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Development of STEM-Based VARK Learning Application to Improve Problem-Solving Skills in Calculus Courses

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Abstract: This research and development aims to develop a STEM-based VARK Learning Application to improve problem-solving skills in Calculus courses. Although the STEM approach has been widely applied in mathematics learning, and learning preferences such as VARK have been explored in various studies, both are generally studied separately and have not been integrated into structured adaptive mechanisms in digital learning products. Furthermore, the effectiveness of the learning styles approach remains debated when not implemented in a systematic instructional design. This research fills this gap by positioning VARK as a basis for differentiating the presentation of multimodal content within a STEM learning framework, explicitly integrated into features, activity flows, and problem-solving exercises within a single digital ecosystem. The development followed a 4-D model (define, design, develop, disseminate) through the stages of needs analysis, prototype design, expert validation, and limited implementation. The participants in the implementation were 50 students in the Mathematics Education program at a university in Semarang City, selected through purposive sampling. The research instruments included expert validation sheets (materials, media, evaluation) and problem-solving ability tests administered at three measurement times. Validation data were analyzed descriptively using mean scores, while changes in ability were analyzed using repeated-measures ANOVA. The results showed a validity score of 4.22 in the Highly Valid category (4 d" x d" 5) with minor revisions. The mean problem-solving ability increased from 74.5 to 81.4 and 84.9, with significant differences across groups. These findings indicate that integrating multimodal differentiation into digital STEM design has the potential to support improvements in problem-solving abilities in a limited research context. Further studies with experimental designs and larger samples are needed to strengthen the external validity of the findings.

Keywords: calculus, learning application, problem solving, VARK.

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INTRODUCTION

Solving high-level problems can involve the problem-solving stage. Problem-solving is often used when solving non-routine problems. (Temur, 2012), complex questions(Greiff, S & Fischer, 2013) where the troubleshooter does not know the previous schema (Schoenfeld, 2007, 1992). Problem-solving is the most important skill for students. (Erlina & Purnomo, 2020; Sulistyaningsih et al., 2021) and become part of the mathematics curriculum in almost all countries, including the United States(Schoenfeld, 2007), Australia (Clarke et al., 2007), Netherlands (Doorman et al., 2007), Chinese(Cai & Nie, 2007), France (Artigue & Houdement, 2007), Hungary (Szendrei, 2007) and the United Kingdom (Burkhardt & Bell, 2007). According to research, students' problem-solving skills are still low. (Amir, 2015; Purnomo et al., 2022; Purnomo & Mawarsari, 2014; Purnomo &

Faturohman, 2014). The difficulties experienced by students when completing mathematics include a lack of understanding of the questions and information provided (Phonapichat et al., 2014), inability to use the correct strategy (Supandi et al., 2021).This is because students are not used to completing tasks and have not yet optimized their learning style. Based on these studies, it is necessary to improve problem-solving skills by linking them to students' learning styles. These problems become increasingly complex in Calculus courses, which require coordination between symbolic representations, graphs, and contextual interpretation. In many cases, students can perform algebraic manipulations procedurally but lack a deep conceptual understanding, making it difficult for them to transfer strategies to new problems.

Poor problem-solving skills are not solely due to a lack of practice, but also relate to how students process and construct meaning from the information presented. The problem-solving process involves understanding the problem, planning a strategy, implementing the strategy, and evaluating the solution. Each stage requires adequate representational support and scaffolding. If learning relies solely on a single presentation format, some students may struggle to develop flexible conceptual schemes. In this context, a diversity of representational pathways is crucial in supporting cognitive engagement and strengthening understanding.

One approach often associated with the variety of ways students receive information is the VARK model. By recognizing a person's learning style, they can determine a more effective way to learn. (El-Bishouty et al., 2019; Wahyuni, 2017; Wassahua, 2016). Given the positive influence of learning styles, many experts have developed systems to identify them. (Callan et al., 2020; Markoviæ & Jovanoviæ, 2012; Nur Habibah et al., 2019; Zhang & Zhang, 2010). Student learning strategies have been explored in relation to context and creativity (Markoviæ & Jovanoviæ, 2012), learning theory, empirical studies, and pedagogical aspects interact with each other (Khanal et al., 2021). This model is used to identify student learning preferences. However, the effectiveness of learning styles-based approaches remains debated in the international literature. Critics of the meshing hypothesis point to limited empirical evidence for rigid categorical matching. This criticism is important because it suggests that simply grouping students by learning style, without substantial changes to instructional design, will not yield significant improvements in learning outcomes.

Based on these criticisms, this study does not position VARK as a deterministic classification system, but rather as a basis for designing multimodal differentiation in learning. The problem lies not in learning styles as the cause of low concentration or ability, but rather in the potential mismatch between dominant teaching methods and students' diverse learning preferences. When learning lacks variety in representations, students with different cognitive needs may struggle to understand concepts and develop problem-solving strategies. This argument becomes relevant when linked to the cognitive mechanisms of problem solving. Effective problem-solving requires a strong conceptual understanding, flexibility in selecting strategies, and the ability to switch between representations. Multimodal differentiation allows students to access concepts through various representational pathways, thereby enriching understanding and reducing misconceptions. By providing graphics, audio explanations, text summaries, and interactive activities in an integrated manner, learning can broaden cognitive access to calculus concepts and support the development of more mature problem-solving strategies.

On the other hand, the STEM (Science, Technology, Engineering, and Mathematics) approach has evolved into a learning framework that encourages concept integration, contextual modeling, technology use, and authentic problem-solving. STEM is an important component of students' learning experiences (Roberts et al., 2018; Shin et al., 2018) that creates a positive learning environment (Vennix et al., 2017), Improving the quality of learning (Buckley et al., 2018; Perignat & Katz-buonincontro, 2018), Troubleshooting (Kwon et al., 2021; Nurkanti, 2019) and affect students' careers in the future (Abe & Chikoko, 2020; Borda et al., 2020; Davenport et al., 2020; Kwon et al., 2021; Rodríguez-Martín et al., 2020). Studies have shown that students who develop an early interest in science, mathematics, and engineering are more likely to pursue STEM-related careers (Alliance, 2015). However, most STEM implementations in mathematics still focus on integrating cross-disciplinary contexts or projects without systematically accommodating multimodal differentiation based on student learning preferences. The development of digital STEM-based mathematics learning has indeed shown improvement, particularly in the use of technology for simulations and concept visualization. However, research that explicitly integrates the identification of learning preferences into the adaptive mechanisms of digital learning systems remains limited.

To address this gap, this research developed a STEM-based VARK Learning Application that integrates learning preference identification with multimodal content presentation and problem-solving activities within a single digital ecosystem. After students complete the VARK instrument, the system generates a learning preference profile that serves as the basis for material presentation and activity recommendations. Visually inclined students receive reinforcement through graphics and concept visualizations; aural preferences are facilitated through audio explanations; read/write preferences through conceptual summaries and analytical step descriptions; and kinesthetic preferences through interactive, exploration-based activities. Nevertheless, the application still provides access to all modes of representation so that students are not confined to a single category. With this approach, multimodal differentiation functions as an extension of cognitive pathways rather than a limitation of learning styles.

Thus, this research makes both conceptual and practical contributions. Conceptually, this research proposes repositioning the learning styles approach from simple matching to the design principles of multimodal differentiation in digital STEM learning. In practice, this research produces a learning product that has been validated by experts and tested on a limited basis to assess its potential to improve students' problem-solving abilities. Based on this background, the research questions posed are: 1) How is the STEM-based VARK learning application designed, particularly in terms of its features and instructional structure, to foster students' calculus problem-solving skills? 2) To what degree does the STEM-based VARK learning application improve students' calculus problem-solving performance after its implementation?

METHOD

Research Design

This research and development (R&D) project aims to produce and test the feasibility of the STEM-based VARK Learning Application. The development model used was the 4-D model, which defines design, develop, and disseminate (Thiagarajan et al., 1974). The define stage was carried out through a needs analysis that included: 1) analysis of student difficulties in solving Calculus problem-solving problems through an initial diagnostic test, and 2) identification of student learning preferences using the VARK instrument. The design stage included designing the application structure, developing STEM-based content, compiling problem-solving activities, and differentiating material presentation in a multimodal way (visual, aural, read/write, and kinesthetic). The development stage included expert validation and product revisions based on validator input, as well as limited trials with students. The dissemination phase in this study focused on disseminating products that have been declared valid, practical, and effective based on limited trials during the development phase. Therefore, implementation with students was not included in this phase. In the dissemination phase, activities are no longer aimed at collecting effectiveness data but rather at introducing and encouraging the use of the STEM-based VARK Learning Application to a wider audience through scientific publications, presentations at academic forums, and dissemination within the educational community. In addition, dissemination was also carried out in the Mathematics Education Study Program at several universities in Central Java through outreach to lecturers, demonstrations of application use, discussions on integration in learning, and the provision of user guides. Thus, the dissemination phase is understood as the process of disseminating the final product and transferring development results to the wider community, rather than as a trial phase or the collection of initial effectiveness data.

Research Subject

Participants in this study consisted of two groups: expert validators and students serving as trial subjects. The expert validators consisted of three people: 1) Calculus material experts with a minimum of five years of teaching experience and publications in the field of mathematics education, 2) Digital-based learning media experts, and 3) mathematics learning evaluation experts. The subjects of limited implementation were 50 students of the Mathematics Education Study Program at a university in Semarang City who were taking the Calculus course. The sampling technique used was purposive sampling with the following criteria: 1) active students who took Calculus lectures in the current semester, 2) willing to take the entire series of measurements, and 3) not taking a parallel remedial program on the same material.

Research Instrument

In developing learning tools or media, product quality is typically assessed from three main aspects: validity, practicality, and effectiveness. These three aspects were used to determine whether a learning product is suitable for use in the learning process. This study used four main instruments: an expert validation sheet, a learning preference identification instrument (VARK), a practicality instrument, and a problem-solving ability test. The expert validation sheet was used to assess the application's feasibility in terms of materials, media, and evaluation before implementation with students. The VARK instrument was used to identify students' learning preference tendencies as a basis for designing differentiated content presentation within the application. Meanwhile, a problem-solving ability test was used to assess students' development in solving calculus problems, using problem-solving process indicators at several measurement points during implementation. The research instruments are described below.

Expert Validation Sheet

Media Expert Validation is an assessment process conducted by experts or specialists in learning media to evaluate the quality of media developed before they are used in the learning process. This validation aims to ensure that the created learning media meet the established criteria. The validation sheet in this study was used to assess the feasibility of the product from the following aspects: Suitability of the material with

Calculus learning outcomes, Integration of the STEM approach, Quality of multimodal presentation, Quality of problem-solving activities, Aspects of application appearance and navigation, Clarity of evaluation and feedback. The validation sheet in this study uses a 1-5 Likert scale. Validation indicators are shown in Table 1.

Table 1. VARK learning application product feasibility grid

No.	Validity indicators	Questions number
1.	Suitability of material with Calculus learning outcomes	1, 2
2.	Integration of STEM approaches	3, 4
3.	Multimodal presentation quality	5, 6
4.	Quality of problem-solving activities	7, 8
5.	App appearance and navigation aspects	9, 10
6.	Clarity of evaluation and feedback	11, 12

The instrument used a 1–5 Likert scale. The average score was used to determine the validity category from Sugiyono (2018) with the following criteria:

The results of tests, interviews, and observations were analyzed using content analysis, which comprises three activities: data reduction, data presentation, and conclusion drawing (Creswell, 2012; Miles et al., 2014). Data reduction was carried out by encoding the interview transcript. The next step is to verify the data with in-depth interviews. The last step was to finalize the field data.

Table 2. Criteria for the validity of learning media

Value Range	Information
$1 \leq x < 2$	Invalid (not yet available)
$2 \leq x < 3$	Quite Valid (can be used with multiple revisions)
$3 \leq x < 4$	Valid (can be used with minor revisions)
$4 \leq x \leq 5$	Highly Valid (can be used without revision)

x = learning media validation score

Learning Preference Identification Instrument VARK

The VARK instrument is used to identify students' learning preference tendencies in four main categories: Visual, Aural, Read/Write, and Kinesthetic (Fleming & Baume, 2006). This instrument was administered at the initial stage of the study to obtain an overview of students' tendencies in receiving, processing, and understanding learning information. The identification results were not intended to classify students into rigid or exclusive groups, but rather to provide diagnostic information to inform the design of differentiated content presentation in the application. The learning preference profile served as the basis for providing a variety of material representations, such as graphic and diagram visualizations, audio explanations, conceptual text summaries, and exploration-based interactive activities. With this approach, VARK is positioned as a multimodal learning design principle that expands students' cognitive access paths to calculus concepts, rather than as a single matching mechanism between learning styles and teaching methods. The learning style instrument contained 8 indicators, translated into

16 questionnaire items (1 indicator is split into 2 questions). The learning style indicators are shown in Table 3.

Based on the 4 learning styles, they were divided into 8 indicators, and each indicator was made into 2 questions. The results of the VARK questionnaire design were then validated by 3 experts, namely an evaluation expert, a learning style expert, and a mathematics expert. In the validation of the VARK instrument, the aspects assessed included: (1) the suitability of the items with the VARK indicators, (2) the clarity of the statement wording, (3) the accuracy of the use of language, and (4) the overall suitability of the instrument. The VARK questionnaire is shown in Table 4.

Table 3. VARK learning style indicators

Learning Style	Indicator
Visual	Understand the material through pictures, diagrams, or videos.
	Understand the material by seeing examples or demonstrations directly
Auditory	Understand the material through oral explanations or stories from lecturers or friends.
	Discuss or listen to other people's opinions in the learning process.
Read/Write	Understand the material by reading books or texts
	Note down or rewrite information to help understand the material.
Kinesthetic	Understand the material through practice or direct experience.
	Learning that involves physical activity or hands-on activities

Table 4. VARK learning styles according to the indicators created

No.	Learning Style	Indicator	Questionnaire Questions
1	Visual	Understand the material through pictures, diagrams, or videos	1. I understand material more easily when it is presented in the form of images, diagrams, or videos. 2. I understand concepts better when the material is accompanied by graphs or visual illustrations.
		Understand the material by seeing examples or demonstrations directly	3. I understand the material by seeing examples of solutions directly. 4. I learn more easily if the lecturer shows the steps visually.
2	Audio	Understanding material through oral explanations or stories	5. I understand the material through oral explanations from the lecturer. 6. I understand the material more easily when it is explained in the form of a story or verbal explanation.
		Discuss or listen to other people's opinions	7. I learn better through discussions with friends or lecturers. 8. I understand the material by listening to other people's opinions or explanations.
3	Read/Write	Understand the material by reading books or	9. I understand the material better by reading books or texts.

		texts	10. I understand the material more easily if I read written explanations.
		Recording or rewriting information	11. I rewrite the material to make it easier to understand. 12. I learn by rewriting the concepts I have learned.
4	Kinesthetic	Understanding the material through practice or direct experience	13. I understand material through practice or direct experience. 14. I understand concepts more easily if I am directly involved in learning activities.
		Learning involves physical activity or hands-on activities	15. I learn better through physical activity or hands-on activities. 16. I understand material better when I try or practice it myself.

After determining the learning style indicators, a learning style instrument is created. The resulting learning style instrument will be validated by experts, and the results will then be categorized according to Sugiyono (2018), as shown in Table 2.

Practical Instruments of VARK Learning Application

Practicality is an important criterion in development research. The practicality of learning media can also be measured through user responses from both lecturers and students. This study examined students' responses to the VARK Learning Application. User responses to a medium can be measured through a questionnaire containing statements regarding ease of use, material clarity, media appearance, and the media's benefits in assisting the learning process (Arikunto, 2016). In this study, the practicality indicators adopted from Arikunto (2016) were developed and comprised four indicators, broken down into 16 questions. The practicality indi cators and criteria are shown in Tables 5 and 6.

Table 5. Practicality indicators of the VARK learning application

No.	Practicality indicator	Questionnaire number
1.	Ease of use of learning media	1, 2, 3, 4
2.	Clarity of material	5, 6, 7, 8
3.	Display of learning media	9, 10, 11, 12
4.	The benefits of media in helping the learning process	13, 14, 15, 16

Table 6. The practicality criteria of learning media (Arikunto, 2016)

Percentage	Practicality category
81% – 100%	Very Good / Very Practical
61% – 80%	Good / Practical
41% – 60%	Enough
21% – 40%	Not enough
0% – 20%	Very less

Problem-Solving Ability Test

The problem-solving ability test is structured around four key indicators: understanding the problem, planning a solution strategy, implementing the strategy, and evaluating the results. (Robson & Polya, 1946). These indicators reflect the stages of the thinking process in solving calculus problems, from identifying relevant information and formulating a mathematical model to rechecking the solution's correctness. The test consisted of four items, measured at three time points during the implementation period, to monitor the development of students' abilities. Assessment was conducted using an analytical rubric that scores each indicator separately, thus measuring not only the final results but also the quality of the students' problem-solving process. The determination of problem-solving indicators was based on the indicators of Robson & Polya (1946). Moreover, an adaptation of the indicators from Purnomo et al. (2024) presented in Table 7

Table 7. Polya's problem-solving indicators

Problem-Solving Stages	Indicator	Code
Understanding the problem	Analyze the questions	I1
Devising a plan	Find the relationship between the data and the unknown.	I2
	Determine the method used to solve the problem	I3
Carrying out the plan	Implement the solution plan and check each step.	I4
	Determine the solution to the problem and write down the solution or answer to the problem.	I5
Looking back	Check the accuracy of the answers to the questions	I6

Each item on the test instrument used in this study was assessed for quality, namely through validity and reliability tests. Validity tests were conducted to determine the extent to which each test item can measure the aspects it should measure according to the research objectives (Sugiyono, 2018). This test determined whether each item is suitable for use, needs revision, or should be eliminated. After the validity test was conducted, the instrument was tested for reliability to assess the degree of consistency in measuring the variables under study. The reliability test results indicated whether the instrument had sufficient reliability for data collection. Thus, only test items that met the criteria for validity and reliability were used as measurement tools in this study. The following is an example of a question that was created before being tested for validity and reliability (Table 8).

Content validation in this study was conducted by three experts, lecturers responsible for Calculus courses with a minimum of 5 years

Table 8. An example of a problem-solving ability test question

Question	Answers according to problem-solving stages and indicators
A company wants to produce a lidless box from a rectangular piece of cardboard measuring 30 cm × 20 cm. A small square with side length x is cut from each corner of the cardboard and then folded to form a lidless box. Determine: a. The volume function model for the box in terms of x	Answer 1. Understanding the Problem (I1): Write down all the known and required information in the problem. 2. Planning Strategy (I2 & I3): • Use the strategy to find the volume of a box without a lid. • Find the volume function in terms of x $(V(x))$. • Find the value of x for maximum volume using $(V'(x) = 0)$ • Check whether the answer obtained is realistic/in

b. The value of x that produces the maximum volume c. The maximum volume that can be obtained d. Explain whether the solution is realistic in the context of the problem	accordance with the question. 3. Implementing Strategy (I4 & I5): • Implement the planned strategy. Volume: $V(x) = x(30 - 2x)(20 - 2x)$ or $V(x) = 4x^3 - 100x^2 + 600x$ • Find the stationary point: $V'(x) = 0$ $12x^2 - 200x + 600 = 0$ • Find the value of x ≈ 3.92. • Maximum volume ≈ 1056 cm^3. 4. Evaluating Results (I6) • Check the limits: The value of x < 10 (because the width is 20 cm) and the value of x ≈ 3.92 (realistic) • The optimal value of x is approximately 3.92 cm with a maximum volume of approximately 1056 cm^3 (in accordance with the expected answer) Answer: a. The function model for the volume of the box in terms of x is $V(x) = 4x^3 - 100x^2 + 600x$ b. The value of x that produces the maximum volume is $x \approx 3{,}92$ c. The maximum volume that can be obtained is ≈ 1056 cm^3. d. Explain whether the solution is realistic in the context of the problem: The value of x < 10 (because the width is 20 cm) and the value of x ≈ 3.92 (realistic), and the optimal value of x is approximately 3.92 cm with a maximum volume of approximately 1056 cm^3 (in accordance with the expected answer)

of teaching experience. All three validators are competent in mathematics education and have experience in developing learning tools. The validation process aims to assess the suitability of the application content with Calculus learning outcomes, the accuracy of mathematical concepts, the quality of problem-solving activities, and the suitability of the material presentation with the STEM approach and the principle of multimodal differentiation based on VARK. In addition, the validators also assessed the clarity of the evaluation instrument used to measure students' problem-solving abilities. The assessment was conducted using a validation sheet on a 1–5 Likert scale, where the score reflects the feasibility of each assessed aspect. Validation results were analyzed by calculating the average score to determine the product's validity category. In addition to quantitative assessments, the validators provided qualitative input, including suggestions for improvement, which served as the basis for product revisions prior to implementation. The instrument used a 1–5 Likert scale. The average score was used to determine the validity category according to Sugiyono (2018), using the following criteria, as presented in Table 9.

After testing content and construct validity, the next step was to conduct empirical testing, namely, assessing the validity and reliability of the problem-solving ability instrument. Validity testing of the problem-solving ability test instrument was

Table 9. Validity criteria for problem-solving ability test instruments (Sugiyono, 2018)

Value Range	Information
$1 \le x < 2$	Invalid (not yet available)
$2 \le x < 3$	Quite Valid (can be used with multiple revisions)
$3 \le x < 4$	Valid (can be used with minor revisions)
$4 \le x \le 5$	Highly Valid (can be used without revision)

conducted to determine the extent to which each item measures the ability it is intended to measure. Item validity testing was conducted using the Pearson Product-Moment correlation developed by Karl Pearson (Sugiyono, 2018). Reliability testing is conducted to determine the instrument's consistency in measuring problem-solving ability. Reliability is calculated using Cronbach's alpha. The results of the reliability test calculations are used to form criteria, as shown in Table 10.

Table 10. Reliability test criteria (Sugiyono, 2018)

No.	Score Results	Criteria
1.	≥ 0.80	very high
2.	0.60–0.79	high
3.	0.40–0.59	high enough
4.	0.20–0.39	low
5.	< 0.20	very low

Research Procedures

The research procedure was carried out in stages according to the established development design. In the initial stage, students completed a diagnostic test to assess their problem-solving abilities with Calculus material and to identify dominant conceptual difficulties. Next, students completed the VARK instrument to identify learning preference tendencies, which were used to differentiate content presentation in the application. The application was then implemented in Calculus learning for a specific period, during which students accessed materials, multimodal activities, and STEM-based problem-solving exercises. To assess the development of problem-solving abilities, tests were administered at three time points during the implementation period. All data were collected and analyzed using established methods to answer the research questions.

Data Analysis Techniques

Data analysis in this study included product validity and improvements in problem-solving ability. Expert validation data on material, media, and evaluation aspects were analyzed descriptively by calculating the average score to determine the product's feasibility category based on established validity criteria. Meanwhile, the improvement in students' problem-solving abilities was analyzed using a repeated-measures ANOVA because this study involved three measurements within the same group. This test was used to determine whether there were significant differences in the average between measurement times. Before the main analysis, the data were tested for normality and sphericity to ensure that statistical assumptions were met, with a significance level set at á = 0.05. This study also used effect size in the ANOVA analysis. Partial Eta Squared describes the strength of an intervention's or treatment's influence on the variables studied (Olejnik & Algina, 2003), so that researchers not only know the statistical significance but also the treatment's practical impact. Based on the effect size value, criteria are used to determine its magnitude. The effect size criteria are shown in Table 11.

Table 11. Effect size categories

Effect Size value	Category
0.01	Small Effect
0.06	Medium Effect
0.14	Large Effect

RESULT AND DISCUSSION

To present the research results more systematically and in accordance with the characteristics of research and development (R&D), this results and discussion section is divided into three main subsections, namely: (1) Characteristics and Validity of the Developed Media, which describes the characteristics of the product developed and the results of validity tests by experts; (2) Practicality and Student Responses, which describes the practicality of using the application in learning and student responses during implementation; and (3) Effectiveness on Learning Outcomes, which presents an analysis of the improvement in students' problem-solving abilities based on the results of repeated measurements. This division aims to clarify the product evaluation process, covering theoretical feasibility, practical implementation in the field, and its impact on learning outcomes, so that the research findings can be interpreted more comprehensively and in a structured manner.

Characteristics and Validity of the Developed Media

The purpose of this phase is to establish and define the learning requirements. The steps are: front-end analysis, learner analysis, task analysis, concept analysis, and specific teaching objectives. The Needs Analysis phase involves two components: identifying teaching problems and analyzing users. To achieve this, a Calculus Diagnostic Test is conducted to identify students' problem-solving abilities. This phase aims to identify and categorize students' existing problem-solving abilities into three levels (low, medium, and high). Before identifying learning styles, the instrument's validity must be tested. The validation results are shown in Table 12.

Table 12. Expert validation results on the VARK instrument

Validator	Average Score	Category	Expert Input	Revisions Made to the Instrument	Impact on instruments
Validator 1	4.15	Very Valid	Some items are still too general and do not specifically reflect indicators of certain learning styles.	Clarify the item wording to be more specific according to the indicators (visual, auditory, read/ write, kinesthetic)	Items are more representative of the construct being measured
Validator 2	4.25	Very Valid	The sentences in some items are too long and could confuse respondents.	Simplify sentence structure and use more communicative language	The instrument becomes easier for students to understand
Validator 3	4.14	Very Valid	There is potential for interpretation bias in some items, and consistency in sentence patterns is needed.	Adjust the wording to be more consistent and avoid ambiguity.	Improve clarity and consistency of measurements
Average Score	4.18	Very Valid			

Validation results for the Learning Preference Identification (VARK) instrument indicated high feasibility, with an average score of 4.18, which is categorized as highly valid. Overall, all instrument items demonstrated good alignment with the VARK conceptual indicators (visual, auditory, read/write, and kinesthetic), adequately representing the constructs being measured. These findings indicate that the instrument has strong content and construct validity for use in research contexts.

However, a qualitative evaluation by experts identified several aspects requiring improvement, particularly regarding item wording specifications, language clarity, and consistency in statement structure. Revisions were made by simplifying wording, clarifying item relationships with indicators, and minimizing potential ambiguity in response interpretation. These improvements were minor and did not alter the substance of the instrument, but they contributed to clearer measurement and greater internal consistency. Thus, the VARK instrument was deemed suitable as a diagnostic tool for identifying students' learning preferences in this study. After being declared valid, the instrument was used to assess student learning style characteristics. The results are shown in Figure 1. The following will be used to identify learning styles and problem-solving abilities.

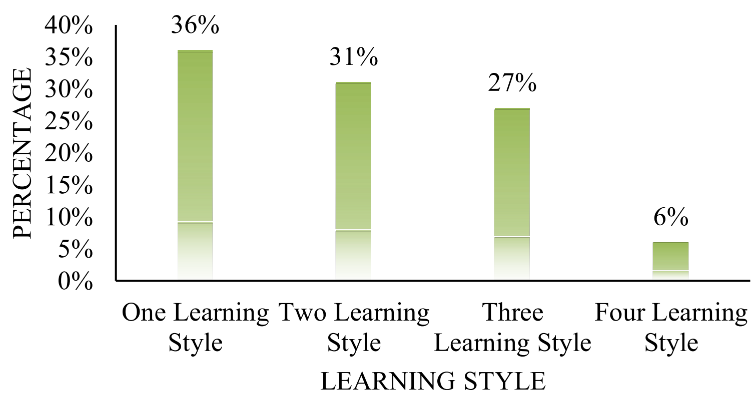


Figure 1. Mapping the use of student learning style categories

Based on this data, we can conclude that the majority of students use more than one learning style in their studies (63%), while 37% use a single learning style. Further analysis reveals that 31% use two learning styles, 27% use three, and 6% use four simultaneously. This suggests that students utilize a variety of learning styles. When we examine the learning styles used, the dominant one is shown in Figure 2.

The results of the learning preference mapping show that students do not have a single learning style but rather use various multimodal combinations, such as AK, RK, VK, and VARK. The results of identifying learning preferences using the VARK instrument show a diverse distribution of tendencies, both in single preferences and multimodal combinations. The differences in percentages between the two data visualizations are due to differences in the basis of the analysis: a single dominant preference versus the overall distribution, including combinations of preferences. Therefore, the differences in figures do not indicate data inconsistencies but rather differences in the units of interpretation. This finding indicates that most students exhibit multimodal tendencies. This situation reinforces the need for learning designs that provide a variety of representations and activities, so that students are not limited to a single representational pathway.

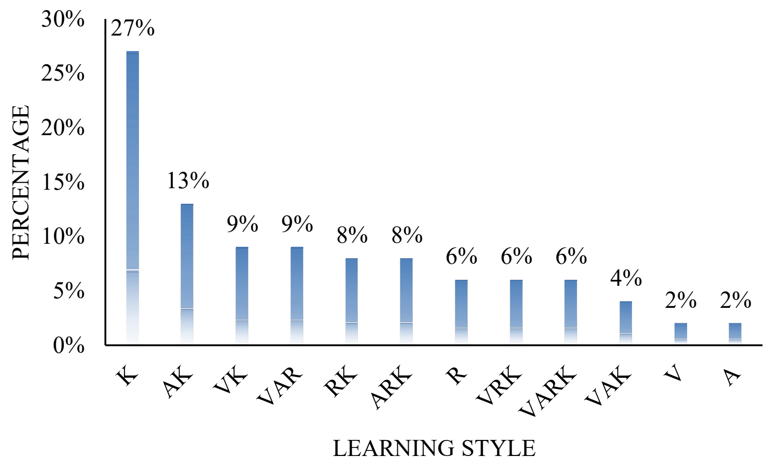


Figure 2. Mapping of overall student learning styles

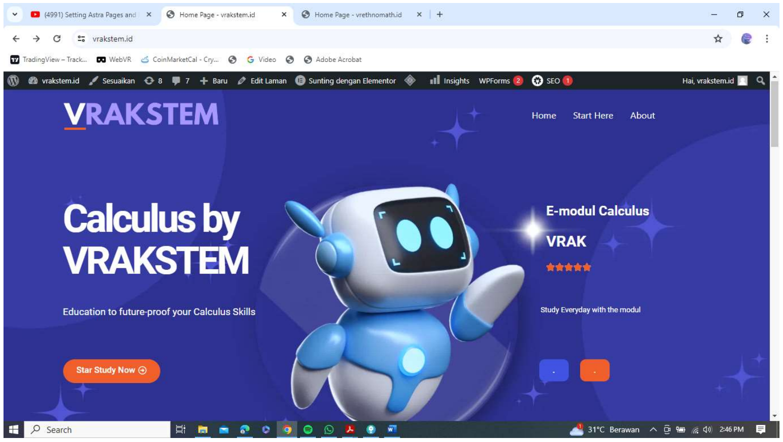
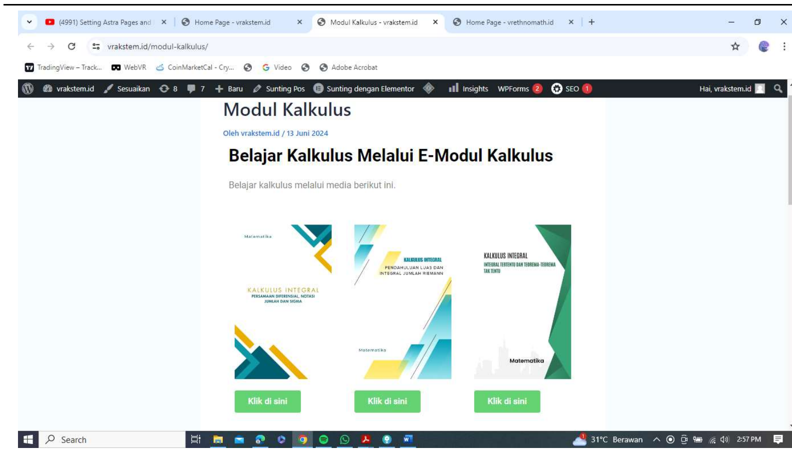
This diversity implies that learning media design cannot rely on a single representational mode. Therefore, the developed application employs a multimodal differentiation approach, providing graphic visualizations, audio explanations, text-based conceptual summaries, and interactive activities. Providing these various representation pathways aims to broaden students' cognitive access to calculus concepts, enabling them to build a more flexible understanding and support the problem-solving process. However, this diversity of learning style combinations should not be interpreted as justification for exclusive learning style matching (meshing hypothesis). This study does not claim that a particular learning style leads to improved learning outcomes; rather, it demonstrates that inclusive and multimodal learning designs can create learning environments that are more responsive to diverse student preferences. Thus, integrating multimodal differentiation within a digital STEM framework is an instructional design strategy that strengthens problem-solving skills in Calculus.

The purpose of this stage is to prepare a prototype of the teaching materials. This stage consists of media selection, format selection, and initial design. The design of the STEM-based VARK Learning Application learning media is based on the competencies of the Calculus course. STEM-based education is a learning process that integrates various approaches to develop high-quality human resources that meet the demands of the 21st century. STEM learning integrates four components: science, technology, engineering, and mathematics into the learning process. The goal of STEM learning is for students to develop technological literacy and utilize concepts from the Calculus course. STEM learning has core principles related to communication, materials, problem-solving skills, and technology integration. Based on the analysis results from the definition stage, the learning media design was created.

The website includes a calculus module with several stages to facilitate students' learning. The website offers several calculus modules for users to access. The website was created using a STEM approach. Modules can be accessed by clicking "Start Study Now." The only learning material accessible on this website is Calculus.

A dashboard design for lecturers includes features for learning, such as student data, learning-style graphs, a material repository, a question repository, and more. The admin dashboard is more comprehensive than the lecturer dashboard. The admin dashboard includes additional learning-style instruments,

Table 13. VARK learning application design

	Home Page: Home page in modules
	Calculus module consisting of several materials
	One of the Calculus modules with Differential Equations, Number Notation, and Sigma material

lecturer data, and master data. At the beginning of media usage, students' learning styles will be identified. The results of this learning-style determination will serve as the basis for students' Calculus learning. Students will have different learning styles so that they will use this application according to their needs.

The student dashboard design includes a learning style assessment feature for each student. This feature is used when students want to understand their learning style tendencies. The adaptive mechanism in the STEM-based VARK Learning Application is based on the principle of multimodal differentiation rather than the exclusive matching of learning styles. After students complete the VARK instrument, the system automatically calculates scores on four dimensions (Visual, Aural, Read/Write, and Kinesthetic) and generates a preference profile with relative weights. This profile is processed by a priority-based rule engine, in which the one or two dimensions with the highest scores determine the order and default view of the learning material, without restricting access to other representations

Each calculus topic is structured in a parallel modular format, comprising four representation formats: visual (graphics and interactive animations), aural (audio explanations of problem-solving steps), read/write (conceptual summaries and procedural descriptions), and kinesthetic (exploratory activities and interactive STEM-based exercises). The system displays the dominant preference as the primary format on the dashboard, while students can access other formats via the navigation tabs. Thus, adaptation occurs at the level of presentation priorities and user experience, not in rigid learner groupings.

The learning flow is controlled sequentially to maintain the validity of the evaluation. Students are required to complete a pre-test before accessing the material, and the post-test can only be administered after all learning activities have been completed, with access to the material temporarily disabled during the evaluation. The system also logs user interactions as part of implementation controls. This approach ensures that the adaptation enriches representation within the digital STEM framework and strengthens problem-solving skills. After completing the learning media design, the next stage is expert validation of the media.

The purpose of this development stage is to determine the validity of the STEM-based VARK Learning Application. After designing the learning media, the next step is expert validation. The expert validation team consists of three experts: a media expert, a content expert, and a learning expert. The experts provide input by revising the created learning media. The next step is to revise the learning materials, taking expert input into account. The validation results are shown in Table 2 below.

Based on expert validation results, the developed media received an average score of 4.22, indicating high validity with minor revisions. Although it met the eligibility standards, the experts provided input regarding strengthening the problem-solving orientation and varying the evaluation instruments. This input was followed up through structured revisions to the material and questions. A more complete overview of the expert input is shown in Table 15.

Table 14. Results of expert validation of media and learning models

No.	Validators	Membership/ Expertise	Average Validation Results
1	Senior Lecturer 1	Calculus Expert	4.25
2	Senior Lecturer 2	Learning Media	4.35
3	Senior Lecturer 3	Learning evaluation	4.05
Average			4.22
Category			Highly Valid

The mathematics expert's evaluation revealed several changes related to the material in the learning media. The expert's input emphasized problem-solving questions and ensuring their implementation in learning. The questions created did not fully emphasize problem-solving skills. The material presented continued to focus on conceptual understanding.

Table 15. Results of expert validation input on media

No.	Expert Validation	Input from Experts	Revisions Made	Impact on Media
1	Calculus/ Mathematician	The material still emphasizes conceptual understanding and is not yet optimal in developing problem-solving skills. The questions do not fully reflect high-level problem-solving.	The material was restructured by adding STEM-based contextual problems to each subtopic and explicitly emphasizing the problem-solving stages (understanding the problem, planning a strategy, implementing the strategy, and evaluating the results). Open-ended, multi-step problems requiring mathematical modeling were added.	The material becomes more applicable, focusing on strengthening problem-solving skills rather than just mastering concepts.
2	Learning Media Expert	The presentation of material and the evaluation flow need to be clarified to be more systematic and to support implementation in learning.	Improved navigation structure, emphasized pre-test → material → post-test flow, and added learning outcome reflection features to the dashboard.	The media become more systematic and easier to use, and they support structured learning experiences.
3	Learning Evaluation Expert	The pre- and post-test questions lacked variety and were still dominated by direct calculation. The assessment did not fully assess the problem-solving process.	Question variety increased by adding contextual questions, graph interpretation, multi-step questions, and strategy-justification questions. The assessment rubric was revised to an analytical rubric that assesses each problem-solving indicator.	Evaluation instruments become more comprehensive, enabling more accurate measurement of problem-solving processes and outcomes.

The expert's analysis of the media evaluation emphasized the pretest and posttest, noting a lack of variety in the evaluation questions. Changes in the variety of questions would further challenge students as they work on the problems. Based on these results, the learning media are highly valid and can be implemented in learning activities. After validation, the next step is implementation in the classroom.

Practicality and Student Responses

The practicality of the STEM-based VARK Learning Application was analyzed using student responses to four indicators: ease of use, clarity of material, media display, and the media's benefits in supporting the learning process. The practicality results are shown in Table 16.

The practicality analysis results show that the STEM-based VARK Learning Application achieved an average score of 84.75%, indicating it is very practical. This indicates that the developed learning media are easy for students to use and can effectively support the learning process. For each indicator, the media's appearance achieved the highest score of 87%, indicating that engaging visual design can increase

Table 16. Practical results of the VARK learning application

No	Practicality Indicator	Percentage	Category
1	Ease of use of learning media	85%	Very Practical
2	Clarity of material	83%	Very Practical
3	Display of learning media	87%	Very Practical
4	The benefits of media in helping the learning process	84%	Very Practical
Average practicality		84.75%	Very Practical

student interest and motivation. A good media appearance is crucial in technology-based learning media because it can increase student engagement in the learning process.

The ease-of-use indicator for the media achieved a score of 85%, indicating that students can use the learning media easily. Clear navigation and easy-to-understand features allow students to access learning materials without difficulty. Furthermore, the media's usefulness in supporting the learning process achieved a score of 84%. This indicates that the developed learning media can help students understand calculus concepts and support problem-solving.

The clarity of the material indicator achieved a score of 83%, indicating that the presentation of the material in the learning media is systematic and easy for students to understand. The structured presentation of the material helps students grasp the concepts being studied. Based on these results, it can be concluded that the STEM-based VARK Learning Application has a very good level of practicality, making it suitable for use in the learning process to help students understand calculus material and improve problem-solving skills. After understanding the practicality of the learning media, the next step is to analyze its effectiveness.

Effectiveness on Learning Outcomes

Before being used in the research, the problem-solving ability test instrument, consisting of six questions, was first tested for quality in terms of content, construct, and empirical validity. This testing aimed to ensure that each question item measured problem-solving ability according to the established indicators and demonstrated good consistency. The results of the expert validation are shown in Table 17.

The validation results for the problem-solving ability test instrument, consisting of 6 questions, indicate that all questions fall in the very valid category. The average overall score was 4.38, which falls within the very valid category (4 d" x d" 5). This indicates that the developed instrument has met the eligibility criteria in terms of content, construction, and suitability with problem-solving ability indicators. Although all

Table 17. Expert validation results of the problem-solving ability test

No	Question Items	Expert 1	Expert 2	Expert 3	Average score	Category
1	Question 1	4.20	4.60	4.40	4.40	Very Valid
2	Question 2	4.10	4.30	4.50	4.30	Very Valid
3	Question 3	4.70	4.20	4.30	4.40	Very Valid
4	Question 4	4.00	4.10	4.20	4.10	Very Valid
5	Question 5	4.80	4.60	4.50	4.63	Very Valid
6	Question 6	4.30	4.70	4.40	4.47	Very Valid
Overall average					**4.38**	**Very Valid**

questions met the very valid criteria, experts still provided input to inform improvements to the instrument. The revisions were minor and focused on improving the quality of the questions to better measure high-level problem-solving abilities. The results thevalidators' input are shown in Table 18.

Table 18. Expert input on problem-solving ability tests

No.	Validator	Expert input	Follow-up on instruments
1	Expert 1	The questions still tend to focus on calculation procedures but need improvement in the context of problem modeling.	Adding real-world context to some questions and clarifying problem-solving steps.
2	Expert 2	Some questions do not explicitly require students to explain their solution strategy.	Add instructions to explain the steps and reasons in the solution.
3	Expert 3	The variety of questions needs to be increased to avoid them becoming routine.	Adding open-ended and multi-step questions.

The validation results showed that although the instrument was categorized as highly valid, the experts provided important input for improving the quality of the questions. Expert 1 found that some questions were still overly focused on calculation procedures and needed to be strengthened with real-world contexts and an emphasis on the problem-solving stages to better reflect problem-solving abilities. Furthermore, Expert 2 highlighted that the questions did not explicitly encourage students to explain their solution strategies, so revisions were made by adding instructions requiring students to explain the steps and the rationale for the solution. Meanwhile, Expert 3 emphasized the importance of question variation, so open-ended and multi-step question formats were added to better measure higher-order thinking skills. Overall, the experts' input improved the instrument's quality, making it not only content-valid but also more comprehensive in measuring the processes and outcomes of mathematical problem-solving. The next step was to empirically test the validity and reliability of the questions administered to students in the Differential Calculus course. The results of the validity test are shown in Table 19.

Table 19. Results of the validity test of problem-solving ability test items

No	Question Items	r_count	r_table (α = 0,05)	conclusion
1	Question 1	0.68	0.279	Valid
2	Question 2	0.72	0.279	Valid
3	Question 3	0.65	0.279	Valid
4	Question 4	0.74	0.279	Valid
5	Question 5	0.66	0.279	Valid
6	Question 6	0.70	0.279	Valid

Based on the table above, item number 6 has a value of $\mathbf{r}_{(count)} > \mathbf{r}_{(table)}$, So it is declared valid. Based on this, it can be concluded that the six questions have good validity and can measure problem-solving ability according to the established indicators. The next step is to test the reliability of the problem-solving ability questions. The results the reliability test shown in Table 20.

Table 20. Results of the reliability test of problem-solving ability questions

Number of question items	Alpha Cronbach	Category
6	0.84	High

The reliability value indicates that the instrument has good internal consistency, making it suitable for use as a measuring tool in this study. Based on the results of the validity and reliability tests, the problem-solving ability test instrument was declared suitable for use with 6 valid questions and a high level of reliability. The evaluation was conducted in 3 parts, each comprising 2 questions. Implementation was carried out in 7 meetings with 3 evaluations. The results of the implementation were evident in improved problem-solving abilities, as assessed by the repeated-measures ANOVA. The results of the improvement in problem-solving abilities are shown in Table 21.

The Tests of Within-Subjects Effects table presents the results of the Repeated Measures ANOVA for the problem-solving ability variable.

Table 21. Results of problem-solving ability analysis

Tests of Within-Subjects Effects						
Measure: Test						
	Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Nilai	Sphericity Assumed	2786.573	2	1393.287	193.743	.000
	Greenhouse-Geisser	2786.573	1.769	1575.242	193.743	.000
	Huynh-Feldt	2786.573	1.830	1522.431	193.743	.000
	Lower-bound	2786.573	1.000	2786.573	193.743	.000
Error (Nilai)	Sphericity Assumed	704.760	98	7.191		
	Greenhouse-Geisser	704.760	86.680	8.131		
	Huynh-Feldt	704.760	89.687	7.858		
	Lower-bound	704.760	49.000	14.383		

Based on the Greenhouse–Geisser correction, the F value was 193.743 with df = 1.769 and a significance value of Sig. = 0.000 ($p < 0.05$). These results indicate a significant difference in problem-solving ability scores between the measurements or conditions analyzed. The very large F value indicates that the variation due to the treatment is much greater than the variation due to error, so the treatment has a strong influence on changes in problem-solving ability. This is also supported by the Type III Sum of Squares value (2,786.573), which is much larger than the Error Sum of Squares (704.760).

Based on the results of the Repeated Measures ANOVA analysis in the Tests of Within-Subjects Effects table, the Sum of Squares effect (SS_effect) value for the Value variable is 2786.573, while the Sum of Squares error (SS_error) is 704,760. The magnitude of the effect size is calculated using the Partial Eta Squared formula. Based on this formula, the value of the η^2_p = 0.798 is obtained. This value indicates that approximately 79.8% of the variation in value changes can be explained by the treatment or factors tested in the study. Thus, the effect of treatment on the test results = 0.798

> 0.14 is classified as a large effect. The next step is to determine whether there is a significant increase in problem-solving ability across the 3 tests. The results of the increase in problem-solving ability are shown in Table 22.

The output table above shows the average content for each measurement over time (Tests 1, 2, and 3). For test 1 (number 1) compared to test 2 (number 2), the average test score increased by 4.091, with a sig value of 0.001 < 0.05, indicating a significant difference in the average scores of test 1 and test 2. For number 1 (test 1) compared to number 3 (test 3), there was an increase in the average Content score of 11.909, with a sig value of 0.000 < 0.05, indicating a significant difference in the average score between test 1 and test 3. For number 2 (test 2) compared to number 3 (test 3), there was an increase in the average Content score of 7.818, with a sig value of 0.000 < 0.05, indicating a significant difference in the average scores of test 2 and test 3.

Table 22. Pairwise comparisons

Measure: Tes						
(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig. [a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-6.860*	.552	.000	-8.228	-5.492
	3	-10.380*	.607	.000	-11.884	-8.876
2	1	6.860*	.552	.000	5.492	8.228
	3	-3.520*	.436	.000	-4.602	-2.438
3	1	10.380*	.607	.000	8.876	11.884
	2	3.520*	.436	.000	2.438	4.602

Based on the results of the Bonferroni pairwise comparisons test, it can be concluded that significant changes occurred in all pairs of measurement times: Test 1 and Test 2, Test 2 and Test 3, and Test 1 and Test 3. Thus, these results indicate a significant, gradual increase in scores over time, suggesting that the treatment in the study had a real impact on improving students' test results. The next step will be to present a scatter plot comparing the pre-test (Test 1) and post-test (Test 3) scores. The scatter plot results are shown in Figure 3.

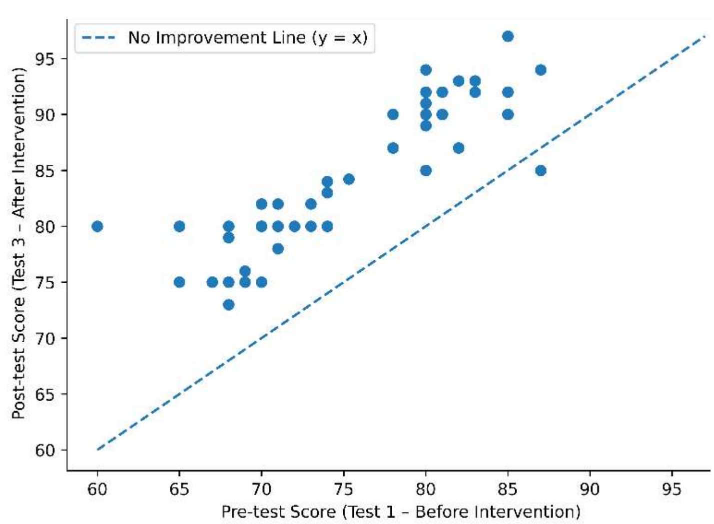


Figure 3. Scatter plot of pre-test vs post-test scores for each student

Based on the scatterplot comparing pre-test (Test 1) and post-test (Test 3) scores of 50 students, it can be seen that almost all points are above the y = x line (the "no improvement" line), indicating that the majority of students experienced an increase in their scores after the intervention/learning. Quantitatively, 49 of the 50 students (98%) improved, with an average increase of approximately 8.9 points and a median increase of 9 points, while only one student experienced a small decrease (-2 points). The range of score changes was quite wide, from -2 to +20 points, indicating some variation in individual responses, but the direction of change was predominantly positive. The pattern of the point distribution also shows that students with lower initial scores tended to experience greater improvement. In comparison, students with higher initial scores continued to improve, but to a lesser extent, indicating a possible ceiling effect as the room for improvement narrows at already high scores. Furthermore, the relationship between pre-test and post-test remained strong, indicating that students who initially performed well tended to remain at a higher level after the intervention, with the distribution of scores generally shifting upward and becoming slightly more even. Overall, this visualization provides strong evidence that the intervention/learning had an effective, consistent impact on individual student achievement.

The practicality of the STEM-based VARK Learning Application in this study is not measured solely by "ease of use" but by instructional usability. The media design truly operationalizes the complex learning needs of calculus into a structured digital learning flow. The 4-D framework incorporates this aspect from the definition stage through front-end analysis and learner analysis, namely diagnostic tests of calculus problem-solving abilities and mapping of VARK learning preferences as the basis for content differentiation. Student response findings reveal a predominantly multimodal learning profile: the majority of students use more than one learning style (63%), with a diverse distribution of combinations.

What makes this study stronger than many previous VARK studies is VARK's non-deterministic stance, which explicitly rejects the meshing hypothesis. This study repositions VARK as diagnostic information for multimodal differentiation, expanding cognitive access rather than relying on exclusive groupings. Student responses are not used to legitimize "teaching according to one style" but rather to inform the design of a learning environment that is more inclusive of diverse ways of processing information, especially when calculus demands the coordination of symbolic, visual, and contextual interpretation. This strategy aligns with the STEM literature (Borda et al., 2020; Hallström & Schönborn, 2019) that emphasizes contextual modeling, technology use, and problem-solving (Delahunty et al., 2020; Rasyid et al., 2023). However, it overcomes the common weakness of STEM implementation, which often stops at the "project context" without a systematic multimodal differentiation mechanism in the digital realm.

Designing learning media based on learning styles and STEM is one such learning innovation. (Rini & Cholifah, 2020). Understanding a person's learning style will help determine more effective learning methods. (Wahyuni, 2017). Learning styles significantly influence learning achievement. (Weggelaar-Jansen et al., 2015; Wassahua, 2016); El-Bishouty et al., 2019; Nur Habibah et al., 2019) and improve mathematical understanding (Azizah & Dien, 2017). Given the positive influence of learning styles on learning outcomes, many experts have developed systems to identify learning styles. (Seyal & Rahman, 2015; Prasetyo & Iqbal, 2016 ; Zhang et al., 2020), thus enabling the prediction of uncertain learning styles (Deborah et al., 2015). Student learning strategies have been explored in relation to context and creativity (Markoviæ & Jovanoviæ, 2012), learning theory, empirical studies, and the interplay of pedagogical aspects (Khanal et al., 2021). These learning strategies will then be implemented by students, becoming learning habits and ultimately becoming learning styles.

Concept maps can assist students in learning the sequence of the material. Learning media also provides summaries of evaluation questions to support students' learning. Explanatory learning videos can clarify the material in the summaries. Learning videos are also more engaging, thus motivating students to learn. Technology-assisted learning media can improve students' problem-solving skills. Expert validation complements the design. Expert input further improves the quality of learning media. Validated tools can be implemented in learning. (Yahya et al., 2020; Yuwono & Syaifuddin, 2017). Designing STEM-based learning media can improve students' competencies and problem-solving skills.

In this study, the key product characteristics lie in the explicit integration of three domains: (i) STEM as the framework of activities and contexts, (ii) VARK as the basis for multimodal differentiation, and (iii) problem solving as the target of core competencies. The uniqueness of the media design in this study can be read as a direct answer to the gap in existing research. Each calculus topic is structured in a parallel, modular format with four representation formats: visual (interactive graphics/animations), audio (audio explanations of problem-solving steps), read/write (conceptual summaries and procedural descriptions), and kinesthetic (exploratory activities and interactive STEM-based exercises). In terms of validity, expert evaluation was conducted by three validators (calculus materials, digital media, and learning evaluation) using a 1–5 Likert scale, with "Highly Valid" scores of 4–5. Validity here does not stop at "attractive appearance," but touches on alignment with problem-solving objectives: expert input encourages strengthening the problem-solving orientation, sharpening the evaluation flow, adding reflection features to the dashboard, as well as variations in questions that better assess the process and revision of the rubric to an analytical rubric. Based on the design results above, further research will be conducted to implement learning media in the Calculus course.

Analysis of student responses indicates that the STEM-based VARK Learning Application has an excellent level of practicality, with an average of 84.75%, placing it in the very practical category (Arikunto, 2016). These results indicate that the developed media is easy for students to use and effectively supports learning. The media's appearance aspect received a high score, indicating that an attractive visual design can increase student interest and motivation. This aligns with the opinion of Purnomo et al. (2021), who stated that technology-based learning media with an attractive, interactive appearance can increase students' attention and engagement in the learning process. Furthermore, the ease-of-use indicator also showed high results, indicating that students can operate the media easily. A learning product is considered practical if users can use it easily without significant difficulties during learning activities.

Indicators of material clarity and the media's usefulness in supporting the learning process also showed positive results. This indicates that the material presented in the media has been systematically structured, making it easier for students to understand the calculus concepts being studied. Learning media can help clarify the presentation of information, making the learning process more effective and easier for students to understand. The results of this study also align with previous research showing that technology-based learning media can increase student engagement and facilitate comprehension of learning materials (Purnomo et al., 2021). Furthermore, research shows that learning media tailored to students' learning styles can enhance learning effectiveness (El-Bishouty et al., 2019; Prihaswati & Purnomo, 2021). Thus, the STEM-based VARK Learning Application learning media is not only conceptually valid but also practically applicable in learning.

Effectiveness in this study was demonstrated by changes in problem-solving ability across multiple measures within the same group (N=50), analyzed using repeated-measures ANOVA as designed in the methods section. The within-subjects test results were significant ($p = 0.000 < 0.05$), indicating a significant difference in means between measurements. Interpretatively, this improvement aligns with the theoretical framework discussed in the introduction. Problem-solving is not merely a result but a process that involves understanding the problem, planning a strategy, implementing the strategy, and evaluating the results (Purnomo et al., 2022b, 2024). This study used a test based on these four indicators and an analytical rubric to assess the quality of the process, not just the final answer. With support from multimodal representations (graphics, audio, text summaries, and exploratory activities), the application has the potential to expand students' cognitive pathways and build flexible conceptual schemes, a prerequisite for strategy transfer to the emphasized non-routine problems. Another strength lies in STEM's consistent emphasis on concept integration, contextual modeling, and the use of technology for authentic problem-solving.

The dissemination stage in this study is positioned as the dissemination stage of a product that has been developed, validated, revised, and tested on a limited basis during the development stage. Therefore, the implementation of the STEM-based VARK Learning Application in Calculus learning for the research subjects is not categorized as a dissemination activity but rather as part of the development stage, as it aims to gather information on the product's practicality and potential effectiveness. This aligns with the 4-D development model, which places limited trials and product evaluation within the development stage, while the dissemination stage focuses on disseminating a product that is ready for use (Plomp & Nieveen, 2013; Thiagarajan et al., 1974). Dissemination in this study was conducted after the product obtained initial evidence of feasibility and applicability. This dissemination included scientific dissemination through the publication of articles and presentations at academic forums, as well as institutional dissemination to Mathematics Education Study Programs at several universities in Central Java.

Institutional dissemination was conducted through product socialization, demonstrations of application usage, discussions with lecturers regarding its potential use in Calculus learning, and the provision of product usage guidelines. This approach aligns with the principle of innovation diffusion, which emphasizes the importance of communicating innovation through specific channels to the social system to encourage adoption. Through these activities, the STEM-based VARK Learning Application was no longer positioned as a product being tested, but as a development product ready to be introduced to a wider audience. The dissemination phase served to expand product utilization, open up opportunities for adoption or adaptation by other institutions, and obtain further input from the academic community and mathematics education practitioners. Thus, dissemination served not only as the final stage in the development model but also as a bridge between research findings and actual implementation in educational practice (Plomp & Nieveen, 2013).

This research contributes to the science of mathematics education and learning technology by 1). operationalizing the theory of mathematical problem solving in the context of calculus through digital media that systematically supports the coordination of symbolic, graphical, and contextual representations, 2). repositioning VARK defensibly as a design input for multimodal differentiation, 3) bridging the STEM–VARK gap by designing a presentation-priority-based adaptation mechanism that maintains open access to all modes, accompanied by implementation control to strengthen the integrity of the procedure. Further research needs to test the causal strength and generalizability of the findings through comparative/experimental designs and cross-institutional replication, and to deepen the analysis of mechanisms using learning analytics from interaction logs to map representation pathways to problem-solving indicators.

CONCLUSION

The results of the study indicate that the learning media are valid and can improve problem-solving skills. The conclusions of this study are: 1) the validity of the learning media, with a score of 4.22, is categorized as very valid and requires little revision, and 2) there is a significant increase in problem-solving skills. Based on these results, it can be concluded that the learning media have the potential to improve students' problem-solving skills. Future research can implement the STEM-Based VARK Learning Application in Calculus courses by testing the causal strength and generalizability of findings through comparative/experimental designs and cross-institutional replication.

DISCLOSURE OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIE

The author declares that, in compiling this article, he used artificial intelligence (AI) technology, specifically ChatGPT, to aid in sentence formulation and language editing. The use of AI does not replace the author's role in analyzing, interpreting, and verifying information. The entire contents of this article, including the accuracy of the data and conclusions presented, are the sole responsibility of the author.

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