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Designing effective digital learning tools and teaching materials based on students' mathematical literacy behavior

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Abstract

Mathematical literacy behavior plays a crucial role in student learning, as higher proficiency in mathematical literacy is closely related to higher behavioral engagement. However, many students still have low mathematical literacy behavior, contributing to Indonesia's low rankings in international assessments, such as TIMSS and PISA, compared to developed countries. This study aims to develop digital teaching materials that differentiate students' mathematical literacy behavior. The analysis was conducted on 309 junior high school students from two schools in each city across Padang, Semarang, Pontianak, Makassar, and Mataram. Among them, 53 students' behaviors in solving mathematical literacy problems were observed. Furthermore, a needs analysis was conducted involving 10 teachers, each representing their respective schools. The product was validated by nine experts and tested on three students with different behaviors (inferior, superior, and regular). Data were collected using questionnaires, interview guidelines, validation sheets, and a mathematical literacy test, then analyzed through descriptive and quantitative methods. This study developed differentiated digital teaching materials that are valid and effective in fostering students' mathematical literacy behavior. These findings imply that integrating differentiated digital teaching materials into the curriculum can enhance students' mathematical literacy development more effectively.

Keywords:
Differentiation, Digital learning, Inferior, Regular, Superior

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1. INTRODUCTION

Mathematical literacy refers to the ability to formulate, apply, and interpret mathematics in various contexts while reasoning critically and connecting concepts to real life. Banerji and Chavan (2016) highlight the role of mathematical literacy in foundational numeracy programs, while Duncan et al. (2014) emphasize its impact on long-term academic success. Strong mathematical literacy enhances problem-solving skills (Asmara et al., 2024;

Ayuningtyas et al., 2024; Burkhardt et al., 2024; Fauzan et al., 2024; Kusmaryono et al., 2024; Laamena & Laurens, 2021; Leton et al., 2025; Lukman et al., 2022; Umbara et al., 2023; Wang et al., 2022) and fosters self-regulation in verifying answers (Cheema, 2017). Recognizing its importance, many countries have integrated mathematical literacy into their curricula to prepare students for academic and real-world challenges (Beccuti, 2024; Sikko, 2023).

Mathematical literacy is a crucial aspect of education, and fostering these skills requires a collaborative effort among teachers and other educational stakeholders (Cunnington et al., 2014; Dewantara et al., 2023; Supianti et al., 2025; Supianti et al., 2022; Umbara et al., 2023). According to Cunnington et al. (2014), when educators integrate mathematical literacy into various learning activities, students develop a deeper understanding of mathematical concepts, enhancing their ability to apply these skills in real-world contexts. The ultimate goal is to improve the overall quality of education by ensuring that students not only acquire mathematical literacy but also develop critical thinking and problem-solving skills that are essential for their future academic and professional success. However, as Çakıroğlu et al. (2023) emphasize, access to mathematical literacy should not be limited to a privileged few; rather, it must be made available to students across all levels of education, including those in underprivileged and marginalized communities. Without equal access, disparities in education will persist, preventing many students from reaching their full potential. To achieve this, as Yang et al. (2019) argue, students must have access to appropriate resources, including well-structured textbooks, engaging learning materials, and a robust educational framework that supports their development. In addition, an effective educational system should provide not only material resources but also a well-planned learning process, ensuring that mathematical literacy is taught in a way that is both accessible and engaging for students of various backgrounds and abilities.

Indonesia’s low mathematical literacy, as evidenced by international assessments such as TIMSS and PISA, highlights significant challenges in students’ ability to read, interpret, and understand mathematical information. TIMSS results show that Indonesia consistently ranks among the lowest, placing 38th out of 42 countries in 2011 and 44th out of 49 countries in 2015 (Wijaya et al., 2024). Linuhung et al. (2024) revealed students’ weak comprehension of mathematical texts and concepts. Similarly, the OECD’s 2019 PISA results ranked Indonesia 62nd out of 70 countries (Burkhardt et al., 2024; Diazgranados et al., 2016; Runtu et al., 2023), further emphasizing students’ difficulties in reading, understanding, and interpreting number-based and symbolic mathematical information. Research has shown that ineffective teaching methods and a lack of emphasis on reading comprehension within mathematical contexts are key contributors to this issue (Burkhardt et al., 2024; Diazgranados et al., 2016). Runtu et al. (2023) emphasize that Indonesia’s education system heavily relies on rote memorization rather than fostering deep understanding of mathematical texts, making it difficult for students to correctly read and interpret problem statements. Additionally, Birgisdottir et al. (2020) highlight the importance of early exposure to mathematical literacy, demonstrating that children who engage with mathematical texts from an early age tend to develop stronger literacy skills later in life. However, rigid teaching approaches and the lack of interactive, reading-based learning methods further hinder students' literacy development. Simic-Muller (2019) and Spitler (2011) argue that insufficient engagement with mathematical reading materials contributes to students' struggles in comprehending mathematical contexts. Overall, these studies suggest that Indonesia's low mathematical literacy stems from an overemphasis on memorization, insufficient integration of reading in mathematics instruction, and a lack of engaging methods to help students actively understand mathematical texts and symbols, highlighting the need for curriculum reforms that focus on strengthening literacy skills in mathematics education.

Researchers have conducted extensive studies to understand and address the causes of students' low mathematical literacy. Several factors contribute to this issue, including the choice of textbooks, misconceptions, non-contextual learning, and students' reading abilities. According to Graven et al. (2022), teachers themselves often lack proficiency in scientific literacy, and inadequate school infrastructure further exacerbates the problem. Students struggle with selecting and comparing strategies to find solutions, using reasoning to connect information from a problem with their existing knowledge, and applying formulas or procedures to solve contextual problems. Additionally, Chen et al. (2019) found that students experience difficulty in expressing their answers in writing. Moreover, they often fail to evaluate their responses before submitting them, as they tend to rush through their work. Another factor contributing to low mathematical literacy is students' anxiety when faced with literacy and numeracy tasks (Domu et al., 2023).

Research on digital learning aimed at improving mathematical literacy has gained significant attention in recent years. Research by Setiawani et al. (2019) emphasized the crucial role of digital technology in developing mathematical literacy, demonstrating how its integration into mathematics education fosters engagement and comprehension. Pratama and Retnawati (2018) support this by showing that digital tools effectively enhance students' mathematical literacy skills through interactive assessments and simulations. Additionally, Busnawir et al. (2023) explored the use of metaverse-based platforms, specifically Roblox, to improve mathematical literacy among college students. They found that these virtual learning environments significantly enhance learning effectiveness. Moreover, Gustiningsi et al. (2024) examined the impact of digital STEAM-inquiry learning modules. Based on the findings, they concluded that the digital STEAM-inquiry learning modules significantly improve students' mathematical literacy compared to traditional methods, with urban students benefiting more than their rural counterparts. Collectively, these studies highlight the transformative potential of digital learning tools in fostering mathematical literacy across different educational settings.

The development of digital learning materials by the experts mentioned above primarily focuses on enhancing students' mathematical literacy. This research aims to develop digital learning materials that cultivate mathematical literacy behaviors, fostering deeper engagement and critical thinking in mathematical problem-solving, thereby improving students' mathematical literacy. Behaviour refers to how mathematical literacy is not only seen as a cognitive ability but also seen as a combination of cognitive aspects such as control, metacognitive,as well as psychomotor aspects (Harisman et al., 2021; Muir et al., 2008). This instructional material is designed with differentiated approaches based on mathematical literacy behaviors (inferior, superior, and regular). The developed material will be tested on three students representing each of these literacy behaviors to evaluate its effectiveness. The research question addressed in this study is: How valid and effective is the differentiated instructional material in enhancing mathematical literacy behaviors?

2. METHOD

The research used the Plomp development model and case study method to collect the data (van den Akker, 2013). The development procedure consists of 3 phases, namely preliminary research, development or prototyping phase, and assessment phase. In the preliminary research phase, several analyses were conducted, including student analysis, curriculum analysis, needs analysis, and concept analysis. Based on the findings, the product was developed according to the specifications and validated by experts. Once developed, the product underwent a one-on-one trial phase, where it was tested on three students representing different behavioral categories: inferior, regular, and superior. This ensured the product's effectiveness across various learner profiles. The stages of this study, adapted from the Plomp development model, are presented in the research flowchart shown in Figure 1.

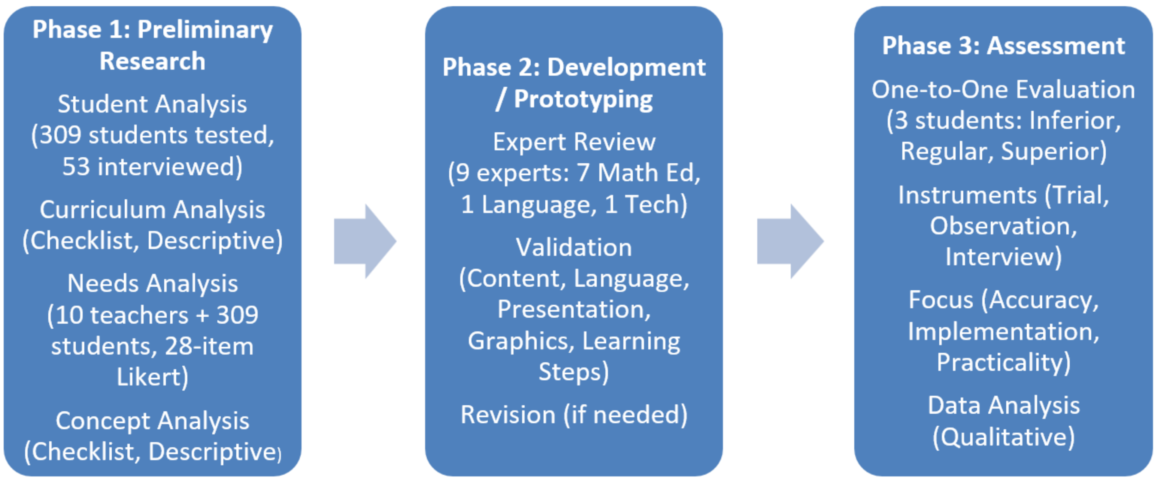


Figure 1. Research flowchart

2.1. Preliminary Research

2.1.1. Student Analysis

In this phase, the activities carried out were collecting information on students' characteristics and categories of their mathematical literacy behaviour. The methods used were interviews and mathematical literacy tests. The mathematical literacy test in this study was primarily intended to measure students' mathematical literacy ability. However, the results of the test also served as an entry point to further explore students' mathematical literacy behavior through follow-up interviews. After completing the test, a number of students were interviewed using a semi-structured approach. The interviews focused on several behavioral aspects, including meta-literacy, by providing scaffolding to examine whether students were aware of their mistakes; psychomotor, by observing the use of mathematical tools, drawings, or applications; and affective, by asking and observing students' self-confidence in solving the problems. In this way, the test and interviews complemented each other, with the test capturing students' ability and the interviews serving as the main instrument to reveal their mathematical literacy behavior. To categorize students' mathematical literacy behaviour, a rubric for students' mathematical literacy behaviour and proper mathematical literacy questions were developed. The steps taken to develop a rubric were: reflection (stage 1) determining observation aspects, listing (stage 2) making category estimates, grouping and labelling (stage 3) validating with experts in their field, and application (stage 4) making observations. The aspects observed in this research are: Cognitive, Meta-Literacy, Psychomotor, and Affective (Harisman et al., 2023). The rubric can be seen in Table 1.

Table 1. Students' mathematical literacy behavior rubric (Harisman et al., 2023)

Aspects	**Indicators**	**Category of Student's Mathematical Literacy Behavior**		
		Inferior	**Regular**	**Superior**
Cognitive	1. Communication: Students can understand the problems and present their answers.	Students do not understand the problems and cannot answer the question.	Students can understand and answer problems, but the answer is wrong.	Students can understand problems, process-solving, and solutions.
	2. Mathematising: Students can transform real-world problems into a mathematical form.	Students cannot transform real-world problems into a mathematical form.	Students can transform real-world problems into a mathematical form, but there is a mistake.	Students can transform real-world problems into a mathematical form.
	3. Representation: Students can represent mathematical objects or situations in another form.	Students cannot represent mathematical objects or situations in another form.	Students can represent mathematical objects or situations in one form.	Students can represent mathematical objects or situations in more than one form.
	4. Reasoning and arguing: Students can think logically to explore and connect the problems to solutions.	Students cannot think logically when exploring and connecting problems to solutions.	Students can connect the problem to solutions using a valid argument, but their answer is wrong.	Students can connect problems to solutions using a valid argument.
	5. Devising strategies for solving problems: Students can choose and use various strategies to solve problems.	Students do not have ideas and strategies to solve problems.	Students can devise a strategy and answer a question correctly.	Students can choose and use various strategies to solve problems.
	6. Using symbolic, formal, and technical language and operations.	The mistakes of symbolic, formal, and technical language and operations are more than 50%.	The mistakes of symbolic, formal, and technical language and operations are less than 50%.	Students can use symbolic, formal, and technical language and operations precisely.

Aspects	Indicators	Category of Student's Mathematical Literacy Behavior		
		Inferior	**Regular**	**Superior**
Meta-Literacy	7. Self-control	Students' metacognition does not appear after receiving the stimulus.	Metacognitive aspects appear after two stimuli.	Metacognitive aspects appear after one stimulus.
Psychomotor	8. Using mathematical tools	Students can only use simple mathematical tools, such as calculators.	Students can use smartphone applications to learn mathematics or solve problems, such as Photomath.	Students can use laptop/computer applications to learn mathematics or solve problems, such as geometry.
Affective	9. Belief	Students are not sure about the presented argument or the selected rule to solve the problems.	Students can confidently present their arguments or select rules.	Students can confidently present all arguments, select rules, and reach the correct conclusion about the final target.

The subjects of this study comprised 309 eighth-grade junior high school students (aged 13–14 years) from five major cities across five different islands in Indonesia: Padang (Sumatra), Semarang (Java), Pontianak (Kalimantan), Makassar (Sulawesi), and Mataram (Lombok). In each city, two schools were selected using purposive random sampling to represent diverse educational contexts. The sample included both male and female students with a relatively balanced distribution. These five cities were purposively chosen to capture geographical, cultural, and educational diversity across Indonesia, thereby strengthening the generalizability of the findings. From this population, 53 students were further selected for in-depth observation and interviews to explore their mathematical literacy behavior, particularly in the cognitive and psychomotor aspects. These students were deliberately chosen to represent three behavioral categories: inferior, regular, and superior. From 309 students, 53 were purposively selected for interviews and observation to represent different ability levels in each school, allowing for a deeper analysis of mathematical literacy behavior.

2.1.2. Curriculum Analysis

The activities carried out involved identifying and sequencing eighth-grade junior high school material for one semester within the Merdeka Curriculum, an Indonesian education framework designed to provide greater flexibility in teaching and learning, emphasizing student-centered approaches and competency-based learning. This analysis aimed to examine the scope of the topics, define learning objectives, and select appropriate instructional strategies. The method used was documentation using a checklist to assess the availability and alignment of learning tools in schools. Additionally, a descriptive method was employed for data analysis to interpret and present the findings systematically. One possible issue with the Merdeka Curriculum is that the same material can be delivered in different semesters or even to different classes, as long as they are within the same learning phase. This flexibility may cause variation across schools, for example, material X might be taught in the first semester in School A but in the second semester in School B. To address this, the present study did not analyze the order of topics, but rather focused on the learning phase. By doing so, the analysis remained consistent across schools despite differences in topic sequencing.

2.1.3. Needs Analysis

The activity focused on analyzing the needs and expectations of both students and teachers regarding the product. To gather comprehensive insights, two data collection methods were used: interviews with 10 teachers and questionnaires distributed to 309 junior high school students across five cities, Padang, Semarang, Pontianak, Makassar, and Mataram. The 10 teachers were selected because they directly taught the classes from which the student research subjects were taken. Their involvement provided relevant insights. The demographics of these teachers include variations in teaching experience and subject specialization. The questionnaire consisted of 28 statements designed to assess various aspects of the product, using a Likert scale ranging from 1 to 4 (strongly disagree, disagree, agree, strongly agree) (Musdi et al., 2024). The indicators are interest, usefulness, understanding, enjoyment, effort, and confidence in learning mathematics. They also include problem-solving skills, use of resources, accuracy, and preference for interactive and contextual materials. A questionnaire was used for students to capture their perceptions, attitudes, and experiences in mathematics learning, while interviews with teachers were conducted to gain deeper insights into teaching practices and supporting factors. This approach ensured a comprehensive understanding of user expectations and requirements from both educators and students.

2.1.4. Concept Analysis

The activities were identifying the main concepts of the topic, detailing them, and arranging them systematically using a concept map. The instrument used was a checklist. The data analysis used in this stage was descriptive method. Concept analysis was carried out to determine the material presented in the teaching materials. The Merdeka Curriculum allows flexibility in sequencing, so the same material may appear in different semesters or classes within the same phase. In such cases, concept analysis can be aligned according to the phase rather than the semester or class order.

2.2. Development Phases

Expert Review

The expert assessment aimed to validate the product by providing assessments and advice according to the experts' field. Nine experts conducted the review, consisting of seven mathematics education experts, one language expert, and one educational technology specialist. The resulting product was validated by language education experts in terms of content and language. The validated aspects were Content, Language, Presentation, Graphics, Learning Steps, and Average (Hidayat & Aripin, 2023). If the product is valid, it can be tested on students; however, if it is not valid, revisions will be made.

2.3. Assessment

One to One Evaluations

The one-on-one evaluation was conducted by gathering feedback directly from students who had used the prototype. These students were carefully selected to represent three different behavioral categories: inferior, regular, and superior. The main goal of this evaluation was to identify any potential errors in the Digital Learning Tools and Teaching Materials based on students' mathematical literacy behavior. This included assessing the content accuracy, ease of implementation, technical quality, and overall practicality of the product (Hidayat & Aripin, 2023). By considering feedback from diverse learners, the evaluation helped refine the product to better meet students' needs. The development and evaluation stages are detailed in Figure 1, showing the process and data analysis for each step.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Preliminary Research

3.1.1.1.Students' Mathematical Literacy Behaviour Analysis

The analysis was conducted on students' mathematical literacy behaviour. Mathematical literacy behaviour is categorized into three categories, which are inferior, regular, and superior. The students' mathematical literacy behaviour can be seen in Table 2.

Table 2. The result of students' mathematical literacy behavior

Inferior	Regular	Superior
Alvean	Gayatri	Faithul
Modesty	Kevin	Shafwa
Delvin	Myiesha	Luthfy
Denisha	Dwi	Arjuna
Syuja	Azzahra	Reihan
Zaki	Mabhita	Kevin
Fransiska	Raihana	Danika
Jessica	Mawaddah	Naila
Faika	Geyka	Setyadi
Nayla	Tasya	Hugo
Ima	Ranum	Tania
Sri	Najwa	Danka
Diva	Athaya	Regita
Eka	Peter	Carlvinna
Fitri	Andika	
Wisnu		
Syifa		
Farras		
Tesa		

Inferior	Regular	Superior
Jenia		
Aufa		
Natasya		
Alfarizi		
Savira		
45.28%	**28.3%**	**26.42%**

The names mentioned are not real names, but pseudonyms created by the researcher. All 309 students took the test, which was then used to classify their abilities. From this classification, 53 students were selected for interviews because involving all students would be impractical. The selected students were considered representative of the larger group. The result shows that 45.28% of the students were in the Inferior class, 28.3% in the regular class, and 26.42% in the superior class. Inferior students are those who exhibit inadequate behavior in all aspects of mathematical literacy; they do not understand the given problems, cannot transform real-world issues into mathematical models, cannot represent problems, and cannot think logically in combining various strategies for problem-solving. Additionally, they struggle with formulating formal symbols, lack self-control or metacognitive skills in problem-solving, and are unable to utilize various mathematical tools, such as calculators and GeoGebra applications, effectively. Students in the regular class are those who demonstrate adequacy in certain aspects of behavior but may lack important skills, such as communication. In contrast, students in superior classes exhibit adequacy in all or most aspects of mathematical literacy behavior.

3.1.1.2.Curriculum Analysis

The results indicate that there are two curricula used in Indonesia: the "2013" curriculum and the "Merdeka" curriculum. In the "Merdeka" curriculum, one of the instructional approaches employed is differentiated learning. Differentiated learning in the "Merdeka" curriculum means that students' learning approaches vary based on their individual learning styles. Furthermore, based on these two curricula, nine topics will be utilized in the product, which can be seen in Table 3.

Table 3. Topic arrangement for eighth-grade junior high school

Learning Objectives	Flow of Learning Objectives
3. Understand and apply knowledge (factual, conceptual, and procedural) based on curiosity about science, technology, art, and culture related to visible phenomena and events.	4. Process, present, and reason in the concrete domain (using, parsing, assembling, modifying, and creating) and the abstract domain (writing, reading, calculating, drawing, and composing) following what is learned at school and other sources from the same perspective.
3.1 Generalize patterns in number sequences and object configuration sequences	4.1 Solve problems related to patterns in number sequences and object configuration sequences

Learning Objectives	Flow of Learning Objectives
3.2 Explain the position of points in the Cartesian coordinate plane, which is related to contextual problems	4.2 Solve problems related to the position of points in the Cartesian coordinate plane
3.3 Describe and state relations and functions using various representations (words, tables, graphs, diagrams, and equations)	4.3 Solve problems related to relations and functions using various representations
3.4 Analyze linear functions (as linear equations) and interpret their graphs about contextual problems	4.4. Solving contextual problems related to linear functions as linear equations
3.5 Explain the system of linear equations in two variables and its solution to contextual problems	4.5 Solve problems related to systems of linear equations in two variables
3.6 Explain and prove the Pythagorean theorem and Pythagorean triples	4.6 Solve the problem related to the Pythagorean theorem and Pythagorean triples
3.7 Explain the central angle, circumferential angle, arc length, and area of a circle, and their relationships, explain the outer and inner tangents of two circles and how to draw them	4.7 Solve problems related to central angles, circumferential angles, arc lengths, and circle area and their relationships
	4.8 Solve problems related to the outer and inner tangent lines of two circles
3.8 Distinguish and determine the surface area and volume of flat-surfaces 3D shape (cube, cuboid, prism, and pyramid)	4.8 Solve problems related to the surface area and volume of flat-surfaces 3D shapes (cubes, cuboid, prism, and pyramids), as well as their combinations
3.9 Distinguish and determine the surface area and volume of curves t-surfaces 3D shape (tube, cone, and sphere)	4.9 Solve problems related to the surface area and volume of Curve-surfaces 3D shape (tube, cone, and sphere), as well as their combinations

These learning objectives were used as topics in the product. For each topic, the learning process must be tailored to suit students in order to improve their mathematical literacy. Furthermore, students' achievement indicators were determined based on these competencies.

3.1.1.3.Needs Analysis

The needs analysis was conducted by administering a questionnaire to 309 students. The results were used as a reference for developing the product. The findings from the questionnaire can be seen in Table 4.

Table 4. The result of the questionnaire

No	City	Indicator	Statement item	Average student answers	Category
1	Padang	Students Like Mathematics	1-2	3.1	Good
		Like the process of learning mathematics	3-12	2.8	Pretty good
		Learning tools are adequate	13-28	2.9	Pretty good

No	City	Indicator	Statement item	Average student answers	Category
2	Semarang	Like mathematics	1-2	2.8	Pretty good
		Like the process of learning mathematics	3-12	2.8	Pretty good
		Learning tools are adequate	13-28	2.7	Pretty good
3	Pontianak	Like mathematics	1-2	2.8	Pretty good
		Like the process of learning mathematics	3-12	2.9	Pretty good
		Learning tools are adequate	13-28	2.9	Pretty good
4	Makassar	Like mathematics	1-2	2.8	Pretty good
		Like the process of learning mathematics	3-12	2.9	Pretty good
		Learning tools are adequate	13-28	3.0	Pretty good
5	Mataram	Like mathematics	1-2	2.9	Pretty good
		Like the process of learning mathematics	3-12	2.9	Pretty good
		Learning tools are adequate	13-28	3.0	Good

Based on Table 4, it can be concluded that almost all students were in the "pretty good" category for each indicator. During interviews, they expressed the need for using teaching tools to enhance their enthusiasm and behavior in mathematical literacy. Furthermore, interviews with ten teachers revealed that most of them believe students require interesting learning tools, preferably digital ones, to ensure accessibility for students regardless of their location. The teachers also mentioned that they have implemented various engaging strategies during the learning process, such as project-based learning, constructivism, and inquiry-based approaches. Some teachers have also employed differentiated learning based on students' abilities and learning styles; however, this has not been effective in improving students' mathematical literacy skills. Teachers want differentiation that addresses students' improvement in mathematical literacy, not solely based on their learning styles. The following are excerpts from the interviews:

Researcher : *What kind of teaching tools do you think would help students improve their mathematical literacy?*
Teacher A : *I often try to make math lessons more engaging, but many students still struggle with motivation. A digital tool could help capture their interest*
Researcher : *How do you feel about using interactive media in learning?*
Student B : *I like learning with interactive media because it makes math feel less intimidating and more fun.*
Researcher : *Have you implemented differentiated learning in your classroom? If so, how effective has it been?*
Teacher C : *Even though I have applied differentiation based on learning styles, some students still struggle with mathematical literacy. We need a more targeted approach.*
Researcher : *Would digital learning tools help you study outside of school hours?*
Student D : *If we had digital learning tools, I could study at home without waiting for school hours.*

Researcher : What kind of differentiation do you think would be most effective for improving students' mathematical literacy?

Teacher E : Students need something more than just different teaching methods—they need tools that truly engage and challenge them at their level.

This is because these learning tools can cover all of the assessment aspects, such as students' cognitive, psychomotor, and affective aspects, which are expected to improve students' mathematical literacy abilities.

3.1.1.4.Concept Analysis

Based on the curriculum analysis, there are 9 competencies that 8th grade students should achieve. In this section, the scope of each basic competency is presented in the form of a concept map. Furthermore, the sub-topics of the basic competencies are also determined.

Concept Map for Eighth-Grade Students in Term 1

The topics or materials consist of two semesters, with five topics in semester 1: number patterns, Cartesian coordinates, function relations, straight line equations, and System of Linear Equations in Two Variables. The concept map can be seen in Figure 2.

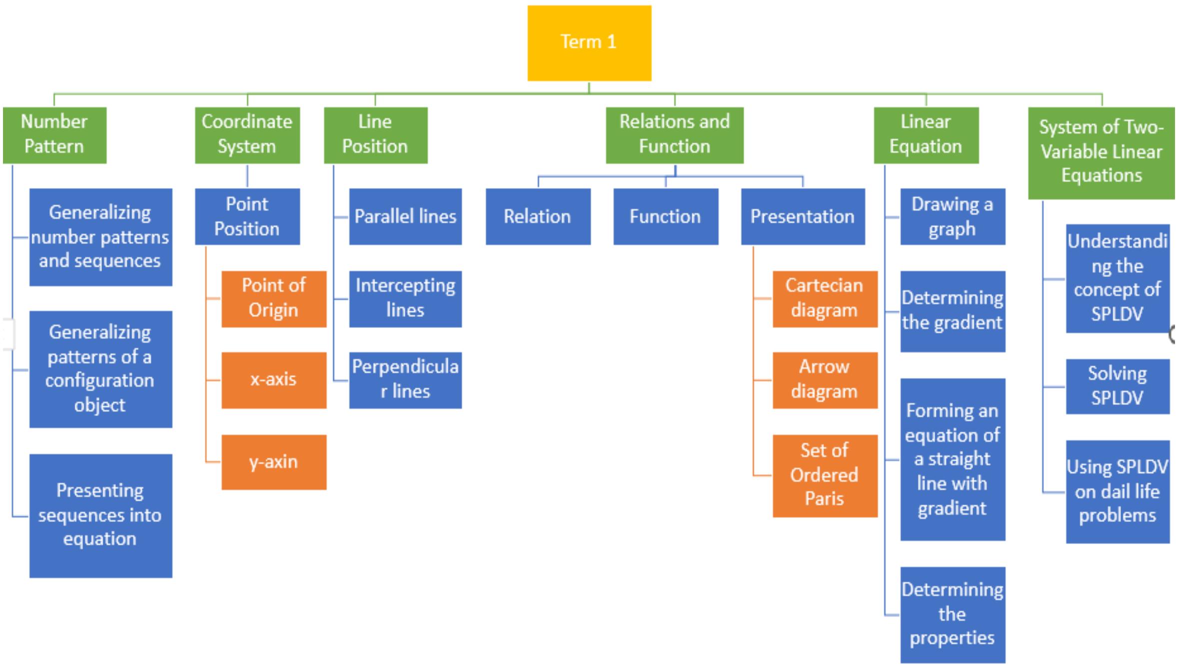


Figure 2. Concept map for eighth-grade students in term 1

In this basic competency, the topic is (1) number patterns, and it is determined that students should achieve three sub-topics or achievement indicators. The sub-topics are: generalizing number patterns and sequences into table form, generalizing patterns of a configuration object, and presenting sequences in equation form. (2) In the coordinate system, two sub-topics will be discussed, namely the position of points and the position of lines, where the position of the point is at the origin, on the x-axis, and on the y-axis.

Furthermore, (3) the position of lines is also divided into three categories: parallel, intersecting, and perpendicular lines. In relation to functions, there are three main sub-topics: the presentation of relations and functions in the Cartesian diagram, arrow diagrams, and sets of ordered pairs. (4) The topic on linear equations can be divided into four main sub-topics: drawing a graph of a linear equation, determining the gradient of a linear equation, forming an equation of a straight line with gradient m that passes through the point (x_1, y_1), and determining the properties of linear equations. (5) In the topic of two-variable linear equations, there are three general sub-topics: understanding the basic concepts of two-variable linear equations, solving systems of two-variable linear equations using elimination, substitution, and graphing methods, and solving systems of linear equations in two variables in real-life problems.

Concept Map for Eighth-Grade Students in Term 2

There are 4 topics in the composition of materials in semester 2, namely: Pythagorean theorem, Circles, Building Flat Side Spaces, and Building Curved Side Spaces. The concept map can be seen in Figure 3.

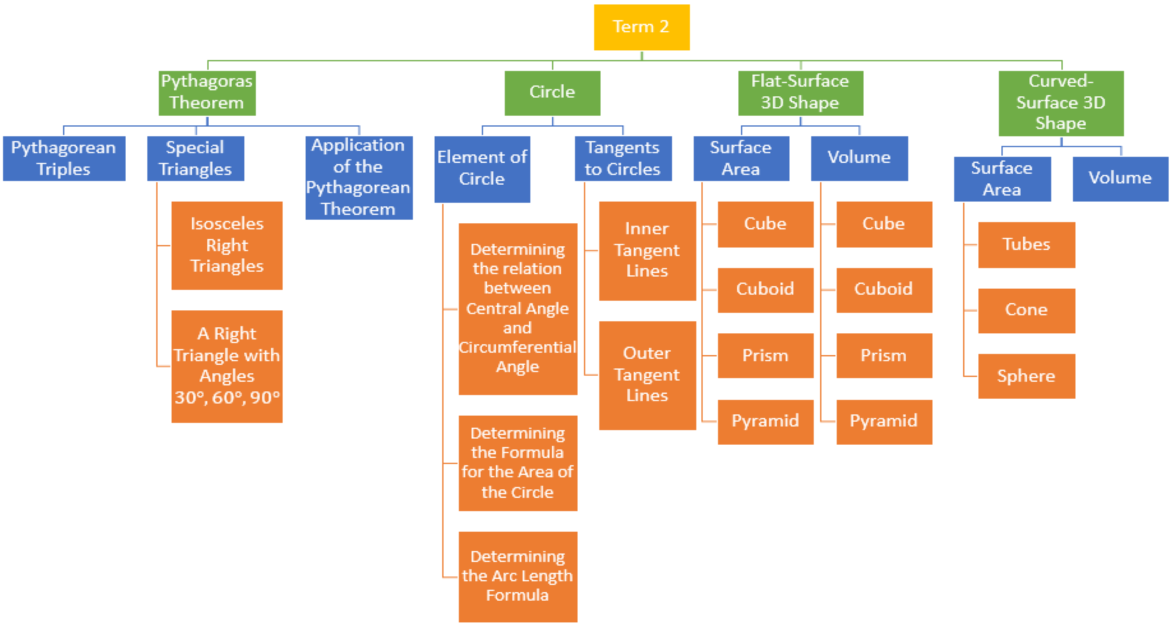


Figure 3. Concept map for eighth-grade students in term 2

The basic competencies are as follows: (1) The Pythagorean theorem, which includes three topics: Pythagorean triples, right triangles, isosceles triangles, and triangles with angles of 30°, 60°, and 90°, as well as solving Pythagorean problems in daily life. (2) The circle, which encompasses central angles, circumferential angles, arc lengths, and the area of circles and their relationships. There are four general sub-topics: determining the relationship between the central angle and the circumferential angle, determining the formula for the area of the circle, determining the arc length formula, and determining the inner and outer tangent lines to circles. In general, there are two sub-topics: understanding tangent lines to circles and inner and outer tangent lines. (3) Flat surfaces and 3D shapes, with sub-topics including the surface area and volume of regular and irregular flat-surface 3D shapes. (4) Curved surfaces of 3D shapes, focusing on the surface area and volume of tubes, cones, and spheres.

3.1.2. Development Phases

Expert Review

This product is developed as a web-based platform based on preliminary research conducted in five major cities representing each island in Indonesia. The developed product focuses on the student work, differentiated by categories of mathematical literacy behavior. On the initial display, the module presents nine chapters of learning topics on the website, with module cover menus for each chapter shown in Figure 4. To access materials in each chapter, students can click on the front cover, which is designed with a dominant green color according to student preferences. The front cover maintains a consistent design across all chapters, with each cover titled according to the topic to facilitate easy access for students. The combination of text, color, and images is designed to be visually appealing to students.

Figure 4. Cover of each learning chapter on the web

Furthermore, when each chapter is clicked, three differentiated teaching modules for mathematical behavior will appear, tailored for inferior, superior, and regular students. The material on each worksheet will be displayed for inferior, regular, and superior students when each worksheet is clicked. The differences in the contents of the worksheets for inferior, regular, and superior students lie in the problem-solving approaches. Each type of worksheet features a cover with a distinct color corresponding to each type of behavior for each topic, with examples illustrated in Figure 5.

Figure 5. Cover of each worksheet

The cover is designed with images, colours and types of writing that are attractive and represent the topic of the material. For example, in the Pythagorean theorem material, the images displayed are pictures of triangles, measuring instruments, and other elements related to the material.

The table of contents is presented to facilitate students' navigation of the material pages. The foreword includes the author's remarks about the product being developed, while the content standards outline the learning achievements and objectives. The concept map illustrates the concepts presented in the worksheet.

Each worksheet includes symbols that characterize mathematical literacy behavior, encompassing communication, mathematizing, representation, reasoning and argumentation, devising strategies for problem-solving, using language and symbolic operations, control, utilizing mathematical tools, and belief, as illustrated in Figure 6.

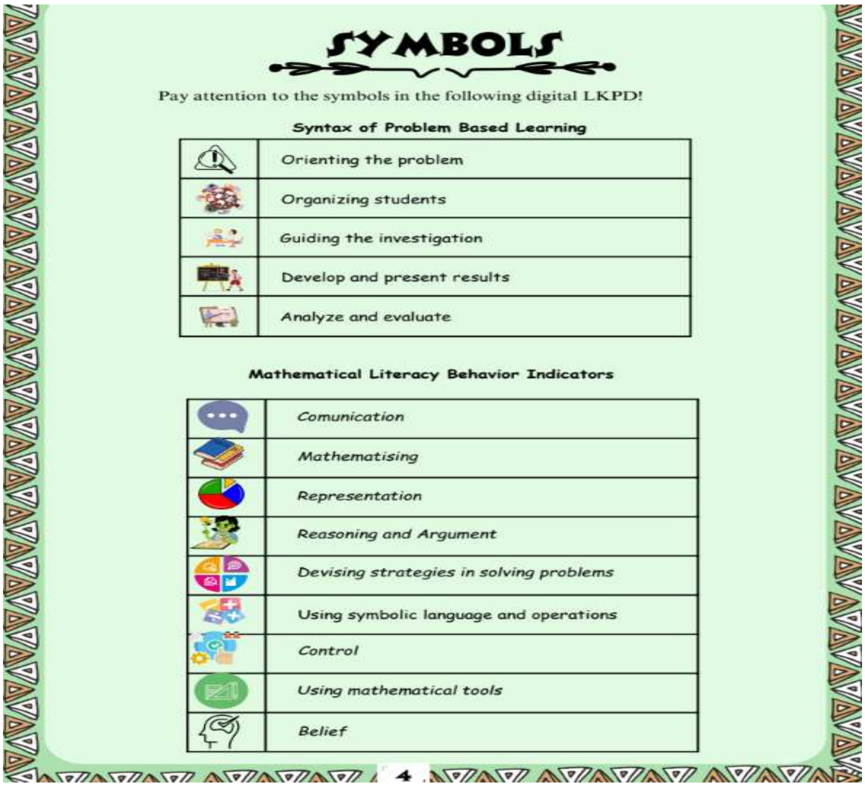


Figure 6. Symbols of mathematical literacy behaviour in the module

These symbols are presented in each problem in the material explanation. The symbol gives a sign to students that they are entering each stage of mathematical literacy behaviour. This is particularly beneficial for educators, as it allows them to observe each phase of behavior in the activities of the worksheet. The symbols are designed to represent the meaning of each indicator of mathematical literacy behavior. The presentation and activities on the worksheet are structured to facilitate the easy observation of students' mathematical literacy behavior across each behavior category.

In each Worksheet and each type of behaviour category, there are several meetings, each of which contains learning objectives. Learning objectives contain a description of the achievement of three aspects of student competence: knowledge, skills, and attitudes that need to be developed through each learning session. Learning objectives are arranged chronologically based on the sequence of learning over time, which serves as a prerequisite for learning outcomes. Operationally, the learning objectives component can encompass the following three aspects: (1) Competency, which refers to the abilities that students can demonstrate or present in the form of products that indicate their success in achieving the learning objectives; (2) Content, which pertains to the core knowledge or main concepts that need to be understood by the end of a learning unit; and (3) Variation, which explains the creative, critical, and higher-order thinking skills that students need to master in order to achieve the learning goals, such as evaluating, analyzing, predicting, creating, and so on.

Each worksheet corresponding to each category of literacy behaviour contains the same mathematical literacy problems at the beginning of the learning process. Examples of mathematical literacy problems for various topics can be seen in Figure 7.

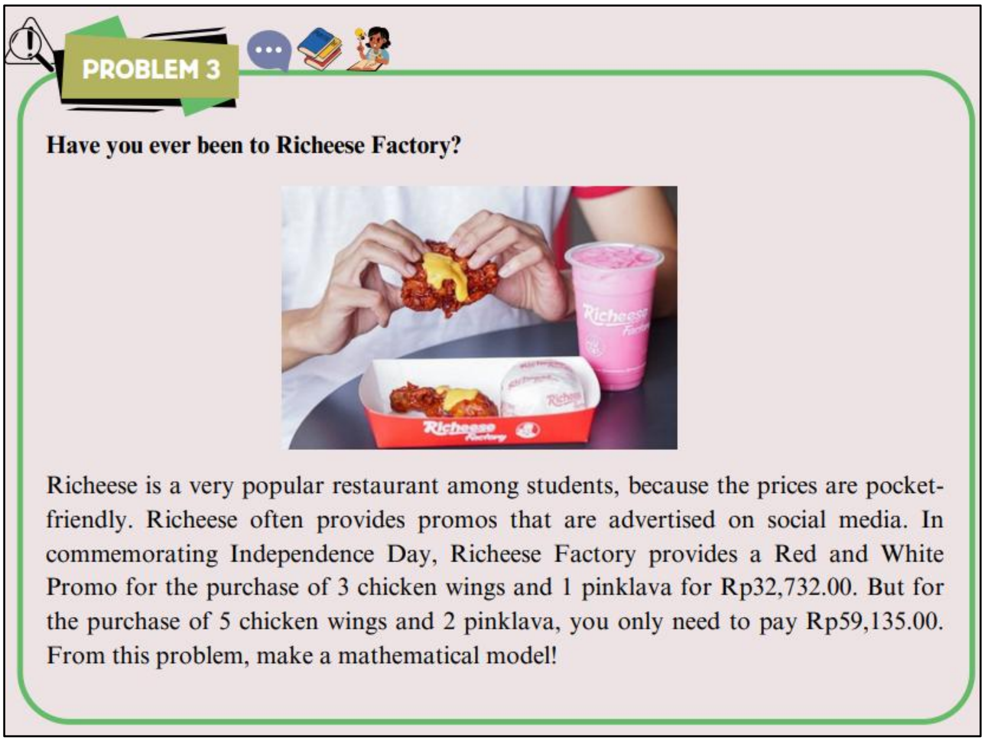


Figure 7. Problems given at the beginning of learning

The problems created are relevant to students' real world. The instructions on how to work through each module differentiate the categories of mathematical literacy behaviour. For the inferior category, there are fewer instructions on how to approach the questions, as illustrated in Figure 8.

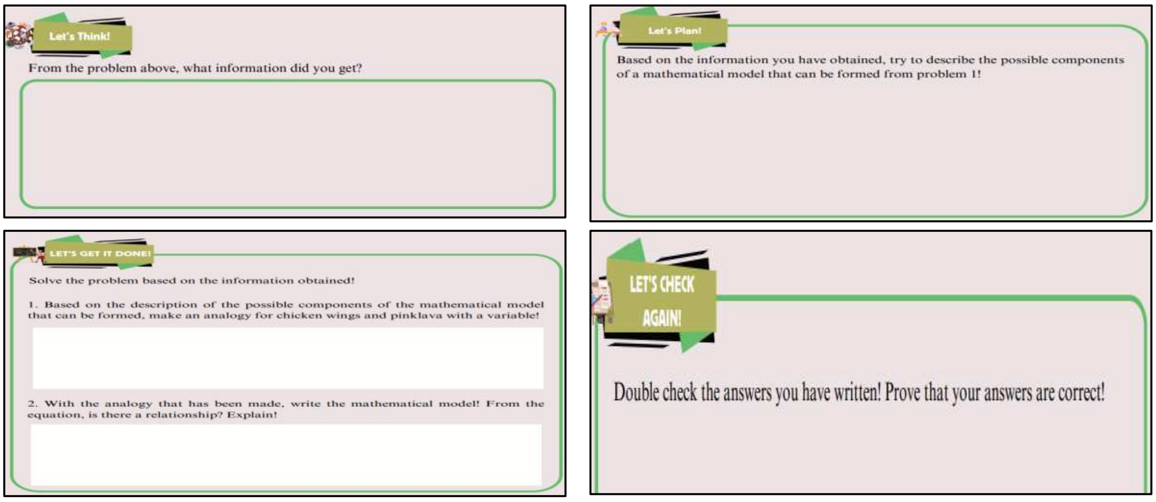


Figure 8. Instructions for solving mathematical literacy problems for inferior students

In the Worksheet, students in the regular category had more instructions for solving questions compared to students in the superior category, which can be seen in Figure 9.

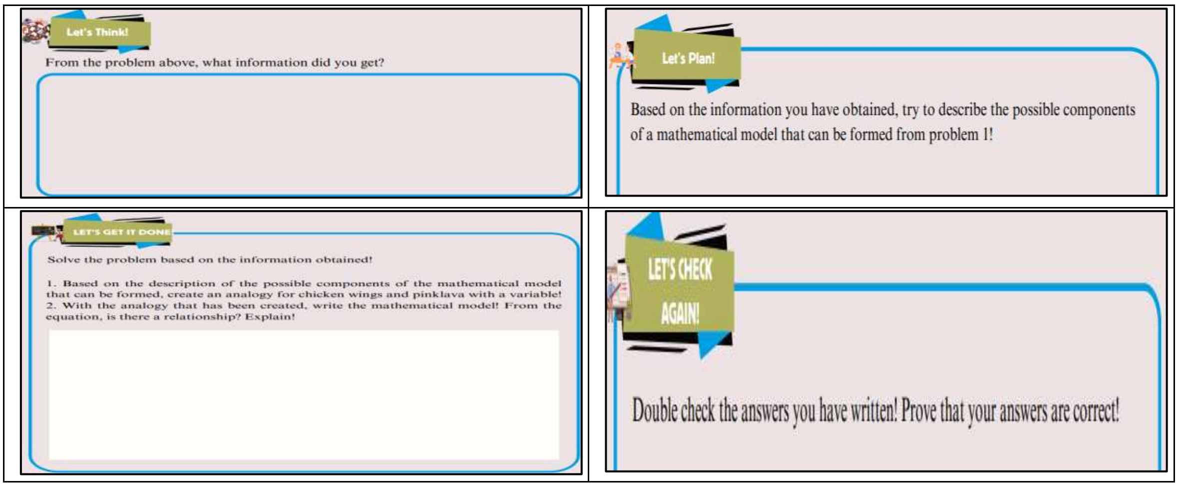


Figure 9. Completion instructions for regular students

Next, inferior students were given many prompts that trained their mathematical literacy behavior as shown in Figure 10.

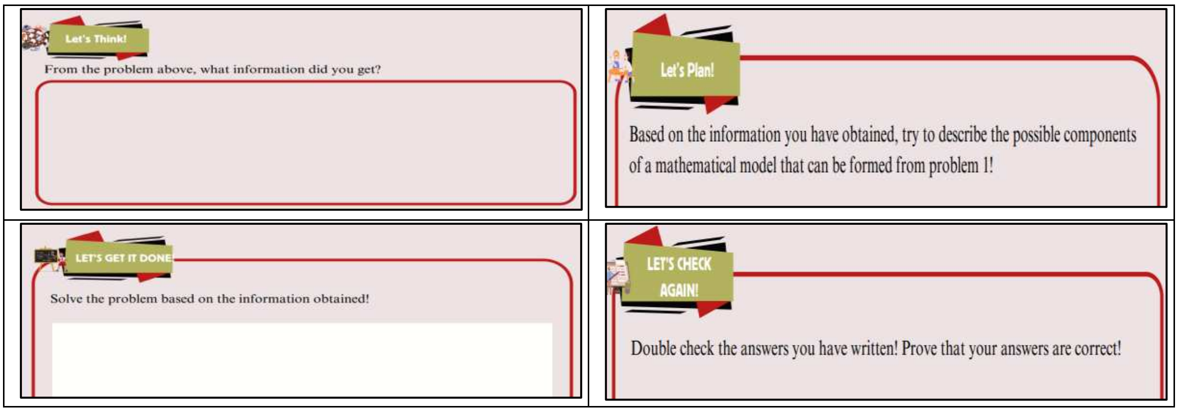


Figure 10. Completion instructions for superior students

After the product was developed, validation was carried out by experts. The validation results obtained were implemented in terms of content, language, and graphics. The validation results can be seen in Table 5.

Table 5. Digital learning tools and teaching materials based on students' mathematical literacy behavior validity

No	Accessed Aspect	Percentage	Criteria
Mathematics Education Experts			
1	Presentation	83.78%	Highly Valid
2	Content Feasibility	83.65%	Highly Valid
3	Learning Steps	85.42%	Highly Valid
4	Average	84.28%	Highly Valid
Language Expert			
1	Linguistics	86.74%	Highly Valid
2	Average	86.74%	Highly Valid

No	Accessed Aspect	Percentage	Criteria
Educational Technology Expert			
1	Graphics/Appearance	88.94%	Highly Valid
2	Average	88.94%	Highly Valid
	Overall Average	**86.65%**	**Highly Valid**

Based on Table 5, the results of the revision suggestions and revisions carried out were obtained, which can be seen in Table 6.

Table 6. Expert review suggestion and revision

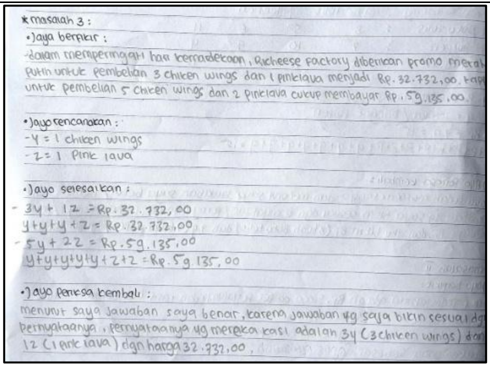
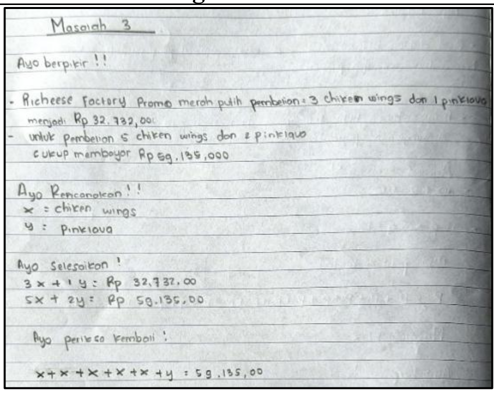
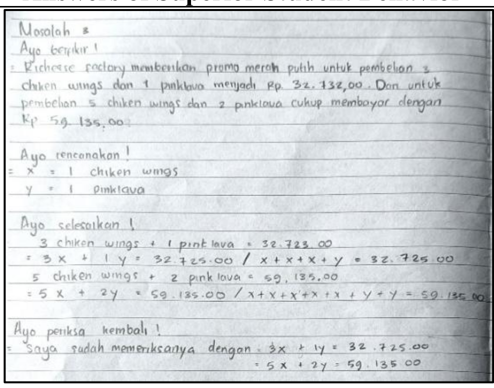
Expert	Suggestions	Revision	
		Before	**After**
Content			
Mathematics Education Experts	Problem-solving steps	In problem-solving, there is a sentence "Explain what material can be taken from the information in the story above, because the scope is too broad if you only ask what information can be taken."	A more specific solution guide has been created.
	In the matter of coordinates, pay attention again to the distance between houses, and adjust it to your daily life.	There is an illogical distance between the two houses	It has been changed on the issue of the distance between the two houses to be more logical.
	Questions (problems) on each behavioural differentiation	The questions / problems / questions at the inferior, regular and superior levels are not much different, not enough to be defined as differentiated teaching materials.	The questions are made the same, what differentiates them are the instructions and steps for solving them.
Appearance			
Educational Technology Expert	In the matter of coordinates, pay attention again to the distance between houses, and adjust it to your daily life.	There is an illogical distance between the two houses	It has been changed on the issue of the distance between the two houses to be more logical.

3.1.3. Assesment Phase

One to one

At this stage, the three instructional material packages for solving a System of Linear Equations in Two Variables were tested on three students categorized as inferior, regular, and superior. The students' working processes to solve the problem in Figure 9 can be seen in the following Table 7.

Table 7. Answers in the digital learning tools and teaching materials based on students' mathematical literacy behavior

Answers of Inferior Student Behavior	**Translate:**
 *masalah 3 : •)aya berpikir : -dalam memperingati hari kemerdekaan, Richeese factory diberikan promo merah putih untuk pembelian 3 chiken wings dan 1 pinklava menjadi Rp. 32.732,00. tapi untuk pembelian 5 chiken wings dan 2 pinklava cukup membayar Rp. 59.135,00. •)ayo rencanakan : -y = 1 chiken wings -z = 1 Pink lava •)ayo selesaikan : - 3y + 1z = Rp. 32.732,00 y+y+y+z = Rp. 32.732,00 - 5y + 2z = Rp. 59.135,00 y+y+y+y+y+z+z = Rp. 59.135,00 •)ayo periksa kembali : menurut saya jawaban saya benar, karena jawaban yg saya bikin sesuai dg pernyataanya, pernyataanya yg mereka kasi adalah 3y (3 chiken wings) dan 1z (1 pink lava) dgn harga 32.732,00.	* problem 3: • Let's think: - In commemoration of Independence Day, Richeese Factory is offering a White Meral promotion for the purchase of three chicken wings and one pinklava for Rp. 32,732.00. Additionally, for the purchase of five chicken wings and two pinklava, the total cost is only Rp. 59,135.00. • Let's plan: y = 1 chiken wings z = 1 Pink lava • Come on, finish it 3y + 1z = Rp32.732,00 y+y+y+z = Rp32.732.00 5y+2z = Rp59,135.00 y+y+y+y+y+z+z = Rp59,135.00 •Please check again: In my opinion, my answer is correct because it aligns with the statement provided. The statement indicated a cost of Rp. 32,732.00 for 3y (3 chicken wings) and 1z (1 pinklava).
Answers of Reguler Student Behavior	**Translate:**
 Masalah 3 Ayo berpikir !! - Richeese factory Promo merah putih pembelian : 3 chiken wings dan 1 pinklava menjadi Rp 32.732,00 - untuk pembelian 5 chiken wings dan 2 pinklava cukup membayar Rp 59.135,000 Ayo Rencanakan !! x : chiken wings y : pinklava Ayo Selesaikan ! 3x + 1y : Rp 32.732,00 5x + 2y : Rp 59.135,00 Ayo periksa kembali ! x+x+x+x+x+y : 59.135,00	Problem 3 Let's think!! Richeese Factory Red and White Promo: 3 chicken wings and I pinklava for Rp. 32,732,000 -To buy 5 chicken wings and 2 pinklava, just pay Rp. 59,135,000 Come on plan!! x = chiken wings y = Pinklava Come on. Finish it! 3x+1y = Rp 32.732.00 5x + 2y = 59.135,00 Come on, let's check again x+x+x+x+x+y = 59,135.00
Answers of Superior Student Behavior	**Translate:**
 Masalah 3 Ayo berpikir ! = Richeese factory memberikan promo merah putih untuk pembelian 3 chiken wings dan 1 pinklava menjadi Rp. 32.732,00. Dan untuk pembelian 5 chiken wings dan 2 pinklava cukup membayar dengan Rp 59.135,00 Ayo rencanakan ! = x = 1 chiken wings y = 1 pinklava Ayo selesaikan ! 3 chiken wings + 1 pink lava = 32.723.00 = 3x + 1y = 32.725.00 / x+x+x+y = 32.725.00 5 chiken wings + 2 pink lava = 59.135.00 = 5x + 2y = 59.135.00 / x+x+x+x+x+y+y = 59.135.00 Ayo periksa kembali ! = Saya sudah memeriksanya dengan : 3x + 1y = 32.725.00 = 5x + 2y = 59.135.00	Problem 3 Come on, think Richeese factory gives a red and white promo for the purchase of 3 chicken wings and 1 pancake to Rp. 32,732.00. And for the purchase of 5 chicken wings and 2 pinklava, you only need to pay Rp. 59,135.00 Come on, plan! x = 1 chiken wings y = 1 Pinklava Let's get it done! 3 chiken wings + 1 pink lava 32.723,00 3x+1y = 32.725,00 / x+x+x+y=32.725,00 5 chiken wings + 2 pink lava 59.135,00 5x+2y = 59.135,00 / x+x+x+x+x+y+y=59.135,00 Let's check again! I've checked it with 3x+ly= 32,725.00 5x + 2y = 59.135 00

Based on Table 7, inferior students were able to correctly form mathematical models. However, in solving the System of Linear Equations in Two Variables using the graphical method, they only reached the stage of creating the model without determining the solution. Despite receiving prompts from the researcher, they were still unable to solve the problem. The same occurred with the combined method, where they only created the mathematical model without fully solving the System of Linear Equations in Two Variables problem. However, after receiving additional prompts, the inferior students were eventually able to solve the System of Linear Equations in Two Variables using the combined method. In learning the System of Linear Equations in Two Variables topic, the students demonstrated a good understanding of the problem, as evidenced by their responses when asked to write down the given information and the question from the problem. They were able to represent problems in mathematical form but struggled with the problem-solving process and finding the correct solution. Additionally, they were unable to use technology-based mathematical tools such as GeoGebra and were unaware that the graphical method could be solved using such tools. When making mistakes, they exhibited metacognitive awareness, verbally and confidently explaining their solutions. Consequently, after using the differentiated digital learning tools, the mathematical literacy behavior of inferior students improved to the regular category.

Regular students were able to correctly form mathematical models. However, in solving the System of Linear Equations in Two Variablesusing the graphical method, they only reached the stage of creating the model without determining the solution. Despite receiving prompts from the researcher, they were still unable to solve the problem. However, they easily solved the System of Linear Equations in Two Variablesusing the combined method. Regular students demonstrated a good understanding of System of Linear Equations in Two Variables problems, accurately representing and solving them while translating real-world situations into mathematical forms. Nevertheless, they were unable to use technology-based mathematical tools such as GeoGebra and were unaware that the graphical method could be solved using such tools. When making mistakes, they exhibited metacognitive awareness, verbally and confidently explaining their solutions. Consequently, after using the differentiated digital learning tools, their mathematical literacy behavior improved to the superior category.

Meanwhile, superior students were able to correctly form mathematical models. However, in solving the System of Linear Equations in Two Variablesusing the graphical method, they only reached the stage of creating the model without determining the solution graphically. After receiving prompts from the researcher, they were able to find the intersection points and plot the graph to obtain the answer. Unlike the graphical method, they easily solved the System of Linear Equations in Two Variables using the combined method. Superior students demonstrated a strong understanding System of Linear Equations in Two Variablesproblems, accurately representing and solving them while translating real-world situations into mathematical forms. They were also able to use technological tools like GeoGebra and exhibited metacognitive awareness by confidently explaining their solutions. Thus, after using the differentiated digital learning tools, their mathematical literacy behavior remained in the superior category.

Each student also filled out a practicality questionnaire. The results are shown in Table 8.

Table 8. Digital learning tools and teaching materials based on students' mathematical literacy behavior practicality

No	Aspect Assessed	Percentage	Criteria
1	Ease of Use	87.28	Very Practical
2	Time Efficiency	88.32	Very Practical
3	Attractiveness	92.50	Very Practical
4	Ease of Understanding	88.98	Very Practical
	Average	**89.27**	**Very Practical**

The results of the assessment indicate that the evaluated aspects, which include ease of use, time efficiency, attractiveness, and ease of understanding, demonstrate a high level of practicality. The consistently high ratings suggest that the subject being assessed provides a smooth and efficient user experience, allowing users to interact with minimal effort. The strong score in attractiveness reflects its ability to engage users, which can contribute to higher satisfaction and sustained usage. Additionally, the positive evaluation of time efficiency implies that it facilitates quick and effective task completion. Overall, these findings highlight that the subject is well-designed, intuitive, and capable of meeting user expectations in terms of functionality and usability.

3.2. Discussion

The analysis shows that Indonesian students are generally in the lower-performing category and need improvement in all areas, which include cognitive, affective, and psychomotor. Several factors may contribute to this, including internal motivation and external influences such as teachers, learning materials, and infrastructure (Bolstad, 2021; Harisman et al., 2023; Runtu et al., 2023). Additionally, the analysis identifies three types of student behaviour in mathematical literacy. Similarly, different categories exist for other abilities. Rohati et al. (2023) classified students' mathematical reasoning into four levels: imitative, algorithmic, semi-creative, and creative. Gunawan et al. (2019) identified three categories of understanding mathematical concepts: instrumentalist, semi-relationalist, and relationalist. Muir et al. (2008) described mathematical problem-solving behaviour in three categories: naive, routine, and sophisticated. Meanwhile, Harisman et al. (2021) added a fourth category: semi-sophisticated. These classifications suggest that mathematical abilities can be developed through various teaching methods and learning media. Therefore, this study aims to develop learning media that enhance students' mathematical literacy.

The curriculum analysis shows that students are utilizing the "2013" and "Merdeka" curricula, which encompass 11 basic competencies: Concept Map on Number Patterns Topic, Concept Map on Coordinate System Topic, Concept Map on Relationship and Function Topic, Concept Map on Linear Equations Topic, Concept Map on Systems of Linear Equations in Two Variables Topic, Concept Map on Central Angle, Circumferential

Angle, Arc Length, Area of a Circle, and Their Relationships, Concept Map on Tangent Line Topic, Concept Map on Flat-Surface 3D Shapes, Concept Map on Statistics, and Concept Map on Probability. These 11 basic competencies are intended for a one-year learning process. The product should incorporate these competencies because, in addition to the completeness of the topics, effective improvement in students also requires a significant amount of time (Sofradzija et al., 2021). Over the course of one year, with these 11 basic competencies, it is anticipated that students' mathematical literacy behavior will improve. The results of this curriculum analysis are also consistent with the concept analysis, where the indicators for student achievement are determined and will serve as the foundation for product development.

Based on the needs analysis and supporting studies, a differentiated digital learning tool was developed in the form of a website. This approach was chosen as it aligns with Indonesia's Merdeka Curriculum and has been proven effective in improving student understanding (Dalila et al., 2022; Graven et al., 2022). Additionally, digital tools offer flexibility and ease of use, making them a suitable medium for enhancing students' conceptual learning (Chowanda et al., 2020; Hillmayr et al., 2020; Moliner et al., 2022). To address students' varying levels, a digital worksheet has been designed with three versions tailored for lower, regular, and advanced students in eighth grade, covering nine chapters. The product has undergone expert validation, ensuring its quality and effectiveness. Further refinements were made in the assessment phase to enhance its functionality as an innovative learning tool. From a theoretical perspective, this study contributes to the development of differentiated learning theories in digital education while also supporting research on technology integration in the Merdeka Curriculum. Practically, it provides educators with a flexible tool to adapt lessons based on students' diverse abilities, thereby improving both teaching effectiveness and student comprehension across various subjects (Graven et al., 2022; Hillmayr et al., 2020).

The findings of this study show that Indonesian students generally exhibit low mathematical literacy behavior, with distinct variations across cognitive, affective, and psychomotor domains. This observation aligns with previous research reporting challenges in students' problem-solving skills and overall mathematical competencies (Sumarni et al., 2023). Similar to prior studies, factors such as intrinsic motivation, prior knowledge, teacher support, learning materials, and classroom environment play a crucial role in shaping student performance (Dewanti et al., 2024; Hafiz et al., 2023). However, while earlier studies primarily describe performance gaps at a general level, this research provides a more nuanced behavioral categorization, identifying lower, regular, and superior groups. This allows for a finer-grained understanding of how individual differences affect engagement and achievement in mathematical literacy tasks.

Comparing these findings to previous research, the study confirms some established patterns while also revealing new insights (Musdi et al., 2024). Earlier classifications of mathematical reasoning and problem-solving behaviors—ranging from imitative, algorithmic, semi-creative, and creative reasoning to naive, routine, sophisticated, and semi-sophisticated problem-solving—offer a theoretical framework for understanding student abilities. This study builds on that foundation by operationalizing these behavioral distinctions into differentiated digital teaching materials, specifically tailored to students' observed profiles. Unlike prior studies, which mainly focused on categorization or assessment, the current research demonstrates the practical effectiveness of aligning instructional interventions with students' behavioral levels (Fauzan et al., 2019; Gunawan et al., 2019; Rohati et al., 2022). The results show that such differentiation not only supports cognitive development but also enhances engagement and motivation, contributing to improved literacy outcomes. Therefore, this study bridges the gap between descriptive research and applied educational practice, confirming previous knowledge about students' challenges while providing actionable strategies to address them through curriculum-aligned, technology-based interventions.

Furthermore, the comparative analysis highlights both similarities and differences with previous studies. While the pattern of lower-performing students mirrors earlier findings, the identification of differentiated responses to digital media offers a novel perspective. Previous research often assumed uniform instructional impact across students, whereas this study demonstrates that tailored interventions can address the specific needs of different behavioural groups. This insight emphasizes the importance of considering both behavioural assessment and curricular alignment when designing digital learning tools. In doing so, the study contributes not only to the literature on mathematical literacy but also to broader discussions on differentiated instruction and technology integration in education.

4. CONCLUSION

This study highlights the importance of differentiated digital learning tools in enhancing students' mathematical literacy. By integrating differentiated instruction with digital technology, this research provides a structured approach to addressing students' diverse learning needs while aligning with the Merdeka Curriculum. The developed digital worksheet, designed for inferior, regular, and superior, aims to improve mathematical literacy. Expert validation confirms its quality, reinforcing its potential as an effective tool for fostering mathematical literacy.

The findings contribute to both theoretical and practical advancements in mathematics education. Theoretically, this study supports the role of differentiated instruction in strengthening students' mathematical literacy, particularly in digital learning environments. Practically, it provides educators with a flexible resource to tailor their teaching strategies, ensuring that students at different proficiency levels can engage meaningfully with mathematical concepts. By offering structured support, this approach helps bridge learning gaps and encourages deeper mathematical understanding.

However, this study has several limitations. The digital learning tool has not yet been tested in real classroom settings, making its direct impact on mathematical literacy uncertain. Additionally, the study focuses solely on eighth-grade students, limiting its applicability to other educational levels. Furthermore, external factors such as student motivation, teachers' ability to implement differentiated learning, and access to digital resources were not extensively analyzed, even though they may influence the tool's effectiveness.

For future research, classroom trials with a larger sample size are recommended to measure the tool's effectiveness in improving students' mathematical literacy. Additionally, future studies could explore the integration of adaptive learning features, such as automated feedback systems and artificial intelligence-based learning, to better personalize the material to each student's needs. Further research could also expand to different educational levels or subjects to examine the broader applicability of this digital differentiated learning model in education.

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Declarations

Author Contribution	: YH: Conceptualization, Data Curation, Formal Analysis, Funding Acquisition, Investigations, Methodology, Resources, Supervision, Validation, Visualization, Writing - Original Draft, and Writing – Review & Editing; FD: Supervision, and Validation; S: Supervision, and Validation; HS: Project administration, and Writing – Review & Editing; H: Project administration, and Writing – Review & Editing.
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