



Open-Ended Problems as a Strategy in Mathematics Modules to Enhance Students' Mathematics Computational Thinking

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Abstract

Computational thinking (CT) is a key competency in 21st-century mathematics education. However, Indonesian students still face challenges in decomposition, abstraction, and algorithmic reasoning due to learning resources dominated by single-solution problems. This study developed and evaluated a mathematics module based on open-ended problems to enhance students' CT skills in quadratic functions. The research adopted an R&D approach using the ADDIE model, including analysis, design, development, implementation, and evaluation. The process involved needs, curriculum, and learner analyses, followed by expert validation, practicality testing, and effectiveness evaluation. Three experts validated the module, while teachers and students assessed its practicality. Effectiveness was tested using a quasi-experimental pretest-posttest control group design involving 61 high school students. Data were analyzed using descriptive statistics, N-Gain, and inferential tests. Results showed the module was valid, practical, and effective in improving CT skills. The experimental group achieved significantly higher N-Gain ($p < 0.05$) than the control group, with abstraction and pattern recognition showing the greatest improvement.

Keywords: Open-Ended Problems, Mathematics Learning Module, Computational Thinking

Abstrak

Berpikir komputasional merupakan kompetensi penting dalam pendidikan matematika abad ke-21. Namun, siswa di Indonesia masih mengalami kesulitan dalam melakukan dekomposisi, abstraksi, dan penalaran algoritmik karena sumber belajar yang didominasi oleh soal dengan satu jawaban benar. Penelitian ini bertujuan untuk mengembangkan dan mengevaluasi modul pembelajaran matematika berbasis *open-ended problem* untuk meningkatkan kemampuan berpikir komputasional siswa pada materi fungsi kuadrat. Penelitian ini menggunakan metode *Research and Development* (R&D) dengan model ADDIE yang meliputi tahap analisis, desain, pengembangan, implementasi, dan evaluasi. Proses pengembangan mencakup analisis kebutuhan, kurikulum, dan karakteristik siswa, diikuti dengan validasi oleh tiga ahli pendidikan matematika dan media pembelajaran. Kepraktisan dinilai melalui tanggapan guru dan siswa, sedangkan efektivitas diuji menggunakan desain kuasi-eksperimen *pretest-posttest control group* dengan melibatkan 61 siswa SMA. Analisis data menggunakan statistik deskriptif, *N-Gain*, dan uji inferensial. Hasil penelitian menunjukkan bahwa modul valid, praktis, dan efektif dalam meningkatkan kemampuan berpikir komputasional. Kelompok eksperimen memperoleh *N-Gain* yang lebih tinggi secara signifikan ($p < 0,05$) dibandingkan kelompok kontrol, dengan peningkatan tertinggi pada aspek abstraksi dan pengenalan pola.

Kata Kunci: Masalah Terbuka, Modul Pembelajaran Matematika, Berpikir Komputasional

1. INTRODUCTION

Mathematics learning continues to evolve, not only in terms of methods but also in approaches that are more adaptive to the needs of the 21st century. Transformative learning that emphasizes exploration and creativity is essential to foster skills such as computational thinking (CT) in facing technological challenges (Putri et al., 2024). Exploratory learning enables students not only to understand mathematical concepts more deeply but also to develop critical and solution-oriented thinking patterns. Engelbrecht & Borba (2024) and Viberg et al., (2023) highlight that mathematics plays a significant role in technological advancement, requiring education to prepare students with computational thinking competence.

Since 2006, computational thinking has become a focus in educational research due to its relevance for academic and professional contexts (Nuraini et al., 2023). CT is defined as an essential competence that supports problem-solving and decision-making (Hsu et al., 2018). Within mathematics, computational thinking facilitates the decomposition of complex problems, abstraction, and algorithmic reasoning (Nuraini et al., 2023; Shute et al., 2017). Studies reveal that CT is positively correlated with critical and creative thinking skills, making it one of the core skills for success in the 21st century (Cahdriyana & Richardo, 2020; Putri et al., 2024).

The 2022 PISA results indicate that Indonesia remains below the international average in mathematical literacy, particularly in tasks requiring pattern recognition, decomposition, and algorithmic reasoning core components of CT (Juldial & Haryadi, 2024; OECD, 2023; Suwarno & Ardani, 2022). Preliminary observations at MAN 1 Mesuji confirmed that students' CT skills are still low. Classroom instruction and textbooks predominantly emphasize single-solution exercises, limiting students' opportunities to explore flexible strategies in problem-solving. Diagnostic assessments further show difficulties in decomposition, abstraction, and designing solution algorithms. This classroom condition contrasts with CT demands in modern mathematics learning and reinforces prior evidence that students struggle to apply CT concepts effectively (Grover & Pea, 2013; Tang et al., 2020).

These challenges suggest a gap between current learning practices and the competencies expected in the curriculum. Existing learning modules still focus on predetermined procedures and closed-ended tasks (Ariesandi et al., 2021), offering limited opportunities to cultivate CT. In fact, closed-ended instruction restricts students to a single correct solution, preventing them from practicing strategy selection (Bahar & June Maker, 2015), formulating alternative solutions, and transferring knowledge to unfamiliar situations which are essential elements of CT. Therefore, an innovative learning resource is required. Open-ended modules allow students to explore multiple pathways and authentic problems, encouraging creativity, and deeper reasoning (Keh et al., 2016). Based on this rationale, the present study proposes the development of an open-ended based quadratic function module that supports decomposition, pattern recognition, abstraction, and algorithmic reasoning. This module is expected to be valid, practical, and effective in enhancing students' computational thinking skills.

2. RESEARCH METHOD

This research is classified as research and development (R&D) aimed at producing a mathematics learning module based on open-ended problems to enhance students' computational thinking skills. The development model employed in this study is the ADDIE model (Branch, 2009), which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model is widely applied in instructional design because it provides a systematic and flexible framework for developing educational products such as modules, multimedia, and teaching materials. A clearer ADDIE flow can be seen in Figure 1 below:



Figure 1. The ADDIE Concept

The Analyze stage identified the needs and challenges in learning quadratic functions through curriculum review, student analysis, and teacher interviews. Results showed that learning remained conventional and students struggled with contextual and open-ended problems, indicating the necessity of an open-ended module to foster computational thinking. The Design stage focused on constructing the module structure, defining objectives aligned with the Merdeka Curriculum, preparing open-ended tasks, and designing a clear visual layout supported by icons, illustrations, and QR-based simulations. Validation instruments, questionnaires, and computational thinking tests were also developed. In the Development stage, the initial module draft was produced and validated by experts, with revisions applied based on their feedback to ensure validity. During Implementation, the module was tested through small-group and field trials using a control group pretest-posttest design to examine practicality and effectiveness. Continuous Evaluation occurred throughout all stages, refining the product until the module was feasible for broader classroom application.

The participants in this study included both experts and students. The validation process involved three experts who were knowledgeable about mathematics learning and the development of instructional media. These experts were selected based on their expertise in mathematics education, their experience in creating educational materials, and their involvement in teaching mathematics. The implementation stage consisted of two phases.

First, a small-group trial was conducted with 12 tenth-grade students to assess the practicality of the module. Next, a field trial was carried out with 61 students, who were divided into an experimental class and a control class. The experimental class comprised 31 students using the developed module based on open-ended problems, while the control class included 30 students who received conventional instruction.

This study employed expert validation sheets, practicality questionnaires, and a computational thinking test as research instruments. The validation sheets covered material and media aspects, examining content accuracy, curriculum alignment, clarity, visual design, and the integration of interactive features, with assessments provided by three experts in mathematics education and instructional media. Practicality was measured using student and teacher questionnaires to assess usability, clarity, appeal, and learning support. Meanwhile, the computational thinking test was developed to assess students' abilities in decomposition, abstraction, and algorithmic reasoning, with indicators adapted from the core components of computational thinking proposed by Wing (2006) ensuring strong alignment with the competencies expected in quadratic function learning.

The data analysis in this study consisted of three stages: validity, practicality, and effectiveness. Validity analysis was based on expert judgments, practicality analysis referred to student and teacher questionnaire results, and effectiveness analysis utilized students' computational thinking test scores.

1. Validity Analysis

The validity of the module was assessed through expert validation. The results were analyzed using the following percentage formula:

$$V = \frac{X - N}{M - N}$$

where V is the validity index, X is the total score given by the validator, N is the minimum possible score, and M is the maximum possible score. The classification categories are shown in Table 1.

Table 1. Validation Categories	
Validity Index (%)	Classification
81–100	Very Valid
61–80	Valid
41–60	Fairly Valid
21–40	Less Valid
10–20	Not Valid

2. Practicality Analysis

The practicality of the module was evaluated using student and teacher response questionnaires. The scores were analyzed with the same percentage formula:

$$P = \frac{X - N}{M - N}$$

where P is the practicality index, X is the obtained score, N is the minimum score, and M is the maximum score. The categories are shown in Table 2.

Table 2. Practicality Categories

Practicality Index (%)	Classification
85–100	Very Practical
70–84	Practical
55–69	Fairly Practical
50–54	Less Practical
0–49	Not Practical

3. Effectiveness Analysis

The effectiveness of the developed module was analyzed based on students' pretest and posttest scores of computational thinking in the experimental and control groups. The improvement was measured using normalized gain (N-Gain) (Hake, 1998):

$$g = \frac{S_{post} - S_{pre}}{S_{max} - S_{pre}}$$

where g is the gain score, S_{post} is the posttest score, S_{pre} is the pretest score, and S_{max} is the maximum score. The mean N-Gain was then classified as in Table 3.

Table 3. Categories of Average N-Gain Classification

Range ($\bar{g}$)	Classification
0.70–1.00	High Effectiveness
0.30–0.69	Moderate
0.00–0.29	Low Effectiveness

The statistical difference between the experimental and control groups was tested using an Independent Samples t-test, since the data met the assumptions of normality and homogeneity. This analysis was conducted to determine whether the open-ended-based module produced a significantly greater improvement in students' computational thinking skills compared to conventional instruction.

3. RESULTS AND DISCUSSION

3.1 Results

1. Descriptive Analysis

This study produced a mathematics learning module based on open-ended problems designed to improve students' computational thinking skills. The module covers quadratic

functions presented through open-ended activities, providing opportunities for students to explore various problem-solving strategies. The feasibility of the module was assessed in terms of validity, practicality, and effectiveness.

2. Validation Testing

The material expert validation focused on content feasibility, clarity of instruction, and the relevance of activities to computational thinking indicators. This process aimed to ensure that the developed module aligned with the learning objectives, presented accurate mathematical concepts, and provided open-ended tasks that effectively fostered computational thinking. The results of the material expert validation are shown in Table 4.

Table 4. Material Validation Results

Validator	M	N	X	P	Category
1	100	20	80	0.75	Valid
2	100	20	76	0.70	Valid
3	100	20	83	0.79	Valid

Kendall's W test (Asymp. Sig. = 0.067 > 0.05) indicated no significant difference among the three validators. Thus, the module was declared valid with revisions implemented according to experts' suggestions.

The revisions primarily addressed the content aspects, including:

- (1) Adjustment of learning objectives, ensuring their alignment with the indicators of computational thinking and the characteristics of open-ended problem-solving in mathematics;
- (2) Refinement of concept explanations, particularly in the sections introducing quadratic functions and problem-solving steps, to strengthen conceptual clarity and mathematical accuracy;
- (3) Improvement of problem examples, by providing open-ended questions that allow multiple strategies and solutions consistent with the intended learning outcomes; and
- (4) Enhancement of content coherence, through restructuring the flow of topics and ensuring logical progression between subtopics and activities.

Media experts evaluated readability, layout consistency, and accessibility. The results are presented in Table 5.

Table 5. Media Validation Results

Validator	M	N	X	P	Category
1	75	15	60	0.75	Valid
2	75	15	55	0.67	Valid
3	75	15	59	0.73	Valid

Kendall's W test (Asymp. Sig. = 0.108 > 0.05) showed no significant difference among validators. The module was declared valid after improving layout consistency, font uniformity, and visual quality. The revisions focused on improving the presentation and technical aspects of the module, including:

- (1) Layout enhancement, by reorganizing page composition to create a more balanced structure between text, figures, and activity spaces;
- (2) Visual design refinement, such as using consistent color schemes, increasing font readability, and adding iconographic cues to emphasize key concepts and procedures;
- (3) Optimization of figure and table placement, ensuring that illustrations directly support the explanation of mathematical concepts and open-ended problems; and
- (4) Improvement of media consistency and accessibility, including uniform margins, numbering, and formatting to facilitate smoother navigation and comprehension for students.

These revisions aimed to ensure that the developed module is visually coherent, pedagogically supportive, and technically suitable for classroom implementation.

3. Practicality Testing

Table 6. Teacher's Response

Total Score	Min	Max	Index (P)	Category
82	20	100	0.78	Practical

The teacher found the module systematic, easy to understand, and supportive of computational thinking development.

Table 7. Students' Response

Aspect	Total Score	Ideal Score	Index (P)	Category
Appearance	269	300	0.87	Very Practical
Content	108	120	0.88	Very Practical
Usefulness	170	180	0.93	Very Practical
Overall	547	600	0.89	Very Practical

Students perceived the module as attractive, easy to use, and motivating, supporting its practicality. The module was categorized as *practical* based on both teacher and student responses. This result aligns with the initial design considerations during the module development. From the beginning, the module was intentionally structured to provide open-ended learning experiences that allow students to explore multiple solution paths while engaging with computational thinking processes. The learning activities were designed to be contextually relevant, visually clear, and adaptable for classroom use, reducing the need for additional teacher explanation. The integration of step-by-step guidance, attractive layout, and open-ended tasks also contributed to ease of use and student engagement. These design principles made the module not only easy to

implement but also enjoyable and effective from the users' perspective, leading to its classification as *very practical*.

4. Effectiveness Testing

The effectiveness of the developed open-ended mathematics learning module was examined to determine its impact on students' computational thinking skills. The analysis was carried out through descriptive statistics, N-Gain computation, and inferential testing using normality, homogeneity, and t-tests, complemented by a mastery proportion test and indicator-based evaluation.

The descriptive analysis of students' pretest and posttest scores in both the experimental and control classes is presented in Table 8.

Table 8. Descriptive Analysis of Pretest and Posttest Scores

Class	Test	Mean	SD	Max	Min
Experiment	Pretest	24.1	8.3	40.0	8.3
Experiment	Posttest	78.0	8.5	91.7	61.7
Control	Pretest	23.7	8.2	38.3	8.3
Control	Posttest	73.1	9.0	86.7	51.7

As shown in Table 8, both groups started with comparable pretest means, indicating similar initial abilities. However, after the intervention, the experimental group achieved a higher posttest mean (78.0) than the control group (73.1), suggesting that the developed module contributed to greater improvement.

To measure the level of improvement more precisely, the normalized gain (N-Gain) was calculated for each class. The results are presented in Table 9.

Table 9. N-Gain Analysis of Computational Thinking Skills

Class	Mean N-Gain	SD	Category
Experiment	0.76	0.15	High
Control	0.63	0.17	Moderate

Based on Table 9, the mean N-Gain of the experimental class (0.76) falls into the high category (Hake, 1998), while the control class achieved a moderate level of improvement (0.63). This indicates that the learning module successfully facilitated a greater proportional increase in students' computational thinking skills compared to conventional instruction.

Before testing the significance of the difference between classes, normality and homogeneity assumptions were evaluated.

Table 10. Results of Normality and Homogeneity Tests

Class	Data	Sig.	α	Conclusion
Experiment	N-Gain	0.543	0.05	Normal
Control	N-Gain	0.109	0.05	Normal
Data	N-Gain	0.984	0.05	Homogeneous

The results in Table 10 indicate that the N-Gain data were normally distributed and homogeneous, fulfilling the prerequisites for parametric analysis using the independent samples t-test.

The results of the t-test revealed a significance value of Sig. (2-tailed) = 0.004 < 0.05, indicating a statistically significant difference in N-Gain between the two classes. This finding confirms that the higher improvement in the experimental group was attributable to the implementation of the open-ended mathematics learning module, not to random variation or prior ability differences.

To further validate this finding, a proportion test was conducted to examine the percentage of students who achieved mastery learning (score ≥ 70) after using the module.

Table 11. Results of Proportion Test

Information	Value
Number of students	28
Students ≥ 70	23
Mastery proportion	82%
Minimum proportion tested	60%
Sig. (Exact Sig. 1-tailed)	0.011

As shown in Table 11, 82% of students in the experimental class achieved mastery learning, significantly exceeding the minimum benchmark of 60% ($p = 0.011 < 0.05$). This confirms that the majority of students benefited from the learning intervention, supporting the conclusion that the developed module effectively facilitated learning mastery.

In addition to overall effectiveness, an analysis of the four computational thinking indicators decomposition, abstraction, pattern recognition, and algorithmic thinking was conducted to identify areas of greatest improvement.

Table 12. Indicator Analysis of Computational Thinking Skills

Indicator	Pretest	Posttest	N-Gain	Category
Decomposition	5.32	14.81	0.75	High
Abstraction	4.52	10.71	0.83	High
Pattern	2.19	9.74	0.77	High
Algorithm	2.42	11.55	0.59	Moderate

The results in Table 12 show substantial improvement across all indicators, with the highest gains in abstraction (0.83) and pattern recognition (0.77). These aspects reflect conceptual understanding and flexible reasoning—core components of computational thinking. Decomposition (0.75) also achieved a high category, indicating that students became better at breaking problems into subcomponents. Meanwhile, the algorithmic thinking indicator (0.59) showed moderate improvement, suggesting that while students could plan and implement procedures, further practice is needed to strengthen procedural fluency. This pattern of improvement indicates that open-ended problem activities particularly enhance students' ability to interpret and generalize quadratic function concepts, although sustained scaffolding is still required to further strengthen their algorithmic skills in constructing and applying step-by-step solution processes.

Based on the overall results of the N-Gain analysis, independent t-test, and proportion test, it can be concluded that the mathematics learning module based on open-ended problems is effective in improving students' computational thinking skills. The module not only produced significant learning gains compared to conventional instruction but also enabled more than 80% of students to achieve mastery learning. These findings confirm that the developed module meets the criteria of effectiveness, demonstrating its potential as an innovative and reliable learning tool for enhancing computational thinking in mathematics classrooms.

3.2 Discussion

The findings of this study indicate that the open-ended mathematics learning module is valid, practical, and effective in enhancing students' computational thinking skills. Validation by material experts confirmed that the module was appropriate, although several revisions were necessary. The improvements primarily concerned the clarity of instructions, the addition of teacher guidelines, and the arrangement of learning activities so that the flow was more systematic. Before revision, some instructions were ambiguous and less operational, which could lead to misinterpretation by students. This result is consistent with Purwoko et al. (2023) and Ravista et al. (2021), who emphasized that clear and structured instructions minimize variation in students' interpretation and improve the effectiveness of learning. Similarly, Gess-Newsome et al. (2019) argue that high-quality learning materials should combine substantive accuracy with pedagogical clarity. In this sense, the module revisions strengthened not only the technical aspects but also the constructivist foundation of the learning design.

Validation by media experts highlighted the importance of layout consistency, readability, and the contextual use of illustrations. Initially, the module displayed uneven font sizes, disproportionate spacing, and images that were not fully aligned with the subject matter. After revisions, the layout became more consistent, color contrast more comfortable, and

illustrations more relevant to quadratic function concepts. These findings are in line with Pastore (2016) and Ögren et al. (2016), who emphasized that high-quality visual design reduces students' cognitive load and increases motivation. In this way, the media validation ensured that the module was not only theoretically sound but also visually engaging and effective as a teaching medium.

From the perspective of teachers, the module was rated highly practical as it was equipped with clear usage guidelines, structured learning flow, and adaptable open-ended tasks. This finding supports Rosanti (2024), Siburian & Zetriuslita (2023), and Ummah et al. (Ummah et al., 2024), who state that practical teaching materials are those that are user-friendly, ready to apply, and require minimal modification. Meanwhile, students also considered the module practical and attractive. They found the content understandable, the design appealing, and the activities challenging yet clear. The role of clear instructions is particularly critical, as Zulhendri & Muhandaz (2020) emphasized that open-ended tasks are only effective if students can comprehend the instructions and engage actively in problem-solving.

The effectiveness of the module was reflected in the significant differences between the experimental and control groups in the pretest-posttest results. Students in the experimental class achieved higher N-Gain scores, with more than 80% reaching the mastery threshold. These findings are supported by Aziz et al. (2025) and Indah et al. (2018), who demonstrated that open-ended approaches enhance mathematical problem-solving and computational reasoning skills. Furthermore, according to Hake (1998), the moderate-to-high N-Gain scores confirm that the module represents an effective learning innovation.

Analysis by computational thinking indicators revealed that abstraction and pattern recognition improved most significantly, followed by decomposition, while algorithmic thinking improved only moderately. This suggests that the module is particularly effective in promoting conceptual and strategic thinking, but algorithmic skills require further reinforcement. This result is in line with Cahdriyana & Richardo (2020), who noted that open-ended learning develops flexible mathematical thinking, though structured practice is needed to strengthen algorithmic reasoning.

The findings of this study have several implications for mathematics education. From a theoretical perspective, the successful implementation of an open-ended problem-based module reinforces the constructivist view of learning, which emphasizes that students build knowledge actively through exploration and reflection. The evidence that abstraction and pattern recognition improved significantly indicates that open-ended tasks can stimulate higher-order thinking and computational reasoning. This contributes to the growing body of research that positions computational thinking not only as a skill related to computer science, but also as an essential mathematical competency.

From a practical perspective, the module provides teachers with a ready-to-use learning resource that integrates open-ended problems into the teaching of quadratic functions. The practicality confirmed by both teachers and students suggests that such modules can be directly adopted in classroom practice without requiring substantial modification. Teachers benefit from the structured flow and clear guidance, while students find the activities engaging and motivating. This highlights the potential of the module to be used as a model for designing other mathematics learning materials, particularly for topics that demand exploration and multiple solution strategies.

The study also has implications for future research. While the module was effective in developing most aspects of computational thinking, algorithmic reasoning showed only moderate improvement. This indicates the need for further investigation into instructional strategies that specifically strengthen students' ability to construct systematic procedures. Moreover, the time-consuming nature of open-ended tasks suggests that future studies should explore models of time management or blended learning that balance exploration with curriculum demands. Expanding the module to different mathematical topics and levels of schooling would also provide a broader understanding of its applicability. Overall, the implications underline that integrating open-ended problems into mathematics instruction is not only feasible but also impactful for fostering computational thinking.

4. CONCLUSIONS

This study aimed to develop an open-ended-based mathematics module on quadratic functions and evaluate its validity, practicality, and effectiveness in improving students' computational thinking skills. The validation results indicated that the content, structure, and media design of the module met the established criteria of a valid instructional product after undergoing expert-guided revisions. Furthermore, teacher and student response data confirmed that the module was easy to implement, engaging, and supported learning activities effectively, demonstrating its strong practicality. Effectiveness testing also showed that students in the experimental class achieved significantly higher learning outcomes compared to those in the control class, including substantial improvements in decomposition, pattern recognition, and abstraction skills, as well as moderate progress in algorithmic reasoning. These results collectively verify that the developed module is valid, practical, and effective in supporting students' computational thinking development.

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6. REKOMENDATIONS

This study confirmed the module's validity, practicality, and effectiveness, yet several limitations remain. Students showed only moderate improvement in algorithmic reasoning, indicating challenges in developing systematic procedures. The open-ended tasks also required more instructional time, making classroom implementation less efficient. Additionally, the research was limited to quadratic functions in one school, restricting generalizability. Future studies should include stronger scaffolding for algorithmic reasoning, explore time-efficient or technology-assisted strategies, and apply the module to broader topics, levels, and school contexts to enhance external validity.

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