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Development of an Interactive Coding-Based Module on Food Chain Topics to Enhance Analytical and Logical Thinking Skills of Fifth-Grade Elementary Students

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Abstract: This study aims to develop a valid, practical, and effective interactive coding-based module on the food chain topic in Natural Sciences (IPAS) to improve the analytical and logical thinking skills of fifth-grade elementary school students. The study employed a Research and Development (R&D) method using the 4D model (Define, Design, Develop, Disseminate). The trial subjects consisted of 21 fifth-grade students at SDN Kembangarum 2 Mranggen, Demak, Central Java. Data collection instruments included expert validation sheets, observation sheets, teacher and student response questionnaires, and pretest and posttest assessments. Data analysis was conducted using both qualitative and quantitative approaches, including N-gain analysis, normality and homogeneity tests, and paired-sample t-tests. The main findings show that: (1) the developed module integrates science concepts with coding using ScratchJr; (2) the module demonstrates a very high level of validity based on expert evaluations (average 95%) and practitioner assessments (average >94%); (3) the module is categorized as highly practical, with a practicality score of 91% based on teacher and student responses; and (4) the module is effective in improving students' analytical and logical thinking skills, as indicated by an N-gain score of 0.7299 (high category) and a statistically significant difference between pretest and posttest results ($p < 0.001$). In addition, the findings indicate that the module contributes to transforming the science learning paradigm in elementary schools from conventional teacher-centered instruction to a more student-centered, interactive, creative, and technology-integrated learning process. Through coding activities, students are encouraged to actively explore concepts, solve problems systematically, and develop higher-order thinking skills, making science learning more meaningful and relevant to the demands of 21st-century education.

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Introduction

21st-century learning emphasizes the importance of developing critical thinking, problem-solving, collaboration, and digital literacy skills from an early age to prepare students for technological and social changes (OECD, 2023). In elementary education, coding has increasingly been introduced as a fundamental literacy skill that supports students' creativity, logical reasoning, and digital competence (UNESCO, 2022). Coding is not merely viewed as the ability to write computer programs, but also as a process of developing computational thinking skills to analyze and solve problems systematically (Shute et al., 2023). This concept is consistent with Piaget's cognitive development theory, which explains that elementary school students at the concrete operational stage require visual and contextual learning experiences to understand abstract concepts. In addition, recent perspectives inspired by Vygotsky highlight that interaction, collaboration, and guided assistance play an important

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pp. 844-852
Email: jklppm@undikma.ac.id

role in strengthening children's reasoning and logical thinking abilities in the learning process (Papadakis, 2021).

However, the reality on the ground shows that programming implementation in elementary schools is not optimal. Many schools struggle due to the lack of interactive, visual, and contextual learning media that are appropriate to student characteristics (Paedagogi, 2023). As a result, students struggle to develop analytical and logical thinking skills, even though these two abilities are core to programming skills and are crucial for understanding scientific concepts such as the food chain in Natural and Social Sciences (IPAS) subjects. This empirical gap is also found at SDN Kembangarum 2, where learning remains conventional and has not integrated activities that train students' logical thinking systematically. Yet, the topic of the food chain is conceptually closely related to programming logic because both are built on sequential and systematic patterns. A food chain describes the organized flow of energy transfer from producers to consumers in a logical sequence, where each organism has a specific role and consequence in the ecosystem. Similarly, programming applies algorithmic thinking through a structured sequence of inputs, processes, and outputs. For example, when a mouse is eaten by a snake, energy is transferred in a predictable sequence, reflecting the same cause-and-effect logic used in coding instructions and conditional commands. Therefore, integrating food chain material with coding activities is not simply a technological addition to science learning, but rather a form of cognitive alignment that connects ecological concepts with computational thinking processes. This integration allows students to understand scientific phenomena more concretely while developing logical reasoning, problem-solving skills, and systematic thinking skills in line with the demands of 21st-century learning.

The novelty of this research lies in the development of an interactive coding-based module that integrates programming activities with the food chain topic in Natural and Social Sciences (IPAS) learning for elementary school students. Unlike existing educational programming applications that generally focus only on introducing coding concepts, games, or computational skills separately from school subjects, this module combines coding and science learning into a contextual and curriculum-oriented learning experience. The integration is conceptually aligned because the food chain contains logical and sequential patterns of energy transfer that parallel algorithmic processes in programming, allowing students to understand scientific concepts through computational thinking activities. In addition, the module is specifically designed according to the cognitive characteristics of fifth-grade students by utilizing ScratchJr as a visual and interactive medium to support analytical and logical thinking skills. Therefore, this research offers a new interdisciplinary approach that positions coding not merely as technological literacy, but as a meaningful learning strategy to strengthen scientific reasoning and 21st-century skills in elementary education. This study aims to produce an interactive coding-based module on the food chain material that is valid, practical, and effective. The contribution of this research is to provide a reference for innovative learning tools that integrate science and coding to develop high-level thinking skills in elementary school students.

Research Method

This study adopts a Research and Development (R&D) framework, strictly adhering to the 4-D developmental model (Define, Design, Develop, Disseminate) (Thiagarajan, Semmel, & Semmel, 1974) to ensure the systematic construction of the learning module. The subjects of the research trial were 21 fifth-grade students of SDN Kembangarum 2,

Jurnal Kependidikan:
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pp. 844-852
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Mranggen, Demak. In addition, two fifth-grade teachers participated as validators, practitioners, and users of the module.

The instruments used included:

a) expert validation sheet;
b) learning implementation observation sheet;
c) teacher and student response questionnaire (Likert scale 1-4);
d) 30 analytical and logical thinking ith indicators: Students are able to understand the components and relationships in the food chain, differentiate biotic and abiotic elements, describe the relationships between living things sequentially, predict the impact of ecosystem changes, and analyze energy flows logically and systematically, ability test items (25 PG, 5 descriptive) that were tested for validity (r-table 0.195; Pearson Correlation 0.443-0.700) and reliability (Cronbach's Alpha = 0.898; very high category).

Data was collected through:

a) document analysis to determine the initial characteristics of the learning device;
b) validation by two experts and one practitioner;
c) limited trials to measure practicality through observation and questionnaires;
d) administering a pretest before learning and a posttest after learning using the module to measure effectiveness.

Validity and practicality data were analyzed by calculating the percentage score and categorizing it. Effectiveness data were analyzed using the N-Gain test, normality test (Kolmogorov-Smirnov), homogeneity test (Levene), and paired sample t-test with a significance level of 0.05 using SPSS 27.

Results and Discussion

Characteristics of a Coding-Based Interactive Module

The developed interactive coding-based module has the main characteristic of integrating the food chain concept with simple coding activities using the ScratchJr application. The module consists of a Learning Objective Flow (ATP), teaching modules, teaching materials/interactive media (ScratchJr), and Student Worksheets (LKPD) that explicitly contain indicators of analytical and logical thinking skills.

Figure 1. Module Characteristics Snippet

Overall, this ScratchJr coding-based teaching material is designed to integrate science learning with digital literacy starting in elementary school. Through simple visual programming, students can learn ecosystem concepts in a more engaging and interactive way,

Vol. 12, No. 2 : June 2026
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pp. 844-852
Email: jklppm@undikma.ac.id

while simultaneously developing analytical skills, logical thinking, creativity, and other skills.

Validation of a Coding-Based Interactive Module

Expert validation results were obtained from questionnaires using a Likert scale for the developed science and natural sciences learning device on the coding-based food chain material to improve analysis and logical thinking. The total validation score was then compared with the maximum score and the percentage calculated. The percentage of expert validation results for the developed learning device can be seen in Table 1 below:

Table 1. Expert Validasi and Average Expert Validation Results

Product	Expert Validation	Percentage	Category
ATP	Expert 1	98%	Very Valid
	Expert 2	93%	Very Valid
Teaching Modules	Expert 1	97%	Very Valid
	Expert 2	92%	Very Valid
Teaching Materials Interactive Media	Expert 1	99%	Very Valid
	Expert 2	93%	Very Valid
Worksheets	Expert 1	93%	Very Valid
	Expert 2	93%	Very Valid

Based on Table 1, the average percentage of validation results for the science learning device on the coding-based food chain material can be obtained to improve the analysis and logical thinking developed. Overall, the four products developed obtained an average percentage above 95% so that they were included in the very valid category and were declared suitable for use without revision.

Table 2. Practitioner Validation

Product	Practitioner Validation	Percentage	Category
ATP	Practitioner	97,5%	Very Valid
Teaching Modules	Practitioner	94,6%	Very Valid
Teaching Materials Interactive Media	Practitioner	96,8%	Very Valid
Worksheets	Practitioner	97,9%	Very Valid

Table 2 shows the average scores of practitioners' validation results for the coding-based science and natural science learning tools for the food chain material to improve analysis and logical thinking. Practitioner validation was conducted by one validator, a fifth-grade teacher at SD Negeri 2 Kembangarum, Mranggen, Demak. The validation results showed that the ATP obtained a percentage of 97.5%, the teaching module 94.5%, the teaching materials 96.8%, and the LKPD 97.9%.

Practicality of a Coding-Based Interactive Module

A practicality test was conducted to determine the level of ease of use, implementation, and user response (teachers and students) to the interactive coding-based module on the Food Chain topic. Practicality was measured through observations of learning implementation, as shown in Table 3.

Table 3. Learning Observation Results

No	Aspects Assessed	Average Score	Percentage	Category
1	Ease of use of the module (clear instructions, easy navigation, directed activity	4.6	92%	Very Practical

	steps)			
2	Suitability with time and learning conditions in the classroom	4.4	88%	Very Practical
3	Implementation of 4D model steps and Scientific–Coding activities	4.5	90%	Very Practical
4	Student responses to interactive activities (enthusiasm, involvement, interest in learning)	4.7	94%	Very Practical
5	Teachers' responses to the ease and usefulness of the module	4.6	92%	Very Practical
Total Average		4.56	91%	**Very Practical**

Based on Table 3, teachers stated that the module was easy to understand, the learning steps were systematic, and the simple coding activities greatly helped explain food chain concepts. Students appeared enthusiastic in using the Food Chain Coding Cards and were able to understand "if-then" relationships more logically. The project-based learning activities, particularly in creating simple food chain algorithms, ran smoothly and created an enjoyable learning atmosphere. Although several students initially experienced minor cognitive challenges when trying programming for the first time, especially in translating biological concepts such as predator–prey relationships into coding logic blocks, these difficulties were generally not significant. Most students were able to adapt quickly because the coding activities were designed visually, sequentially, and in accordance with their cognitive development level. Their high enthusiasm and active involvement during the learning process also helped reduce the difficulties commonly associated with "logical transition" or abstract algorithmic thinking. Overall, the interactive coding-based module achieved an average percentage of 91% (Very Practical category), indicating that the module was easy to use, efficiently implemented in science learning, and effective in encouraging active student participation.

Effectiveness of a Coding-Based Interactive Module

An effectiveness test was conducted to determine the effect of using a coding-based interactive module on the food chain material on the analytical and logical thinking skills of fifth-grade elementary school students. The study used a single-group pretest-posttest design to observe changes in abilities before and after treatment. The instrument used was a 30-question learning outcome test (25 multiple-choice and 5 descriptive) that measured two indicators: analytical skills (describing the relationships between organisms and the roles of ecosystem components) and logical thinking skills (developing cause-and-effect patterns, simple algorithms, and drawing conclusions). The N-Gain test results showed a value of 0.7299, categorized as very high, indicating a significant improvement in student abilities after using the module.

Table 4. Categories N-Gain

Range N-Gain	Categories
$g > 0{,}70$	Very High
$0{,}30 < g \leq 0{,}70$	High
$g \leq 0{,}30$	Low

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pp. 844-852
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The normality test using the Kolmogorov–Smirnov test showed that the data were normally distributed (Sig. pretest = 0.163 and posttest = 0.077; > 0.05). Furthermore, the homogeneity test showed a significance value of 0.728 (> 0.05), so the data were declared homogeneous.

Table 5. Results of Normality and Homogeneity Tests

Test	Mark Sig.	Information
Pretest	0,163	Normal
Posttest	0,077	Normal
Homogenitas	0,728	Homogen

Based on the results of the paired sample t-test, the Sig. (2-tailed) value was <0.001 (<0.05), indicating a significant difference between the pretest and posttest scores. The mean difference value of -36.524 indicates an increase in learning outcomes after the treatment.

Table 6. Paired Sample T-Test Results

Aspect	Mark	Information
Sig. (2-tailed)	< 0,001	Significant
Mean Difference	-36,524	There has been an increase

Thus, it can be concluded that coding-based interactive modules are effective in improving students' analytical and logical thinking skills.

Discussion

The study results show that the interactive coding-based module achieved a very high validity level (average >93%), indicating that the module is appropriate in terms of content, presentation, language, and alignment with learning objectives. These findings are consistent with the study by Mahendri et al. (2025), which reported that interactive flipbook-based e-modules obtained very high feasibility scores. The integration of coding elements also strengthens the relevance of the module to 21st-century learning needs, particularly in developing critical thinking and digital literacy skills, as highlighted by Sakti (2025). In addition, research by Wing Wah Ki et al. (2022) demonstrated that coding-integrated learning environments significantly support students' computational thinking and problem-solving abilities in primary education contexts. Similarly, Yadav Aman et al. (2023) emphasized that coding-based instructional media can improve student engagement and conceptual understanding through interactive digital activities.

The practicality score of 91% demonstrates that the module is easy to implement by both teachers and students. Teachers found the module helpful in presenting science material more systematically and interactively, while students responded positively to ScratchJr-based coding activities because they made learning more engaging. This supports the findings of Maria et al. (2022), who stated that interactive learning media can enhance higher-order thinking skills and student independence. These findings are also aligned with research conducted by Marina Umaschi Bers (2020), which found that ScratchJr activities encourage active participation, creativity, and collaborative learning among elementary students. Furthermore, Karen Brennan and Mitchel Resnick (2019) argued that programming activities provide meaningful learning experiences by allowing students to create, test, and revise digital projects independently.

The effectiveness test showed a significant improvement in students' analytical and logical thinking skills (N-Gain = 0.7299; high category). This improvement occurred because ScratchJr activities trained students to think through computational thinking processes. When students modeled food chains using coding blocks, they first performed decomposition by

Vol. 12, No. 2 : June 2026
E-ISSN: 2442-7667
pp. 844-852
Email: jklppm@undikma.ac.id

breaking down the ecosystem concept into smaller components such as producers, consumers, and decomposers. Students then applied pattern recognition by identifying recurring relationships in the sequence of energy flow between living organisms. After recognizing these patterns, students arranged coding commands sequentially to form an algorithm, for example determining which character moves first, what actions occur next, and how interactions continue within the food chain simulation. These findings are strengthened by the study of Paulo Blikstein (2018), which explained that computational thinking activities help students develop logical reasoning through iterative problem-solving and debugging processes.

This process strengthened logical reasoning because students had to predict outcomes, correct errors, and reorganize command sequences when the simulation did not work as expected. ScratchJr also helped transform abstract ecosystem concepts into concrete visual experiences, enabling students in the concrete operational stage to understand causal relationships more easily, in line with Jean Piaget's cognitive development theory. Similar findings were reported by Linda Liukas (2021), who emphasized that visual programming environments support children's conceptual understanding by connecting abstract ideas with interactive and concrete representations. Therefore, the module not only improves science understanding but also develops computational thinking skills that are essential for learning in the digital era.

Conclusion

This study successfully developed an interactive coding-based module for food chain topics that meets high standards of validity, practicality, and effectiveness. Beyond its statistical success in enhancing analytical and logical thinking skills, the module offers a novel pedagogical framework by integrating computational thinking via ScratchJr into the elementary science curriculum. This integration allows students to transform abstract biological interdependencies into concrete, algorithmic representations. Consequently, this research provides a scalable blueprint for educators to foster 21st-century competencies within traditional subject areas. Future research should move beyond pilot-scale testing to longitudinal studies to assess the durability of these cognitive gains. Furthermore, investigating the transferability of the developed logical skills to other scientific domains remains a critical avenue for the broader implementation of coding-integrated learning.

Recommendation

Based on the development and evaluation of the coding-based IPAS module, the following recommendations are proposed:

- **Pedagogical Implications:** Educators are encouraged to adopt coding-integrated modules not merely as digital supplements but as primary tools for fostering analytical reasoning. It is recommended that teacher-learning communities (KKG) provide collaborative training on ScratchJr integration to ensure pedagogical consistency across different grade levels and scientific topics.
- **Technical and Curricular Development:** Future module iterations should explore more complex ecological systems or physical sciences to test the versatility of coding-based logic. Furthermore, incorporating adaptive learning features within the coding platform could address individual student variances in logical thinking progression discovered in this study.
- **Methodological Directions:** To strengthen the empirical evidence, future research should transition from pilot-scale interventions to large-scale, multi-site longitudinal

Vol. 12, No. 2 : June 2026
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pp. 844-852
Email: jklppm@undikma.ac.id

studies. Investigating the long-term retention of computational logic and its transferability to non-scientific problem-solving tasks would provide a more comprehensive understanding of the impact of coding literacy in primary education.

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