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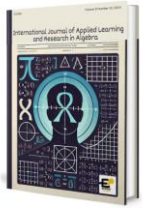

Developing Teaching Materials to Enhance Critical Thinking Skills through Group Investigation in Composite Functions

Anggun Apriliani[1], Nia Kania[2*], Nasir Umar[3]

[1,2]Universitas Majalengka, Indonesia
[3]Abubakar Tafawa Balewa University Bauchi, Nigeria

*Corresponding author: niakania@unma.ac.id

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Abstract

This study aims to develop Group Investigation (GI)-based teaching materials to enhance the critical thinking skills of vocational high school (SMK) students in understanding and solving problems related to composition functions. Using the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), the research produced teaching materials validated by subject matter experts, ensuring their quality, relevance, and alignment with curriculum objectives. Through GI stages—grouping, planning, investigation, organizing, presenting, and evaluating—students not only deepened their understanding of composition functions but also developed critical thinking, problem-solving, and teamwork skills. The findings highlight contribute to the development of innovative teaching materials and provide a foundation for transforming mathematics education into a more practical and effective discipline, particularly for vocational students.

Keywords: Composite Functions; Critical Thinking Skills; Developing; Group Investigation; Teaching Materials.

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1. Introduction

Recent research highlights the importance of early algebraic thinking in enhancing students' mathematical abilities. Studies show that algebraic thinking is linked to fundamental cognitive processes, including spatial-imaginal, causal-experimental, qualitative-analytic, and verbal-propositional systems (Chimoni & Pitta-Pantazi, 2017). Early introduction to algebra can significantly improve students' critical thinking skills, with evidence suggesting that even young children have the capacity for algebraic reasoning, particularly in recursive and functional thinking when solving pattern problems (Afonso & Mc Auliffe, 2019). Teachers play a crucial role in promoting algebraic thinking through appropriate instructional practices and non-routine activities (Sibgatullin et al., 2022). Research also emphasizes the importance of exploring physical models and implementing strategies such as geometry representation and multiple representation techniques to enhance algebraic thinking (Cañadas et al., 2019). These findings suggest a need to reconsider traditional approaches to algebra instruction and incorporate pattern-based methods from an early age.

Mathematical critical thinking ability is a cornerstone of academic and professional success (Kania, Fitriani, et al., 2023), particularly for vocational high school students who are often required to apply these skills in real-world, problem-solving contexts (Efendi1 & Suastra, 2023). This ability enables students to interpret, analyze, and evaluate mathematical problems systematically, fostering a deeper understanding of complex concepts and enhancing their capacity to make informed decisions. Recent research underscores the significant positive correlation between computational thinking skills and mathematical critical thinking ability (Göran & Britt-Marie, 2014), suggesting that students with higher computational thinking proficiency demonstrate superior performance in tackling mathematical challenges (Angraini et al., 2024; Kania & Kusumah, 2025). Computational thinking, which encompasses problem decomposition, pattern recognition, abstraction, and algorithmic thinking, provides a structured framework that complements and amplifies critical thinking processes in mathematics.

This synergy between computational and mathematical critical thinking has profound implications for educational practices, particularly in vocational high school settings (Yassir et al., 2022) where problem-solving (Kania, Kusumah, Dahlan, Nurlaelah, Gürbüz, et al., 2024) and analytical skills (Malalina et al., 2023) are paramount. By integrating computational thinking into mathematics curricula, educators can create more engaging and effective learning environments that not only enhance students' mathematical proficiency but also prepare them for the demands of a technology-driven workforce (Kania, Suryadi, et al., 2024; Reid O'Connor & Norton, 2024; Riccomini et al., 2015) . Furthermore, the development of teaching strategies and materials that explicitly link computational thinking to critical thinking in mathematics could catalyze improving student outcomes. Future research should explore the longitudinal impacts of such interventions, as well as the potential for cross-disciplinary applications of these skills in STEM (Science, Technology, Engineering, and Mathematics) education.

The development of mathematical critical thinking skills is a pivotal educational objective, with implications for academic success and real-world problem-solving across all levels of education (Kania, Santoso, et al., 2023; Rohyana et al., 2024; Walters et al., 2018). Recent research highlights the efficacy of innovative teaching models and strategies in fostering these skills, tailored to the unique needs and cognitive processes of learners at different stages. For instance, the Group Investigation (GI) model has demonstrated significant potential in enhancing critical thinking performance among elementary school students in mathematics (Chytrý et al., 2020; Wijayanto et al., 2023). By promoting collaborative inquiry and active engagement, the GI model encourages students to explore mathematical concepts deeply, analyze problems systematically, and evaluate solutions critically. At the higher education level, functional thinking processes have been identified as a critical component in understanding complex mathematical topics, such as function composition (Kania et al., 2020). These processes enable students to deconstruct problems, identify patterns, and apply abstract reasoning, thereby strengthening their ability to think critically and solve mathematical challenges effectively. Furthermore, the integration of open-ended questions and activities, designed to align with student learning preferences, has proven effective across all achievement levels (Carnine, 1997; Fatade et al., 2013; Hidajat, 2021). Such approaches not only cater to diverse learning styles but also foster creativity, independence, and a deeper conceptual understanding of mathematics.

The ADDIE (Analysis, Design, Development, Implementation, Evaluation) model stands as a robust and versatile framework for the systematic development of instructional materials across diverse educational and professional contexts (Alsaleh, 2020; Saputri & Hadi, 2021). Its structured, five-phase approach—spanning analysis, design, development, implementation, and evaluation—ensures that instructional materials are not only tailored to meet specific learning needs but also aligned with the goals of stakeholders, thereby fostering user buy-in and engagement. The iterative nature of the ADDIE model promotes continuous improvement, allowing designers to refine materials based on feedback and evolving requirements. This adaptability has enabled the model to transcend traditional instructional design, finding applications in innovative domains such as funding proposal development (Mudjisusatyo et al., 2024), where its systematic approach enhances clarity, coherence, and impact. For instance, the model's emphasis on thorough analysis ensures that materials address learners' prior knowledge and skill gaps, while its design and development phases facilitate the creation of engaging, pedagogically sound resources.

The implementation phase focuses on seamless integration into existing curricula, and the evaluation phase provides critical insights for iterative refinement. This holistic approach not only enhances the quality of instructional materials but also empowers educators to deliver more effective and impactful learning experiences. The versatility of the ADDIE model makes it particularly valuable in addressing the complexities of modern education (Sitepu et al., 2020), where the demand for personalized (Walkington, 2013), adaptive (Garcia-Ortiz et al., 2024), and technology-enhanced learning solutions is growing (Yuliati & Lestari, 2018). By leveraging the model's structured framework, educators and instructional designers can develop materials that are both innovative and evidence-based, ensuring that learners are equipped with the skills and knowledge needed to thrive in a rapidly changing world. Future research should explore the scalability of ADDIE-based interventions across different educational settings, as well as their potential for integration with emerging technologies such as artificial intelligence and virtual reality. Such investigations could further solidify the model's position as a cornerstone of instructional design and a catalyst for transformative educational practices.

The development of critical thinking skills is a central goal in mathematics education, particularly in the context of complex topics such as composite functions (Evans & Jeong, 2023; Wijayanto et al., 2023). This study explores the design, implementation, and evaluation of teaching materials grounded in the GI model, aimed at enhancing students' critical thinking abilities in understanding and solving composite function problems. The GI model, which emphasizes collaborative inquiry, problem-solving, and active engagement, provides a robust framework for fostering higher-order thinking skills (Chytrý et al., 2020; Sulistianingsih & Amir, 2021). This study employs a Research and Development (R&D) approach to design, implement, and evaluate teaching materials grounded in the Group Investigation (GI) model, aimed at enhancing students' critical thinking abilities in understanding and solving composite function problems.

2. Methods

This research is a Research and Development (R&D) initiative aimed at designing instructional materials centred on circle-related topics through a discovery-based approach (Alsaleh, 2020; Smith, 2019). The study employs the ADDIE development model, a robust and flexible framework widely recognized in development research. The ADDIE model consists of five iterative phases: analysis, design, development, implementation, and evaluation. During the analysis phase, the necessity for creating new instructional resources (such as models, methods, media, and training materials) is assessed, along with evaluating the feasibility and prerequisites for product development. Figure 1 illustrates the sequential progression of the ADDIE model within this research context.

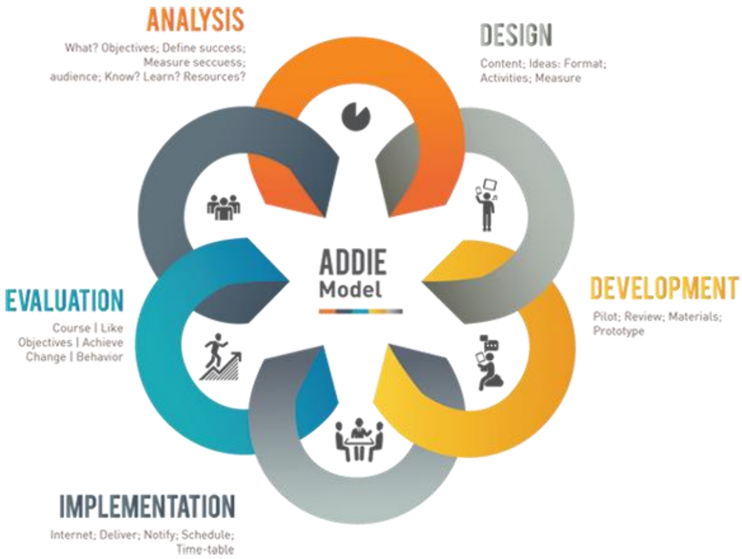


Figure 1 ADDIE Stage

(source: google.com)

The design phase involves a systematic process of conceptualizing the product and structuring its content. The development phase focuses on transforming the conceptualized ideas into tangible instructional resources. The implementation phase entails the practical deployment of the developed product within the ADDIE framework to collect user feedback and identify potential improvements. The evaluation phase provides critical feedback to users, enabling refinements based on assessment outcomes or unmet needs. However, due to time limitations, this study primarily concentrates on the development phase, with other phases being excluded.

3. Results and Discussion

3.1. Results

This study produces high-quality, reliable instructional resources focused on circle-related topics, designed to significantly improve mathematical problem-solving skills. The development of these teaching materials adheres to the ADDIE framework, with a specific emphasis on the development stage due to project constraints. The outcomes of this research are detailed in the subsequent phases of the development process, highlighting the systematic creation and refinement of the resources.

3.1.1. Analysis stage

The initial phase of the ADDIE development paradigm is analysis. The ADDIE model, a fundamental framework in instructional systems design, begins with the critical analysis phase. This initial stage has evolved from simply analyzing content to identifying performance gaps and organizational needs (Yabu, 2021). It serves as the foundation for subsequent phases, encompassing needs assessment, goal determination, audience analysis, and resource consideration (Masuku et al., 2020). The analysis phase informs problem identification, learning objectives, and existing knowledge assessment (Dewanti et al., 2020). While some criticize ADDIE as overly systematic and inflexible. its structured approach ensures effective development of instructional systems, including mobile applications. The model's other phases—design, development, implementation, and evaluation—build upon the analysis stage, with formative assessment occurring throughout the process. Despite critiques, the analysis phase remains crucial in shaping the entire instructional design process and addressing performance improvement needs.

The initial phase of the ADDIE development paradigm involves a comprehensive analysis to determine the necessity and feasibility of developing new educational products. At this stage, the practicality and prerequisites for product development are thoroughly evaluated. Research conducted at Al Gozali Majalengka Vocational School highlights a significant need for the development of teaching materials aimed at enhancing students' critical thinking skills, particularly in the context of composition function material. This need is substantiated by the substandard test scores of students across varying ability levels. Specifically, the assessment results reveal that only high-proficiency students were able to answer the questions with limited success, indicating a widespread lack of comprehension among the majority of students. Furthermore, interviews with students underscore that their limited understanding stems primarily from difficulties in grasping the concept of composition functions.

The inadequacy of existing teaching materials in fostering and improving critical thinking skills further exacerbates this issue (Szabo et al., 2020). Teachers also reported that the overreliance on textbooks as the sole instructional resource leads to student disengagement and apathy, particularly in mathematics. Consequently, there is a pressing need to develop more engaging and effective teaching resources to enhance students' critical thinking abilities (Alshammari, 2021). In response, the researchers propose the creation of innovative educational materials centered on the theme of composition functions, incorporating progressive learning stages to address these challenges effectively. This approach aims to provide a more dynamic and interactive learning experience, ultimately improving students' proficiency in critical thinking and mathematical comprehension.

3.1.2. Design Stage

The ADDIE research and development model activities adhere to a systematic approach that commences with designing the product's concept and content. The activities of the ADDIE research and development model adhere to a systematic approach, beginning with the design of the product's concept and content. This initial phase involves the creation of instructional materials using the Group Investigation (GI) approach within the context of composition function material. The process entails identifying and gathering relevant materials, selecting appropriate applications, and detailing the production process.

The phases of the ADDIE model, a methodological framework for instructional design, are structured to ensure a comprehensive learning experience (Sitepu et al., 2020). The first step involves conducting an analysis to understand the learning context, including identifying needs, goals, and objectives. The subsequent phase, known as design, focuses on selecting suitable resources and establishing the teaching strategy. Following this, the development phase utilizes all gathered information as the foundation for creating the instructional materials. The implementation phase then involves delivering the developed learning materials to students. The evaluation phase provides feedback on the effectiveness and efficiency of the training process. The logical progression of each phase ensures a comprehensive and effective instructional design methodology.

The source materials used include textbooks aligned with the prescribed curriculum. The design process involves developing educational materials that follow a series of discovery-based steps, specifically tailored to the GI approach. These steps include summarizing and organizing content to align with the GI process. Figure 2 illustrates the outcomes of creating educational resources that incorporate a sequence of GI-based activities within the composition function material. Below are the composition function materials developed in accordance with the GI steps, aimed at enhancing critical thinking skills:

GROUPING ACTIVITY

Create a study group with a maximum of 5 people!

Figure 2 Grouping Activity

The grouping activity is a critical component of the Group Investigation (GI) approach, designed to foster collaborative learning and enhance critical thinking skills. In this phase, students are organized into small, heterogeneous groups based on their abilities, interests, or other relevant criteria. Each group is assigned a specific task or problem related to the composition function material, encouraging active participation and collective problem-solving.

The grouping activity serves as the foundation for the GI process, enabling students to engage in discussions, share diverse perspectives, and collaboratively explore solutions (Wijayanto et al., 2023). This structured interaction not only promotes deeper understanding of the subject matter but also cultivates essential skills such as communication, teamwork, and analytical thinking. The outcomes of this activity are then used as a basis for further investigation and presentation, aligning with the progressive stages of the GI approach.

PLANNING ACTIVITY

Pay attention to the following topics!

Topic 1:

It is known that book production goes through the editorial stage by following the function f(x)=4x+5 and the book printing process follows the function g(x)=10x+5.

The process of making tempeh goes through the boiling stage followed by the fermentation stage. The boiling stage is expressed by the function f(x)=3x+5 and the fermentation stage is expressed by the function g(x)=5x-7.

Topic 2:

It is known that novel creation goes through the editorial stage by following the function f(x)=2x+5 and the novel printing process follows the function g(x)=3x-4.

In the process of making tofu, it goes through the cooking stage followed by the clotting stage. The ripening stage is expressed by the function f(x)=2x+1 and the coagulation stage is expressed by the function g(x)=x-2

Topic 3:

It is known that making cloth goes through two stages. The first stage is the process from cotton to yarn by following the function f(x)=3x+4. The second process from thread to fabric follows the function g(x)=5x-4.

A clothing designer will make a shirt through two stages. The designing stage is expressed by the function f(x)=3x+5 and the sewing stage is expressed by the function g(x)=5x-7.

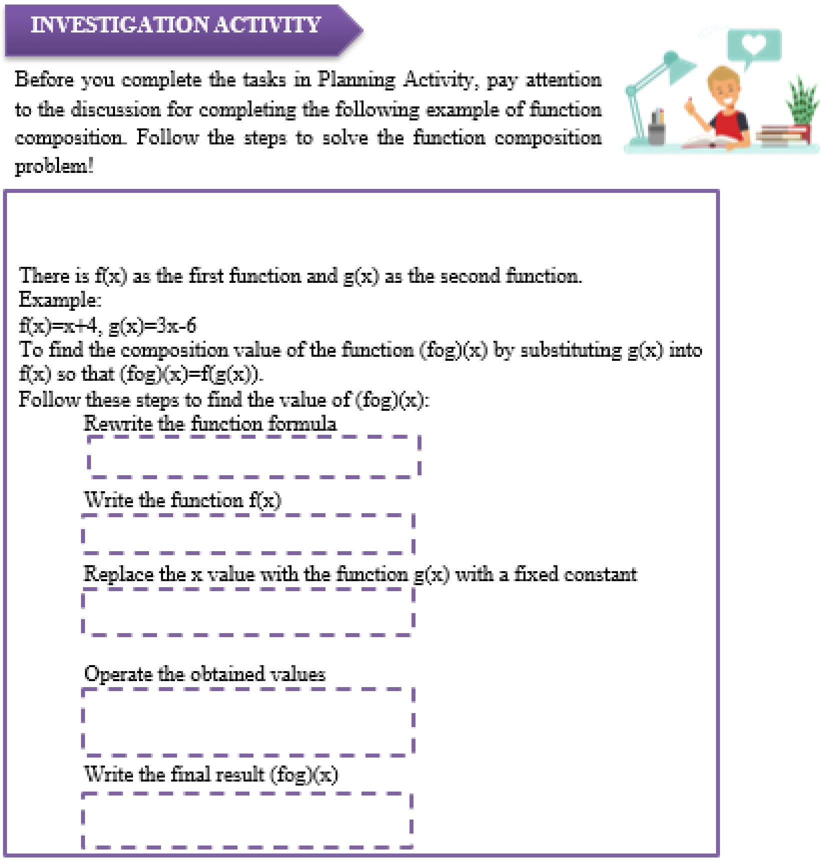
From these three topics, determine the functional composition!

*Groups 1 and 2 will complete topic 1, groups 3 and 4 will complete topic 2, groups 5 and 6 will complete topic 3.

Figure 3 Planning Activity

The planning activity is a pivotal stage in the Group Investigation (GI) approach, where students collaboratively design a strategy to investigate and solve the assigned problem or task related to the composition function material. During this phase, group members discuss and outline the steps necessary to achieve their learning objectives, including defining roles, allocating tasks, and determining the resources and methods required for their investigation.

This activity emphasizes critical thinking and organizational skills, as students must analyze the problem, set clear goals, and develop a logical plan of action. The planning process encourages active participation, fosters teamwork, and ensures that all group members are aligned with the group's objectives (Chytrý et al., 2020; Kania, Kusumah, Dahlan, Nurlaelah, & Arifin, 2024). By engaging in this structured planning, students take ownership of their learning and develop a deeper understanding of the material through a systematic and inquiry-based approach. Figure 2 visually illustrates the planning activity, showcasing its role in guiding students through the initial stages of the GI process. This stage lays the groundwork for subsequent phases, such as investigation and presentation, and highlights its importance in promoting collaborative problem-solving and enhancing critical thinking skills.


INVESTIGATION ACTIVITY

Before you complete the tasks in Planning Activity, pay attention to the discussion for completing the following example of function composition. Follow the steps to solve the function composition problem!

There is f(x) as the first function and g(x) as the second function.
Example:
f(x)=x+4, g(x)=3x-6
To find the composition value of the function (fog)(x) by substituting g(x) into f(x) so that (fog)(x)=f(g(x)).
Follow these steps to find the value of (fog)(x):
Rewrite the function formula
Write the function f(x)
Replace the x value with the function g(x) with a fixed constant
Operate the obtained values
Write the final result (fog)(x)

Figure 4 Investigation Activity

The investigation activity is the core phase of the Group Investigation (GI) approach, where students actively engage in exploring, analyzing, and solving the problem or task assigned to their group. During this stage, group members utilize the plan developed in the previous phase to gather information, conduct research, and apply critical thinking skills to understand the composition function material in depth.

This activity involves collaborative efforts, such as sharing ideas, testing hypotheses, and synthesizing findings. Students are encouraged to use various resources, including textbooks, digital tools, and peer discussions, to support their investigation (Brown & Usoro, 2023; Sulistianingsih & Amir, 2021). The process not only enhances their understanding of the subject matter but also develops essential skills such as analytical reasoning, problem-solving, and effective communication.

Figure 3 visually represents the investigation activity, highlighting its dynamic and interactive nature. It underscores the importance of this phase in fostering student engagement, promoting inquiry-based learning, and achieving the learning objectives of the GI approach. The outcomes of this activity serve as the foundation for the final presentation and evaluation stages, ensuring a comprehensive and meaningful learning experience.

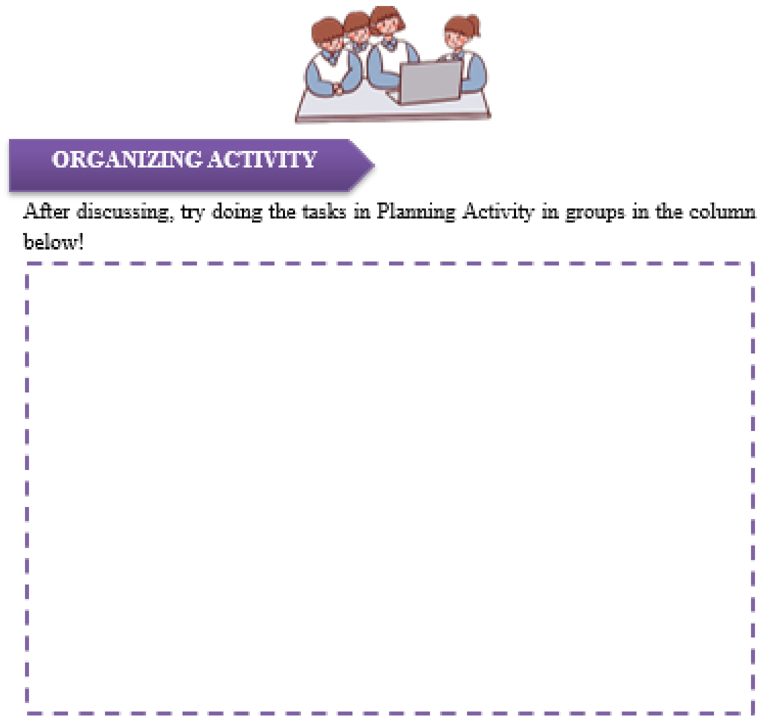


Figure 5 Organizing Activity

The organizing activity is a crucial stage in the Group Investigation (GI) approach, where students systematically structure and synthesize the information gathered during the investigation phase. In this stage, group members collaborate to organize their findings, analyze data, and prepare a coherent presentation or report that effectively communicates their results. This activity emphasizes critical thinking, teamwork, and organizational skills, as students must categorize information, identify key insights, and develop a logical flow for their presentation (Güven & Alpaslan, 2022; Parindang et al., 2024). The organizing process ensures that the group's work is clear, concise, and well-structured, enabling them to convey their understanding of the composition function material effectively.

Figure 4 visually illustrates the organizing activity, showcasing its role in transforming raw data and findings into a structured and meaningful output. This stage bridges the gap between investigation and presentation, ensuring that students are well-prepared to share their insights and demonstrate their learning outcomes. By engaging in this activity, students further develop their ability to think critically, work collaboratively, and present information in a compelling manner.

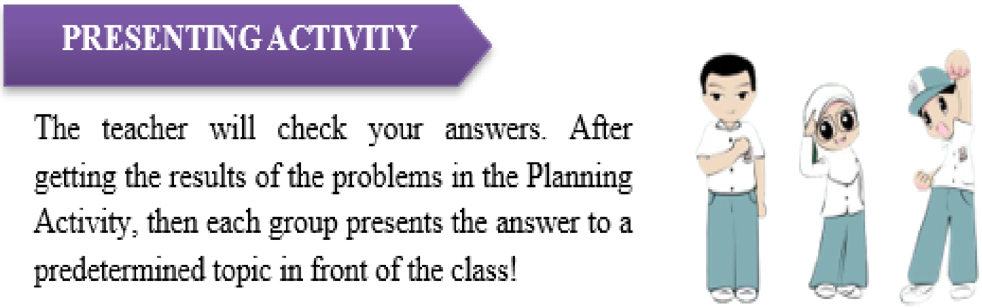
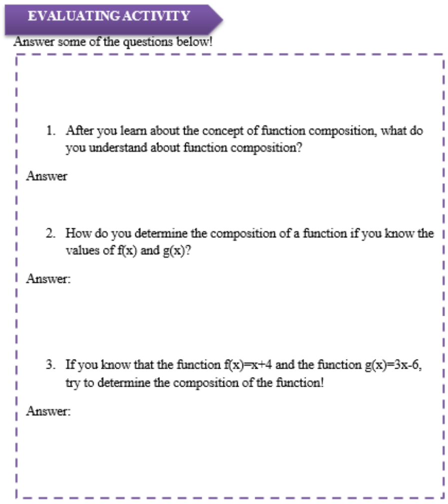


Figure 6 Presenting Activity

The presenting activity is the culminating stage of the Group Investigation (GI) approach, where students share their findings and insights with the entire class. During this phase, each group presents the results of their investigation, organized and synthesized during the previous stages, in a clear and engaging manner. This activity not only demonstrates their understanding of the composition function material but also highlights their ability to communicate effectively and work collaboratively.

The presenting activity encourages students to use various presentation tools and techniques, such as visual aids, demonstrations, or interactive discussions, to convey their ideas. It fosters public speaking skills, confidence, and the ability to respond to questions or feedback from peers and instructors (Güven & Alpaslan, 2022; Muryanti, 2023). Additionally, this stage provides an opportunity for the class to learn from each group's unique perspective and approach, enriching the overall learning experience.

Figure 5 visually represents the presenting activity, emphasizing its role in showcasing the outcomes of the GI process. This stage reinforces the importance of collaboration, critical thinking, and effective communication, ensuring that students not only understand the material but can also articulate their learning in a meaningful and impactful way.



EVALUATING ACTIVITY

Answer some of the questions below!

1. After you learn about the concept of function composition, what do you understand about function composition?

Answer

2. How do you determine the composition of a function if you know the values of f(x) and g(x)?

Answer:

3. If you know that the function f(x)=x+4 and the function g(x)=3x-6, try to determine the composition of the function!

Answer:

Figure 7 Evaluating Activity

The evaluating activity is the final and reflective stage of the Group Investigation (GI) approach, where students and instructors assess the effectiveness of the learning process and the outcomes achieved. During this phase, both individual and group performances are evaluated based on predefined criteria, such as the depth of understanding, quality of collaboration, critical thinking demonstrated, and the clarity of the presentation. This activity involves self-assessment, peer feedback, and instructor evaluation, providing a comprehensive perspective on the learning experience (Kokotsaki et al., 2016; Lee et al., 2022). Students reflect on their contributions, identify strengths, and recognize areas for improvement. Instructors offer constructive feedback to guide future learning and reinforce key concepts related to the composition function material.

Figure 5 visually represents the evaluating activity, highlighting its role in closing the learning cycle. This stage ensures accountability, promotes continuous improvement, and reinforces the development of critical thinking, collaboration, and self-reflection skills. By engaging in this activity, students gain a deeper understanding of their learning journey and are better prepared to apply their knowledge and skills in future academic or real-world contexts.

3.1.3. Development Stage

The next stage in the process is the development stage, which includes a validation process. This step is crucial for refining and finalizing the teaching materials that were initially designed, particularly those that integrate mathematical concepts such as composite functions and the Guided Inquiry (GI) model. The goal is to produce the ultimate version of the teaching materials, ensuring they are accurate, effective, and aligned with the learning objectives, especially in fostering critical thinking skills among vocational high school (SMK) students.

During this stage, the teaching materials, which incorporate the GI for composite functions material and the application of composite functions within the context of real-world problems, are reviewed and validated by subject matter experts. These experts evaluate the content for its educational quality, relevance, and adherence to the curriculum. Specifically, they assess how well the Guided Inquiry (GI) model is integrated to encourage active student participation, problem-solving, and critical thinking. The validation process ensures that the materials are scientifically sound, pedagogically effective, and suitable for the intended audience, particularly SMK students who require practical and applicable knowledge.

Table 1 - Validation Results from Experts

Validator	Score	Interval	Categories
1	49	$35 < x < 52$	Valid
2	48		Valid
3	40		Valid
4	47		Valid

The results of this expert validation are systematically documented and presented in Table 1. This table provides a detailed overview of the feedback, recommendations, and improvements suggested by the experts, as well as the final adjustments made to the teaching materials. For instance, experts may highlight the need to simplify the explanation of composite functions or suggest more contextual examples that align with the vocational competencies of SMK students. Additionally, they may recommend enhancing the GI model's scaffolding techniques to better guide students through the inquiry process, thereby strengthening their critical thinking abilities.

By incorporating expert insights, the development stage ensures that the materials are of high quality and ready for implementation in the classroom. The integration of composite functions and the Guided Inquiry model is designed to challenge students to think critically, analyze problems systematically, and apply mathematical concepts to practical scenarios. This approach not only enhances the credibility of the teaching materials but also ensures that they effectively support the development of students' critical thinking and problem-solving skills, which are essential for their future careers.

4. Conclusions

Utilizing the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), the research successfully produced teaching materials that are valid, effective, and aligned with the curriculum requirements and competencies of SMK students. Validation by subject matter experts confirmed that the developed materials meet educational quality standards, relevance, and alignment with learning objectives. The integration of the Guided Inquiry (GI) model into the teaching materials fostered a collaborative, active, and student-centred learning environment. Through GI stages such as grouping, planning, investigation, organizing, presenting, and evaluating, students not only gained a deeper understanding of composition functions but also developed critical thinking, problem-solving, and teamwork skills. Additionally, this approach encouraged students to apply mathematical concepts in real-world contexts, which is particularly crucial for SMK students who require practical skills for the workforce.

The implications of this study are multifaceted. For educators, the GI-based materials offer an alternative for teaching composition functions and other mathematical topics, enhancing student engagement and critical thinking through collaborative inquiry. Educators are encouraged to integrate contextual examples relevant to the workplace, making learning more meaningful for SMK students. This study contributes to innovative teaching material development and lays the groundwork for transforming mathematics education into a more relevant and effective practice, particularly for SMK students..

Conflict of Interest

The authors declare no conflicts of interest.

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