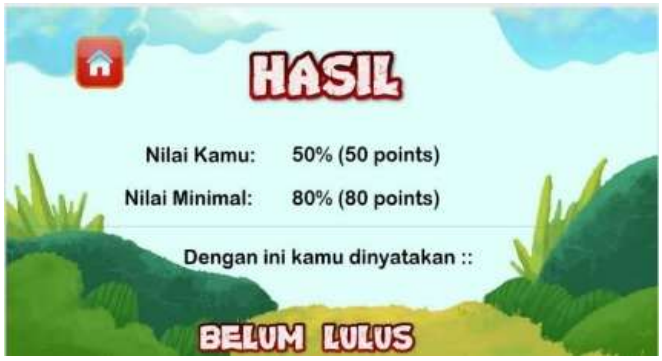

Figure 6. Quiz result and performance summary

Figure 6 shows the quiz result page of the developed Edugame. The interface provides students' final score, the minimum passing score, and the achievement status after completing the quiz.

Overall, the Interactive Articulate Storyline Food Chain Edugame was successfully developed as an integrated interactive learning medium and was subsequently evaluated for its validity, practicality, and effectiveness.

Product Validity

The validity of the developed Interactive Articulate Storyline Food Chain Edugame was evaluated by two material experts and two media experts to assess the appropriateness of the instructional content, language, learning design, interface, navigation, and technical quality. The expert validation results are presented in Table 6.

Table 6. Expert Validation Results

Validator	Percentage (%)	Category
Material Experts	84.00	Very Valid
Media Experts	86.00	Very Valid
Average	85.00	Very Valid

Based on the experts' suggestions, several revisions were made to improve the quality of the Edugame before classroom implementation. The revisions mainly focused on enhancing visual presentation, navigation, instructional clarity, and feedback mechanisms to improve usability and learning effectiveness. The main revisions are summarized in Table 7.

Table 7. Product Revisions Based on Expert Suggestions

Expert Suggestions	Revisions Made
Improve the readability of instructional text	Font size and text layout were adjusted for better readability.
Enhance navigation consistency	Navigation buttons were standardized across all pages.
Improve image quality and layout	Several illustrations were replaced with higher-resolution images and reorganized.
Provide clearer feedback after quizzes	Immediate feedback messages and score displays were refined for better understanding.

The expert validation results indicate that the developed Edugame met the criteria of a very valid learning medium. After incorporating the recommended revisions, the final version of the Edugame was considered suitable for classroom implementation and was subsequently subjected to practicality and effectiveness testing.

Product Practicality

Product practicality was evaluated through teacher and student response questionnaires administered after classroom implementation. Practicality assessment focused on the ease of use, interface design, clarity of learning materials, interactivity, and overall usability of the Interactive Articulate Storyline Food Chain Edugame. Practicality evaluation results are presented in Table 8.

Table 8. Practicality Evaluation Results of the Developed Edugame

Respondents	Percentage (%)	Category
Teacher Response	88.00	Very Practical
Student Response	87.00	Very Practical
Average	87.50	Very Practical

Teacher and student responses demonstrated a high level of practicality for the developed Edugame. Teacher responses reached 88.00%, while student

responses reached 87.00%, resulting in an average practicality score of 87.50%. Based on the predetermined practicality criteria, scores within the range of 86–100% are classified as Very Practical. High practicality ratings indicate that the Interactive Articulate Storyline Food Chain Edugame was easy to operate, featured an attractive interface, presented learning materials clearly, and effectively supported interactive science learning activities. Positive evaluations from both teachers and students further suggest that the developed learning media can be implemented effectively in fifth-grade classrooms without requiring substantial revisions. High practicality scores reflected that the learning media was easy to operate, visually attractive, and suitable for supporting science learning activities in fifth-grade classrooms.

Table 9. Practicality Evaluation Based on Teacher and Student Responses

Aspect	Teacher (%)	Student (%)	Category
Ease of Use	90.00	88.67	Very Practical
Interface Design	89.00	87.33	Very Practical
Learning Content	88.00	86.67	Very Practical
Interactivity	90.00	89.33	Very Practical
Motivation	89.00	88.00	Very Practical
Average	89.20	88.00	Very Practical

Teacher and student responses indicated a high level of practicality for the developed Edugame. Teacher ratings averaged 89.20%, while student ratings averaged 88.00%, both of which fall within the Very Practical category. High practicality scores reflected that the learning media was easy to operate, visually attractive, and suitable for supporting science learning activities in fifth-grade classrooms. Positive responses from both teachers and students further confirmed that the Interactive Articulate Storyline Food Chain Edugame was practical for classroom implementation, particularly in terms of ease of navigation, engaging visual presentation, and interactive learning activities.

Instrument Quality

Instrument quality was evaluated prior to classroom implementation to ensure that the critical thinking test accurately and consistently measured students' learning outcomes. The initial instrument consisted of 12 essay items, which were administered to students outside the research sample for validity and reliability testing. Item validity analysis indicated that 10 items met the validity criteria, whereas 2 items (Items 7 and 11) did not satisfy the required correlation threshold and were therefore excluded from the final instrument. Reliability analysis of the remaining valid items produced a Cronbach's Alpha coefficient of 0.877, indicating high internal consistency. These findings confirm that the final instrument was sufficiently valid and reliable for measuring fifth-grade students' critical thinking skills in the pretest and posttest assessments.

Effectiveness of the Developed Edugame

Effectiveness of the developed Interactive Articulate Storyline Food Chain Edugame was evaluated through assumption testing, descriptive analysis, normalized gain analysis, and hypothesis testing. Prior to inferential analysis, the assumptions of normality and homogeneity were examined to determine the suitability of parametric statistical procedures. Students participated in learning activities using the Edugame before completing the posttest assessment. Several stages of the classroom implementation are illustrated in Figures 7–9.

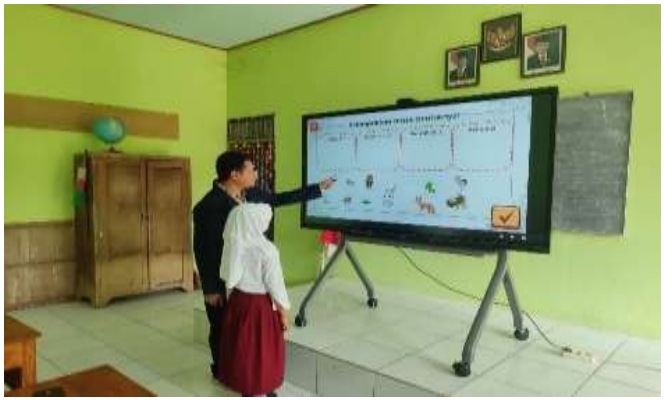

Figure 7. Classroom implementation of the interactive articulate storyline food chain edugame

Figure 7 shows the implementation of the Interactive Articulate Storyline Food Chain Edugame during classroom learning. Students participated in an interactive food chain classification activity under teacher guidance using a smart interactive display.

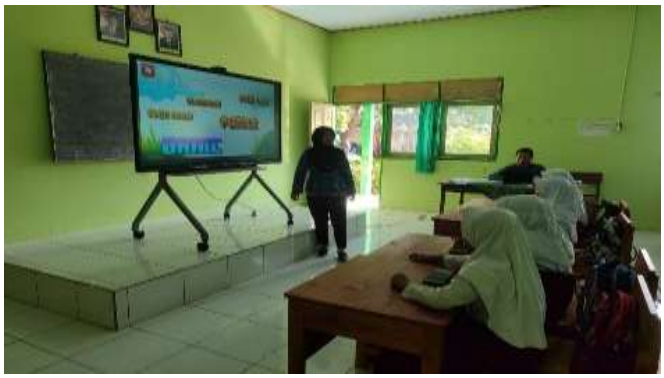

Figure 8. Classroom introduction to the interactive articulate storyline food chain edugame

Figure 8 shows the implementation of the Interactive Articulate Storyline Food Chain Edugame in the experimental classroom. The teacher introduced the game-based learning activities using a smart interactive

display, while students followed the learning instructions before engaging with the Edugame.

Figure 9. Students using the interactive articulate storyline food chain edugame

Figure 9 shows students accessing the Interactive Articulate Storyline Food Chain Edugame through mobile devices during classroom implementation. The Edugame enabled students to engage individually in interactive learning activities as part of the instructional process.

Shapiro–Wilk test results indicated that all pretest and posttest data were normally distributed, with significance values ranging from 0.445 to 0.707 ($p > 0.05$). Levene's test further confirmed homogeneous variances between the experimental and control groups for both pretest ($p = 0.743$) and posttest ($p = 0.491$). These findings indicate that the data satisfied the assumptions for subsequent parametric analyses.

Table 10. 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)	0.961	0.703	Normal
Levene's Test (Pretest)	0.109	0.743	Homogeneous
Levene's Test (Posttest)	0.487	0.491	Homogeneous

Descriptive statistics showed that both groups had comparable critical thinking abilities before the intervention. The experimental group obtained a mean pretest score of 55.83, while the control group obtained 55.31. Following the learning intervention, the experimental group achieved a substantially higher mean posttest score (85.63) than the control group (67.34), indicating greater improvement in students' critical thinking performance.

Table 11. Descriptive Statistics of Students' Critical Thinking Scores

Group	N	Pretest	Posttest
Experimental	15	55.83	85.63
Control	16	55.31	67.34

Normalized gain analysis further demonstrated higher learning improvement in the experimental group. Students who learned using the Interactive Articulate Storyline Food Chain Edugame obtained a mean N-gain of 0.680, categorized as moderate, whereas students receiving conventional instruction achieved a mean N-gain of 0.273, categorized as low. These findings indicate that the developed Edugame produced greater improvement in critical thinking skills than conventional learning.

Hypothesis testing was conducted using independent-samples t-tests and paired-samples t-tests. Independent-samples t-test results indicated no significant difference in pretest scores between the experimental and control groups ($p = 0.725$), confirming comparable initial abilities. However, a significant difference was observed in posttest scores ($t = -11.942$, $p < 0.001$), indicating that students who learned using the developed Edugame achieved significantly higher critical thinking scores than those receiving conventional instruction.

Table 12. Normalized Gain (N-Gain) Scores

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

Paired-samples t-test results for the experimental group also demonstrated a significant improvement in critical thinking skills after the intervention ($t = -59.657$, $p < 0.001$). Furthermore, independent-samples analysis of the normalized gain scores revealed a significant difference between groups ($t = -19.515$, $p < 0.001$), confirming that the developed Edugame produced greater learning improvement than conventional instruction. Therefore, the null hypothesis was rejected, and the alternative hypothesis was accepted, indicating that the Interactive Articulate Storyline Food Chain Edugame effectively improved fifth-grade students' critical thinking skills.

Discussion

According to constructivist learning theory, knowledge is constructed through active interaction and

reflection. Accordingly, the effectiveness of the Edugame can be attributed to the integration of multimedia learning, game-based learning activities, and immediate feedback that continuously engaged students in higher-order cognitive processes. By analyzing trophic relationships, solving contextual ecological problems, and evaluating their responses with immediate feedback, students actively developed analysis, reasoning, and reflection, which are essential components of critical thinking. These sequential learning experiences promoted analysis, reasoning, and reflection, which are essential components of critical thinking. Previous studies have similarly reported that interactive multimedia and game-based learning enhance cognitive engagement through active participation and timely feedback (Dahlan & Sriyanto, 2024; Barz et al., 2024; de Freitas et al., 2023).

High validity and practicality indicate that the developed learning environment fulfilled both pedagogical and technical requirements for elementary science instruction. Revisions based on expert feedback improved instructional clarity, interface consistency, navigation, and feedback quality, resulting in a learning medium that was easy to use while maintaining meaningful learning experiences. Positive responses from teachers and students further demonstrate that effective instructional design contributes not only to usability but also to successful classroom implementation. Similar findings have been reported by Fatoni et al. (2024) and Daryanes et al. (2023) who concluded that well-designed Articulate Storyline media combining clear instructional organization with user-friendly interfaces are more feasible for elementary learning.

Improved critical thinking skills can be explained by the cognitive demands embedded in the Edugame. Interactive activities required students to analyze ecological relationships, classify organisms, compare alternative answers, and justify their decisions instead of relying on factual memorization. These cognitive processes are reflected in the substantially higher posttest score achieved by the experimental group (85.63) compared with the control group (67.34), together with a moderate N-gain (0.680), indicating that students developed critical thinking through repeated reasoning and problem-solving activities. These findings are consistent with previous studies showing that game-based learning promotes higher-order thinking by encouraging active engagement and inquiry-oriented learning (Rifayanti et al., 2024; Hwang et al., 2024; Nofitri et al., 2024).

Although the experimental group demonstrated substa ntial learning improvement, the N-gain remained within the moderate category. This finding is reasonable because critical thinking develops progressively through sustained learning experiences rather than a single instructional intervention. The relatively short implementation period and the focus on only one science topic limited opportunities for students to repeatedly practice higher-order thinking across broader scientific contexts. Therefore, the moderate N-gain should be interpreted as meaningful educational improvement rather than limited effectiveness. Similar observations have been reported by Diaz et al. (2023), who emphasized that normalized learning gains are influenced by instructional duration, learning design, and students' engagement throughout the intervention.

Food chain concepts are particularly suitable for game-based learning because they involve sequential relationships, ecological interactions, and cause-and-effect reasoning that require students to analyze, classify, predict, and explain ecosystem changes. Unlike many abstract science concepts, food chains can be visualized through dynamic interactions among living organisms, making them particularly appropriate for interactive game design. Consequently, game-based learning provides meaningful opportunities for students to construct scientific understanding while simultaneously strengthening critical thinking skills. This interpretation supports previous findings that inquiry-oriented science learning effectively develops scientific reasoning and higher-order thinking through contextual problem-solving (García-Carmona, 2024; Z. Zhang & Crawford, 2024; Widodo et al., 2023).

The primary novelty of this study lies not in the use of Articulate Storyline itself but in the integration of instructional content, multiple game mechanics, formative assessment, and immediate feedback within a single learning environment specifically designed to foster critical thinking in elementary science. Unlike previous studies that mainly focused on interactive multimedia presentation, the developed learning environment encouraged continuous reasoning through repeated cycles of exploration, evaluation, feedback, and reflection. This study therefore contributes theoretically by demonstrating that the effectiveness of educational games depends primarily on instructional design that integrates meaningful interaction, formative assessment, and immediate feedback rather than on digital technology itself. This finding extends previous work on interactive science learning by highlighting learning design as the key mechanism underlying improvements in critical thinking (Song & Cai, 2024; Rea et al., 2024; Alfirzan et al., 2024).

The developed Edugame has practical implications for elementary science education by providing teachers with an interactive digital learning resource that can be integrated into regular classroom instruction to strengthen students' critical thinking skills. The learning design may also serve as a practical model for

developing other game-based science learning media targeting higher-order thinking skills in primary education. Nevertheless, this study was limited by the relatively small sample size, implementation in a single elementary school, and the use of only one science topic, which may limit the generalizability of the findings. Future studies should evaluate the developed learning environment across broader science topics, larger and more diverse samples, longer implementation periods, and comparisons with other digital learning approaches to further validate its effectiveness and educational contribution.

Conclusion

The findings of this study address the need for an integrated game-based learning environment capable of promoting critical thinking in elementary science education. Collectively, the results demonstrate that the developed learning environment satisfies the essential quality criteria of educational media, namely validity, practicality, and effectiveness. Rather than functioning solely as interactive multimedia, the Edugame engaged students in analysis, reasoning, reflection, and self-correction through the integration of instructional content, game-based activities, formative assessment, and immediate feedback. These findings indicate that meaningful learning experiences designed around active student engagement can effectively support the development of fifth-grade students' critical thinking skills in science learning. Unlike previous studies that primarily focused on interactive multimedia, this study demonstrates that integrating instructional content, multiple game mechanics, formative assessment, and immediate feedback within a single learning environment provides a more comprehensive approach to fostering critical thinking. Conceptually, the findings extend current knowledge by demonstrating that learning design, rather than digital technology itself, constitutes the primary factor underlying improvements in students' critical thinking. Practically, the developed Edugame offers an alternative instructional model that can be integrated into elementary science classrooms to support higher-order thinking through meaningful and interactive learning experiences. Future studies should investigate how different game mechanics influence specific dimensions of critical thinking, evaluate the long-term transfer of these skills across broader science topics, and examine the effectiveness of the learning design in diverse educational contexts. Overall, the present study provides empirical evidence that thoughtfully designed game-based learning environments can transform elementary science learning from content acquisition into a process of scientific reasoning and critical thinking development.

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Author Contributions
Conceptualization, TAR, IP, and JS; methodology, TAR and IP; software, TAR; validation, TAR, IP, and JS; formal analysis, TAR and IP; investigation, TAR; resources, TAR; data curation, TAR; writing—original draft preparation, TAR; writing—review and editing, IP and JS; visualization, TAR; supervision, IP and JS; project administration, TAR. All authors have read and agreed to the published version of the manuscript.

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The authors declare no conflict of interest.

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