UNP JOURNAL MANAGEMENT CENTER

math.ppj.unp.ac.id
p-ISSN 2716-0726
e–ISSN 2716-0734

Indexed

Mathematics Learning Based on Jean Piaget's Cognitive Development Theory in Vocational Schools

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Article History
Received: Dec 27, 2024 | **Revised**: Jun 17, 2025 | **Accepted**: Jul 29, 2026 | **Published Online**: Oct 29, 2026

Subject Areas:
Mathematics Education

Keywords:
Jean Piaget's Cognitive Development Theory, Mathematics Learning, Merdeka Curriculum, Vocational Schools

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DOI:
https://doi.org/10.24036/rmj.v5i2.62

How to Cite:
Hevardani, K., A., Gistituati, N., Bentri, A., Yerizon, Y., & Yarman, Y. (2026). Mathematics Learning Based on Jean Piaget's Cognitive Development Theory in Vocational Schools. *Rangkiang Mathematics Journal*, 5(2), 91-99. https://doi.org/10.24036/rmj.v5i2.62

Abstract- This study aims to analyze the application of Merdeka Curriculum in mathematics learning at vocational schools based on Jean Piaget's cognitive development theory. The Merdeka Curriculum is designed to provide flexibility to educators in designing learning that is relevant to student needs, including mathematics subjects that are often considered complex by students. This research includes qualitative research with a case study type. Data were collected through document analysis and interviews. Then the data were analyzed descriptively through data reduction, data presentation, and conclusion drawing. To ensure data validity, source triangulation is used. The results showed that the application of Merdeka Curriculum in mathematics learning can support students' formal operational cognitive development stage. The project- and problem-based approach, which characterizes the Merdeka Curriculum, develops logical, abstract, and analytical thinking skills that are essential in mathematics. However, there are challenges in its implementation, such as some teachers' low understanding of learning strategies based on cognitive developmental stages and limited interactive learning media. This research recommends intensive training for mathematics teachers to improve their understanding of cognitive development-based learning strategies and the provision of adequate supporting facilities. With the right approach, the implementation of Merdeka Curriculum in mathematics learning can be more effective in improving students' cognitive abilities in vocational schools.

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1. Introduction

Education in Indonesia continues to evolve to adapt to the needs of the 21st century, one of which is through the implementation of the Merdeka Curriculum. This curriculum was introduced in response to the need for an education system that is more flexible, relevant and adaptive to the times (Anggraena, 2021; Rokayah, 2023). One of the main objectives of this curriculum is to facilitate learning based on students' potential and interests so that they can develop competencies to the fullest (Supriyoko, 2022; Wahyudin, 2024; Umar, 2025). Educators are given the freedom to design and implement learning that suits student characteristics, focuses on essential learning, and emphasizes mastery of in-depth competencies through project-based learning.

This approach is designed to answer the challenges of the Industrial Revolution 4.0 era where students need to master critical thinking, communication, collaboration, and creativity skills (Prihantoro, 2020; Wahyudin, 2024). Merdeka curriculum allows students to be more active in exploring and solving problems (Anggraena, 2022; Rizaldi, 2022). For example, project-based learning gives students real experience in solving problems collaboratively so as to develop logical and applicative thinking skills (Sugiyono, 2013; Jazuli, 2019; Rehman, 2025). With the flexibility offered, teachers can adjust the teaching approach to overcome the learning loss experienced by students (Anggraena, 2021; Brilliananda, 2025). It can be done by providing remedial, reinforcement, or accelerated learning according to students' achievement levels. This curriculum also allows students to choose subjects that suit their interests and talents (Wahyudin, 2024; Umar, 2025).

As one of the compulsory subjects, mathematics serves as a tool to develop logical thinking, analytical, and problem-solving skills that are relevant to the needs of the world of work (Jazuli, 2019; Prihantoro, 2020). Compared to other secondary schools, vocational schools teach mathematics using a more applied approach (Dalby, 2021; Maryanti, 2021). This aims to support students' vocational skills according to their field of expertise. For example, engineering students use geometry concepts to understand machine design, while accounting students utilize algebra and arithmetic in completing financial reports. Thus, learning mathematics in vocational schools is designed to help students understand mathematical concepts in a practical context that suits their needs in the real world (Namli, 2024; Yorganci, 2017).

However, vocational students face various difficulties that affect their ability to understand mathematical concepts, ranging from motivational issues to limitations in basic mathematical skills (Mutohhari, 2021; Saadati, 2023). These difficulties stem from the perception that mathematics is an abstract subject, difficult, and less relevant to their daily lives (Guner, 2020; Murni, 2023). This perception becomes a major obstacle in building students' interest and motivation to learn mathematics (Akgunduz, 2021; Puspita, 2023). One of the causes is students' weak mathematical foundation from their previous education. Low numeracy skills make it difficult for students to follow the learning of algebra, geometry and trigonometry (Guner, 2020; Rohmah, 2022; Ibrahim, 2024).

Students' inability to understand this basic material makes them feel left behind, lose motivation, and eventually avoid mathematics (Ozdemir, 2020; Saadati, 2023). Vocational students feel that the mathematics material taught is not relevant to their field of expertise or daily life (Mutohhari, 2021; Suominen, 2024). Teachers who focus on theoretical approaches without providing practical applications make students lose interest (Nurtanto, 2021). When mathematics is linked to a workplace or vocational context, such as accounting calculations, engineering measurements, or business data analysis, students become more interested and motivated to learn.

Most students experience emotional distress when faced with tasks or exams (Murni, 2023). It causes students to lack confidence and feel like a failure before trying, hindering their ability to think logically and solve problems (Yorganci, 2017). To overcome these difficulties, a learning approach that is in accordance with the characteristics of their cognitive development is needed. Jean Piaget's cognitive development theory explains how human thought processes develop from childhood to adulthood (Babakr, 2019). Cognitive development is the result of the interaction between individual biological abilities and environmental experiences (Piaget, 1952). According to him, vocational students are at the formal operational stage where they are able to think abstractly, logically and hypothetically.

To support this cognitive development, mathematics learning must be designed in such a way that students understand concepts mechanically and are able to apply them in real situations. Unfortunately, the implementation of Merdeka Curriculum in mathematics learning in vocational schools still faces

various challenges (Ozdemir, 2020). Teachers have difficulty adjusting learning methods to the stage of cognitive development of students, especially in integrating project- and problem-based approaches which are the core of the Merdeka Curriculum (Nurtanto, 2021). In addition, the lack of training and supporting resources means that mathematics learning in vocational schools is not yet fully optimal in supporting students' cognitive development in accordance with Piaget's theory.
Based on these problems, an in-depth analysis is needed on how Merdeka Curriculum is applied in learning mathematics in vocational schools by considering Piaget's cognitive development theory. This research is expected to provide insight into effective and relevant learning strategies, as well as provide recommendations to improve the quality of mathematics learning in vocational schools.

2. Methods

(a) Research Design

This type of research is qualitative with a case study type. Case studies aim to explore in depth a particular phenomenon in a real-life context (Yin, 2018). It is usually used when researchers want to understand how and why a phenomenon occurs (Creswell, 2018). First, the researchers analyzed the mathematics teaching module used in the school and conducted an interview with one of the vocational mathematics teachers. This was followed by searching various literatures and analyzing how mathematics learning in vocational schools should be in the Merdeka Curriculum.

(b) Participants

This study involved one vocational school mathematics teacher in Agam Regency, West Sumatra Province. The subject was selected by purposive sampling based on the consideration of availability to be interviewed. This technique is commonly used in qualitative research when researchers want to explore data in depth from sources that are considered the most representative or have direct experience of the phenomenon under study (Creswell, 2018). This allows the researcher to obtain a sample that is relevant and contextual to the research questions (Palinkas, 2015).

(c) Instruments

Case studies usually combine multiple data sources to provide a comprehensive picture of the phenomenon under study (Creswell, 2018; Yin, 2018). In this study, data were collected through document analysis and interviews. The documents referred to here are Merdeka Curriculum documents and mathematics teaching modules used by the school concerned. Meanwhile, the interview guideline focuses on the learning process, learning challenges, solutions and teacher expectations.

(d) Data Analysis

Descriptive techniques were used to describe the data from document analysis and interviews. First, researchers conducted data reduction by selecting, focusing, simplifying, and transforming raw data obtained from the field into a more organized form. This aims to maintain the focus of the research and help researchers understand patterns or relationships between data. Second, the data is presented in the form of narrative text. Good data presentation helps researchers see patterns, relationships, or trends in the data more clearly. Finally, researchers formulate key findings based on patterns, themes or relationships that emerge from the simplified and presented data. In this case, the conclusions drawn are not final. Therefore, researchers need to verify through source triangulation and compare their findings with relevant literature. The researchers analyzed the mathematics teaching module used by the school then confirmed the data obtained through an interview with one of the vocational school mathematics teachers. Furthermore, it was also seen how the implementation of mathematics learning in vocational schools should be in the Merdeka Curriculum. It is important to ensure that the conclusions drawn are valid and reliable (Miles, 2014).

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3. Results and Discussion

(a) Results

The school we analyzed is geographically located in the East Agam area and is very easy to become an educational destination especially for junior high school graduates and equivalent from the East Agam neighborhood. The school is one of the oldest vocational schools in Agam Regency. Established in 1996, it is better known as the Handicraft Industry Secondary School because at the beginning of its establishment, it had majors in Wood Craft and Batik Craft. Vocational education that is increasingly closely related to the business world and the industrial world will produce human resources needed in the world of work as professionals or entrepreneurs. The school has become a vocational school center of excellence and implements the Merdeka Curriculum for four areas of expertise, seven program of expertise, and eight concentrations of expertise.

Mathematics is a vocational subject that must be studied by all students in the concentration of expertise. From the document analysis, we found the correspondence between the learning outcomes of mathematics and the learning objectives and criteria for achieving the learning objectives designed by the teacher. For example, at the end of learning algebra and functions, students can express data in matrix form. They can determine inverse functions, function composition, and function transformation to model real-world situations using appropriate functions (linear, quadratic, exponential). Then the teacher formulates several learning objectives on this element including expressing data in matrix form, as well as determining function composition, inverse function, and function transformation. Furthermore, the teacher formulates three criteria to achieve matrix learning objectives, two criteria to achieve function composition learning objectives, one criterion to achieve inverse function learning objectives, and three criteria to achieve function transformation learning objectives.

The mathematics subject team divided the first five learning objectives for semester three with a total of 60 lesson hours and the next three learning objectives for semester four with a total of 48 lesson hours. Henceforth, we will discuss the matrix teaching module for grade XI vocational students. The teaching module contains elements, Pancasila Student Profile, facilities and infrastructure, target students, learning models and modes, learning objectives and achievement indicators, learning activities, student worksheets, learning assessments, learning materials, and bibliography. Matrix learning consists of four meetings, starting from defining the notion of matrix, completing matrix operations, to presenting data in matrix form.

In the first meeting, the teacher started the learning by saying greetings and asking one of the students to lead the prayer together. Then proceed with checking students' attendance, providing apperceptions related to learning materials and linking them to everyday life, as well as conveying learning objectives and materials about presenting data in matrix form. The teacher also explains the scenario of learning activities and assessments that will be carried out.

The core activities began with implementing differentiated learning based on the results of the initial formative assessment. This assessment is in the form of a checklist and is done orally to find out the extent of students' understanding of expressing data in matrix form. If more than 50% of the students score more than or equal to 50 then the students are ready to follow the learning. However, if not, students are given the opportunity to read the prerequisite material independently or with teacher guidance. The teacher and students ask questions and answers about how to group numbers based on rows and columns. Students are guided by the teacher to discuss the definition of a matrix, matrix notation, rows and columns in a matrix, matrix elements, and how to notate matrix elements and matrix order. Next, students are given the task of writing five matrices with different number of rows and columns then mentioning the elements and order.

Students pay attention to the teacher's explanation of the types, similarity, and transpose of matrices. Then students work on student worksheets in groups as a form of formative evaluation of the process, and the teacher goes around checking student understanding and providing guidance to students who need it as a form of positive differentiation. Student representatives present the results of their group discussions, while other students respond. Students are given the opportunity to ask questions about material that they do not understand.

We only saw a brief snapshot of the student worksheet in the matrix teaching module so not much information was obtained. Broadly speaking, student worksheets contain titles, instructions for use,

learning objectives, criteria for achieving learning objectives, descriptions, tools and materials, work steps, and formative assessments. In the implementation section, there is no syntax of the discovery learning model for each student worksheet. The teacher used the contextual problem on the fourth student worksheet as an introduction to present the data in matrix form (can see in Figure 1).

Problem 1

Siska was asked to recap the absence of students in class XI of a vocational high school in August with the following data. The Accounting and Finance class had 2 sick students, 3 permits, and 1 unspecified student. Office Management and Business Services class had 1 sick person, 2 permits, and 2 without information. Computer Network and Telecommunication Engineering class had 2 people sick, 1 person with permission, and 1 person without information. Visual Communication Design class had 3 people who were sick, 1 person with permission, and 2 people without information. Class XI Culinary had 3 sick, 3 permits, and 4 people without information. Based on the problem above, arrange the numbers into rows and columns!

Figure 1. Snippet of One of the Contextual Problems on the Fourth Student Worksheets

Figure 1 shows that the problems presented in the student worksheets are related to the expertise program at the school. This was confirmed by the teacher when interviewed that she gave examples of problems that were in accordance with their vocational program. The aim is to link the mathematics material with students' daily experiences so that learning becomes more meaningful and interesting. Contextual problems in mathematics learning refer to the use of real-world situations or relevant scenarios as a tool to assist students in understanding mathematical concepts. The following is an excerpt from an interview with one of the mathematics teachers.

Researcher	:	How do you see the implementation of Merdeka Curriculum in mathematics learning so far?
Teacher	:	In my opinion, Merdeka Curriculum provides flexibility for teachers to adapt learning to students' abilities and interests. In this school, we try to relate mathematics material to the context of the world of work that they will face. However, the challenge is that not all students are ready for independent learning. Some students are still accustomed to learning patterns that await the teacher's direction completely.
Researcher	:	Do you consider students' cognitive developmental stages based on Jean Piaget's theory when designing mathematics lessons?
Teacher	:	The average vocational high school student is at the formal operational stage, so we give problems that hone abstract and logical thinking skills, such as calculating production costs, area or volume in their future work. However, some students have difficulty thinking abstractly so we have to fall back on using concrete media or real examples.
Researcher	:	What is your strategy to help students who are still at the concrete thinking stage to be able to follow mathematics learning that should already require formal thinking?
Teacher	:	I usually use props, pictures, diagrams or simple applications to help them visualize concepts. I give real-life examples from the work environment so that they can see the connection between mathematics and the real world. I also use group discussions so that students help each other understand more abstract concepts.
Researcher	:	In Merdeka Curriculum, how do you relate mathematics learning to students' cognitive development needs?
Teacher	:	Merdeka Curriculum provides opportunities to create projects. For example, we give the task of creating a simple design using geometry concepts or calculating the raw material requirements of a product. That way, students learn to think logically and systematically, which is in accordance with Piaget's formal operational stage. We also provide sparking questions to provoke them to think critically before starting the main material.
Researcher	:	What are the biggest challenges in implementing Merdeka Curriculum by considering students' cognitive development?
Teacher	:	The biggest challenge is the variation in students' thinking abilities. Some are already able to think abstractly well, while others still need guidance to understand basic concepts. In addition, not all students are motivated to learn mathematics

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		because they feel it is not relevant to their majors. So, we have to be creative in linking the material with vocational contexts to make them more interested.
Researcher	:	What are your expectations for the implementation of Merdeka Curriculum to optimize mathematics learning for vocational students?
Teacher	:	I hope there will be more focused training for vocational mathematics teachers, especially on how to develop mathematics-based projects that are appropriate to the cognitive development of students and their majors. In addition, IT equipment and learning software are also important so that we can visualize mathematical concepts more interestingly and easily understood by students.

At the end of the lesson, the teacher and students reflect on the learning activities that have been done to check students' understanding. The teacher also provides a checklist sheet to record the end-of-learning assessment. Then the teacher conveys the plan for the next meeting and students receive appreciation and motivation from the teacher. The learning activity ends with a prayer. After completing four meetings, the teacher gives a written test as a form of summative evaluation of the scope of the material. If the student scores less than 71 then it is incomplete and remedial is given. Conversely, students who score more than or equal to 71 are said to be complete and are given enrichment.

(b) Discussion

The mathematical thinking process of vocational students is strongly influenced by their stage of cognitive development. In general, they are at the formal operational stage, where students begin to think abstractly and manipulate symbols logically without the help of concrete objects (Piaget, 1952; Santrock, 2024). Deductive and hypothetical thinking skills begin to develop which allows students to solve complex problems with systematic logic (Piaget, 1952). For example, in studying linear functions, students are asked to determine the relationship between the number of goods produced and the cost of production. Students can analyze data, determine a linear equation, and predict the cost of production for a given quantity of goods. This process demonstrates their ability to manipulate mathematical symbols and think abstractly (Dahiana, 2024; Santrock, 2024).

When studying analytical geometry, vocational students are able to determine the point of intersection of two lines based on given equations. Without the help of concrete tools, students are able to rearrange the equations to facilitate substitution, use elimination or substitution methods, and check the correctness of their solutions through recalculation. This process reflects the logical thinking and abstraction skills that are dominant in the formal operational stage (Ahmad et al, 2016; Babakr, 2019). Students are more easily encouraged to analyze statistical data or create mathematical models relevant to their vocational field. However, teachers still guide students by providing systematic exercises so that their abstract thinking skills develop optimally.

In Merdeka Curriculum, mathematics learning is designed to be relevant to students' vocational needs (Anggraena, 2021; Wahyudin, 2024). Project and problem-based learning is very suitable to support students' cognitive development according to Piaget. Mathematical thinking processes, such as understanding problems, formulating solutions, and evaluating results, are developed gradually through this approach. For example, students majoring in electrical engineering are given the task of calculating electric current using mathematical formulas, while culinary students can calculate the proportion of ingredients using algebraic equations. This kind of activity helps students develop logical and systematic thinking skills that are appropriate for their formal operational stage.

A contextual approach that is relevant to the world of work or majors greatly helps vocational high school students understand the relevance of mathematics in everyday life (Saadati, 2023). Teachers can use project-based learning, such as calculating production costs for culinary students or analyzing financial data for business students. The goal is to provide students with direct experience so that they feel more connected to the material. We also found efforts by teachers to link student worksheet problems with the students' surroundings at this school. However, its implementation has not been optimal. Teachers said that the majority of students have low basic mathematics skills so that they find it difficult to understand more complex concepts. Some students find mathematics difficult and less relevant, but if I give examples that are relevant to their field, they are more enthusiastic.

Integration of mathematical software helps students access more interesting and interactive materials (Soboleva, 2020). For example, the use of GeoGebra for geometric visualization or a graphical calculator to understand mathematical functions. This technology allows students to learn independently outside the classroom in accordance with the principles of Merdeka Belajar. Teachers play an important role in

implementing adaptive and innovative learning strategies (Wahyudin, 2024). However, some teachers face challenges in integrating elements of the Pancasila Student Profile in mathematics learning. Therefore, various strategies are needed to support students in learning more effectively.

Teachers expect more training to make learning more relevant, interesting, and appropriate to the needs of vocational high school students, especially in integrating mathematics material with vocational elements. This training includes the development of project-based learning modules, the use of technology, and differentiated learning strategies. The provision of multimedia devices and technology-based mathematics laboratories greatly supports innovative learning. Involving students in group activities allows for discussion and collaboration, thereby helping them in understanding difficult concepts (Ridwan, 2022). Collaborative math game activities or team projects that solve real-world problems help students learn from peers (Ilhan, 2022; Namli, 2024). Collaboration can also be expanded by involving the industrial world or the community to provide practice-based learning experiences.

The Merdeka Curriculum encourages differentiated learning that is tailored to students' abilities, interests, and needs (Wahyudin, 2024). Teachers can give assignments with different levels of difficulty or guide students individually according to their learning styles. This approach ensures that all students can achieve learning goals (Anggraena, 2022). Some students have negative perceptions of mathematics due to previous learning experiences. Therefore, it is important to provide psychological support through counseling and character development. Students are encouraged to understand that mistakes are part of the learning process and that each individual has the potential to develop. It can increase students' self-confidence in learning mathematics.

4. Conclusion

The implementation of the Merdeka Curriculum in mathematics learning in vocational schools based on Jean Piaget's cognitive development theory provides a new perspective on education that is more adaptive to students' needs. Through this approach, mathematics learning is designed to support students' cognitive development according to their stages, strengthen student-centered learning, and emphasize exploration activities, concept manipulation, and collaborative discussions. The Merdeka Curriculum offers flexibility in teaching methods, including the integration of project-based and problem-based learning, the use of technology, and contextual approaches that are relevant to the world of work. Although the implementation of the Merdeka Curriculum provides opportunities to improve students' mathematical understanding, challenges remain in aligning mathematics material with the vocational context, limited facilities, and teacher readiness in implementing this approach. Therefore, greater support is needed through teacher training, development of learning resources, and collaboration between mathematics and vocational teachers.

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