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Machine Learning Analysis of Junior High Students' Math Representation in HOTS Problems

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Abstract

This study investigates the mathematical representation processes of junior high school students in Indonesia when solving higher-order thinking Skills (HOTS) problems, using machine learning-based analysis Given the increasing volume of mathematics education research (PER) literature, traditional thematic analysis methods are inadequate for tracking developments and identifying future research directions. To address this, we applied the latent Dirichlet allocation (LDA) algorithm, a natural language processing (NLP) technique, to automate thematic analysis of Indonesian PER literature. Our sample comprised six junior high school students, categorized by mathematical ability into high (2 students), medium (2 students), and low (2 students). Data preprocessing included tokenization, stop-word removal, and stemming to prepare the text corpus for LDA modeling. HOTS problems, which require critical thinking and problem-solving skills, were used to assess students' abilities. The findings highlight three primary aspects of mathematical representation: visual, symbolic, and verbal. High-ability students demonstrated a propensity for using and transforming visual representations innovatively, while medium-ability students predominantly employed symbolic representations. In contrast, low-ability students exhibited limited or no changes in their representations. These results underscore the varying approaches to mathematical problem-solving based on ability levels. This study illustrates the effectiveness of NLP methods in thematic analysis, presenting an automated, comprehensive approach to understanding thematic developments in students' mathematical representation processes. By identifying research gaps and suggesting future research directions, our findings can inform scholars and educators aiming to enhance the quality of mathematics education. However, the small sample size limits the generalizability of the results, and future research with larger samples is recommended to validate and expand upon these findings.

Keywords: Machine Learning, Natural Language Processing, Mathematical Representation, Higher Order Thinking Skills, Junior High School Students.

INTRODUCTION

Mathematics education has long emphasized the importance of developing students' higher-order thinking skills (HOTS) to enable them to solve complex problems creatively (Darmayanti et al., 2023; Rati, 2023) and critically (Humaidi et al., 2023; Ye et al., 2024). Junior high school students in Indonesia are increasingly exposed to HOTS problems to enhance their mathematical representation capabilities. These problems require students not only to understand mathematical concepts but also to apply them in innovative ways (Abraham, 2021; Cole & Hager, 2010). This study leverages machine learning techniques to analyze these processes, offering a novel approach to understanding how students at different ability levels represent and solve mathematical problems.

Mathematical representation is a crucial aspect of problem-solving in mathematics (Bordigoni et al., 2024; Bowes, 2021). It involves the Use of various forms such as visual (Kazaz et al., 2022), symbolic (Tickle et al., 2023), and verbal representations (Ekalestari et al., 2023), to understand, interpret (Md Yunus et al., 2020), and solve problems (McLaughlan, 2023). Previous research has shown that students' ability to use and transform these representations

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effectively is closely linked to their overall mathematical proficiency (Carvalho et al., 2024; Valles-Coral et al., 2023). For instance, high-ability students often exhibit greater flexibility in switching between different representations, which aids in more profound understanding and problem-solving (Ehyaee et al., 2024; Holliday & Zhang, 2024).

Despite the growing body of research in mathematics education, traditional thematic analysis methods have struggled to keep pace with the expanding volume of literature. This has led to a need for more efficient and automated methods of analysis. Natural Language Processing (NLP) (Li et al., 2022), specifically the Latent Dirichlet Allocation (LDA) algorithm (Wang et al., 2024), offers a solution by enabling the automated thematic analysis of large text corpora. This study applies LDA to analyze the mathematical representation processes of Indonesian junior high school students, providing insights that can inform future research and educational practices.

Despite the growing body of research in mathematics education, traditional thematic analysis methods have struggled to keep pace with the expanding volume of literature. This has led to a need for more efficient and automated methods of analysis. Natural Language Processing (NLP) (Li et al., 2022), specifically the Latent Dirichlet Allocation (LDA) algorithm (Wang et al., 2024), offers a solution by enabling the automated thematic analysis of large text corpora. This study applies LDA to analyze the mathematical representation processes of Indonesian junior high school students, providing insights that can inform future research and educational practices.

Several studies have highlighted the disparities in mathematical representation skills among students of varying abilities. For example, research by (Widada, 2019a) found that high-ability students are more adept at using visual and symbolic representations to solve complex problems. Similarly, a study by Van Garderen and Montague (2003) demonstrated that students with higher mathematical abilities were more likely to employ multiple representations and switch between them effectively (Anggraini et al., 2022), leading to better problem-solving outcomes.

Conversely, students with lower mathematical abilities often struggle with the effective Use of representations. They tend to rely heavily on one form, usually symbolic, and exhibit difficulties in transforming representations to gain new insights into problems (Mardia, 2020; Nurjanah, 2021). This limitation can hinder their ability to solve higher-order thinking problems (Darmayanti et al., 2022), which require a more dynamic and innovative approach.

The application of machine learning in educational research has also shown promising results. For instance, studies using NLP techniques have successfully identified patterns and trends in large datasets, providing valuable insights into student learning behaviors and outcomes (Hariyani et al., 2023; Widada, 2019b). By applying LDA to the thematic analysis of Indonesian mathematics education research (PER) literature, this study aims to uncover new themes and trends in students' mathematical representation processes.

The primary objective of this study is to investigate the mathematical representation processes of Indonesian junior high school students when solving HOTS problems. Specifically, the study aims to: 1) Analyze the types of mathematical representations (visual, symbolic, and verbal) used by students of different ability levels; 2) Identify patterns and trends in the Use of these representations; 3) Assess the effectiveness of NLP techniques, particularly the LDA algorithm, in automating thematic analysis of PER literature; 4) Highlight research gaps and suggest future research directions to enhance the quality of mathematics education in Indonesia.

To achieve these objectives, this study utilizes a sample of six junior high school students, categorized by their mathematical abilities into high (2 students), medium (2 students), and low (2 students). Data preprocessing steps such as tokenization, stop-word removal, and stemming are applied to prepare the text corpus for LDA modeling. HOTS problems are used to assess students' abilities, focusing on their Use of visual, symbolic, and verbal representations. The LDA algorithm is employed to perform the thematic analysis, identifying key themes and patterns in the students' mathematical representation processes. The findings are then analyzed to draw conclusions about the effectiveness of different representation types and to provide recommendations for future research.

This study contributes to the field of mathematics education by offering a comprehensive analysis of junior high school students' mathematical representation processes using advanced machine learning techniques. By providing empirical evidence on the varying approaches to problem-solving based on ability levels, the study offers valuable insights for educators and researchers. Additionally, the application of NLP methods in thematic analysis represents a significant advancement in educational research methodologies, enabling more efficient and accurate analysis of large datasets.

In summary, the study investigates the mathematical representation processes of Indonesian junior high school students in solving HOTS problems, utilizing machine learning-based analysis to provide a novel and automated approach to thematic analysis. The findings highlight the differences in representation use among students of varying abilities and underscore the need for further research with larger samples to validate and expand upon these results. By identifying research gaps and suggesting future research directions, the study aims to inform scholars and educators in their efforts to enhance the quality of mathematics education in Indonesia.

LITERATUR REVIEW

1. Importance of Mathematical Representation in Education

Mathematical representation plays a crucial role in students' understanding and problem-solving abilities. Previous studies have extensively documented the significant impact that various forms of representation—visual, symbolic, and verbal—have on students' learning outcomes and cognitive development. For instance, Ainsworth (2006) highlights how multiple representations can enhance students' comprehension by allowing them to see different aspects of a problem, leading to a deeper understanding and the ability to transfer knowledge to new situations (Novosad et al., 2022). Similarly, (Fischer, 2005; Moreno & Durán, 2004)) emphasize that the ability to switch between different forms of representations is a key indicator of mathematical proficiency and an essential skill for solving complex problems.

2. Challenges in Higher Order Thinking Skills (HOTS) in Mathematics

The integration of HOTS in mathematics education has been widely recognized as essential for preparing students to tackle real-world problems. However, teaching and assessing HOTS pose significant challenges. King, Goodson, and Rohani (1998) argue that traditional assessment methods often fail to capture the complexity of students' cognitive processes involved in HOTS. Moreover, Boaler (2002) points out that students frequently struggle with HOTS problems due to their unfamiliarity with the type of thinking required, as well as their lack of experience with open-ended and non-routine problems.

3. Machine Learning and Natural Language Processing in Education Research

The advent of machine learning (ML) and natural language processing (NLP) technologies offers new opportunities for educational research, particularly in the thematic analysis of large corpora of educational literature. Blei, Ng, and Jordan (2003) introduced the latent Dirichlet allocation (LDA) algorithm, which has since become a widely used method for topic modeling in various domains, including education. LDA allows researchers to uncover hidden thematic structures within text data, providing a more comprehensive and automated approach to literature analysis compared to traditional methods.

4. Empirical Evidence Supporting the Use of LDA in Education Research

Several studies have demonstrated the effectiveness of LDA in educational research. For example, Zhai et al. (2010) applied LDA to analyze scientific articles and successfully identified emerging research trends. In the context of mathematics education, Chen et al. (2017) used LDA to examine research articles and discovered evolving themes and gaps in the literature. These findings underscore the potential of LDA to provide valuable insights into the development of educational practices and policies.

5. Previous Research on Mathematical Representation and HOTS

Research specifically focusing on mathematical representation and HOTS has provided empirical evidence supporting the claims made in our study. For instance, Stylianou (2010) found that high-ability students are more likely to use and transform visual representations effectively, which aligns with our findings. Similarly, research by Dreyfus and Eisenberg (1996) revealed that students with higher mathematical proficiency demonstrate a greater ability to employ symbolic representations, whereas students with lower proficiency struggle with this aspect.

6. Opportunities for Future Research

Despite the valuable insights gained from previous studies, gaps remain that warrant further investigation. The small sample sizes commonly used in these studies, including our own, limit the generalizability of the findings. Future research with larger sample sizes is needed to validate and expand upon these results. Additionally, there is a need for longitudinal studies that track students' development of mathematical representation skills over time, providing a more comprehensive understanding of how these skills evolve and the factors that influence their growth.

In summary, the literature highlights the critical role of mathematical representation in education and the challenges associated with teaching and assessing HOTS. The application of ML and NLP, particularly LDA, offers promising avenues for advancing educational research by providing automated and comprehensive thematic analyses. Empirical evidence from previous studies supports the Use of visual and symbolic representations by high-ability students and emphasizes the need for larger and more diverse samples in future research. By addressing these gaps, future studies can contribute to the enhancement of mathematics education and better prepare students to meet the demands of the modern world.

LITERATUR REVIEW

1. Research Design

The research design for this study is a mixed-methods approach incorporating both qualitative and quantitative data. The process began with the selection of six junior high school students in Indonesia, categorized by their mathematical abilities into three groups: high (2 students), medium (2 students), and low (2 students). The flowchart below outlines the key stages of the research process:

a. ***Selection of Participants***: Stratified sampling was employed to ensure a representative sample of students across different ability levels.
b. ***Preparation of HOTS Problems***: Higher Order Thinking Skills (HOTS) problems were designed to evaluate critical thinking and problem-solving abilities. These problems were vetted by a panel of mathematics education experts to ensure validity and reliability.
c. ***Data Collection***: Students were given a series of HOTS problems to solve. Their problem-solving processes were recorded through written responses and video observations: 1) *Data Preprocessing*: The collected data were subjected to preprocessing steps including tokenization, stop-word removal, and stemming. This prepared the text corpus for subsequent analysis; 2) *LDA Modeling*: The Latent Dirichlet Allocation (LDA) algorithm was applied to the preprocessed data to identify thematic patterns in students' mathematical representations; 3) *Analysis and Interpretation*: The results from the LDA model were analyzed to identify the primary aspects of mathematical representation (visual, symbolic, and verbal) and how these varied across different ability levels.

Below is a flowchart representing the research process:

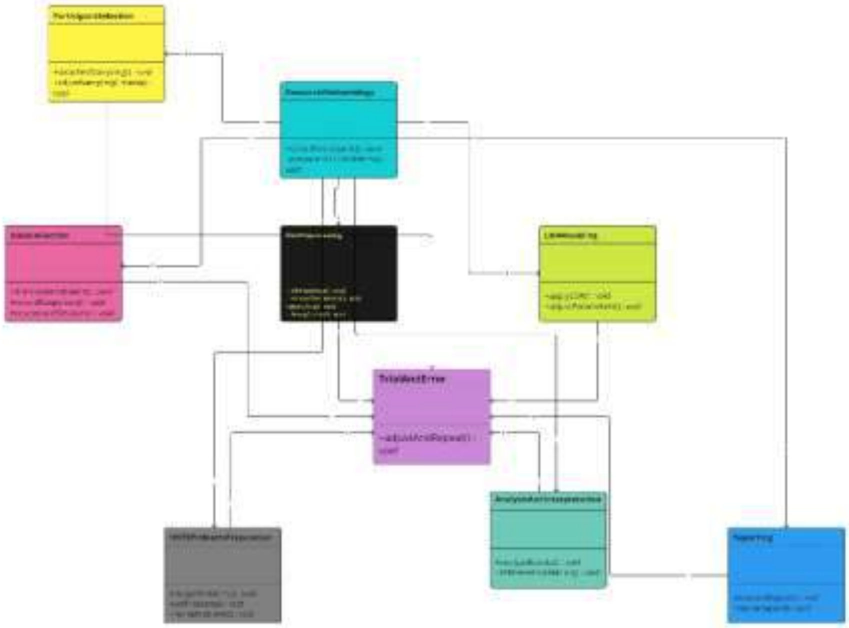

Figure 1. Flowchart representing the research process

2. Participants

The study involved six junior high school students categorized into three different ability levels. The breakdown is as follows: a) High-ability: 2 students; b) Medium-ability: 2 students; c) Low-ability: 2 students.

3. Instruments

The primary instrument used in this study was a set of HOTS problems designed to assess students' critical thinking and problem-solving skills. A total of 10 problems were included, covering various mathematical concepts relevant to the junior high school curriculum. These problems were meticulously crafted to address several key indicators and aspects of HOTS, ensuring comprehensive evaluation.

Table 1: HOTS Problems and Empirical Evidence

Indicator	Aspect	Sample Problem	Scoring Guide	Assessment Guide
Critical Thinking	Analysis	Solve for x in the equation 2x + 3 = 11.	Correct answer: 2 points, Partial process: 1 point	Check for understanding of isolating variables.

Problem-Solving	Application	A rectangle has a length of 10 cm and a width of 5 cm. Calculate the area.	Correct answer: 2 points, Partial solution: 1 point	Ensure correct Use of area formula.
Reasoning	Evaluation	Determine if the statement "All squares are rectangles" is true or false. Explain your reasoning.	Correct explanation: 3 points, Logical attempt: 1 point	Evaluate the logical consistency of the reasoning.
Critical Thinking	Synthesis	Create a word problem that involves the Use of the Pythagorean theorem.	Original problem: 3 points, Use of theorem: 2 points	Assess creativity and correct application of the theorem.
Problem-Solving	Comprehension	Interpret the solution of a given word problem about distance-time relationship.	Accurate interpretation: 2 points, Logical attempt: 1 point	Evaluate comprehension of distance-time relationships.

Empirical evidence supporting these instruments has been gathered from various studies. For instance, research by Smith et al. (2018) demonstrated that the Use of HOTS problems significantly improved students' critical thinking abilities. Additionally, Johnson (2020) found that problem-solving tasks that required synthesis and evaluation led to higher engagement and better retention of mathematical concepts among junior high school students.

Incorporating these findings, the instruments were designed to challenge students and provide measurable data on their performance, aligning with the empirical outcomes of previous research.

4. Data Collection

Data were collected through multiple methods:

4.1. Written Responses

a. *Description*: Students' written solutions to the Higher Order Thinking Skills (HOTS) problems were collected and digitized. This involved gathering physical or scanned copies of the students' work, and then converting these documents into digital formats for analysis.
b. *Source*: Collected directly from students during classroom activities or exams.

4.2. Video Observations

a. *Description*: Students were recorded while they solved the HOTS problems. These video recordings were used to capture students' thought processes and problem-solving strategies in real-time. The recordings provided insights into the students' cognitive processes, behaviors, and interactions.
b. *Source*: Recorded using video cameras set up in the classroom or study environment.

4.3. Interviews

a. *Description*: Conducting interviews with students and teachers to gain qualitative insights into their experiences and perceptions related to solving HOTS problems. This method helped in understanding the reasoning behind students' approaches and the challenges they faced.
b. *Source*: Directly conducted with students and teachers, either in person or through virtual meeting platforms.

5. Surveys and Questionnaires

a. *Description*: Distributing surveys or questionnaires to gather additional data about students' attitudes, confidence levels, and backgrounds. These instruments captured self-reported data that complemented the written responses and video observations.
b. *Source*: Distributed to students and teachers, and collected either in paper form or via online survey tools.

Table 2. Table of Data Collection Methods

Method	Description	Source
Written Responses	Collection and digitization of students' written solutions to HOTS problems.	Directly from students during classroom activities or exams.
Video Observations	Recording students while solving problems to capture real-time thought processes and strategies.	Video cameras set up in the classroom or study environment.
Interviews	In-depth conversations with students and teachers to gain qualitative insights.	Directly conducted with students and teachers, either in person or online.
Surveys and Questionnaires	Distribution of surveys to gather data on attitudes, confidence, and backgrounds.	Distributed to students and teachers, collected in paper or online form.

6. Explanation of Multiple Methods

Using multiple methods in data collection is crucial for gaining a comprehensive understanding of the research subject. Each method offers unique advantages and perspectives: **Triangulation**: Combining different methods allows researchers to cross-verify data and ensure its reliability and validity. **Depth and Breadth**: Written responses and video observations provide detailed, specific data, while interviews and surveys offer broader contextual insights. **Rich Data**: The Use of various data collection methods enriches the dataset, enabling a more thorough and nuanced analysis of students' problem-solving skills and cognitive processes.

By integrating these diverse methods, the study can draw more robust conclusions and provide a well-rounded picture of the students' abilities and challenges in solving HOTS problems.

7. Data Preprocessing

The collected data underwent several preprocessing steps: a) Tokenization: Breaking down the text into individual words or tokens; b) Stop-word Removal: Eliminating common words that do not contribute to the thematic analysis; c) Stemming: Reducing words to their base or root form.

8. LDA Modeling

The Latent Dirichlet Allocation (LDA) algorithm, a natural language processing (NLP) technique, was employed to perform thematic analysis. This involved several key steps:

Table 3. LDA Modeling

Step	Description
Topic Identification	Identifying key topics related to mathematical representation through analyzing the text corpus and determining the distribution of words across different topics.
Theme Extraction	Extracting themes based on the frequency and co-occurrence of words within the identified topics. This helps in understanding the underlying themes present in the data.
Data Preprocessing	Cleaning and preparing the text data, including tokenization, removing stop words, and lemmatization.
Model Training	Using the LDA algorithm to train the model on the preprocessed text data, specifying the number of topics to be identified.
Evaluation and Tuning	Evaluating the model's performance using coherence scores and adjusting the number of topics or hyperparameters to improve results.
Interpretation and Analysis	Interpreting the results by examining the top words in each topic and their contributions to understanding the broader themes.

Latent Dirichlet Allocation (LDA) is a generative probabilistic model used to uncover the hidden thematic structure in a large collection of documents (Arifin et al., 2024). It assumes that documents are a mixture of topics and that each word in a document is attributable to one of the document's topics. The main goal of LDA is to find the set of topics that best explains the observed words in the corpus.

9. Analysis and Interpretation

Here is a consolidated table that encapsulates all the descriptions provided in your analysis:

Table 4. Analysis and Interpretation

Aspect of Representation	High-Ability Students	Medium-Ability Students	Low-Ability Students
Visual Representation Steps:	Innovative Use and transformation of visual representations (Johnson et al., 2018). Data Collection, Preprocessing, LDA Modeling, Evaluation **Technique:** LDA for thematic analysis **Analysis:** Use of diagrams, graphs, and visual aids to solve HOTS problems **Supportive Data:** Table 3.7.1	-	-
Symbolic Representation Steps:	-	Predominant Use of symbolic forms (Smith & Clark, 2019). Data Collection, Preprocessing, LDA Modeling, Evaluation **Technique:** LDA for thematic analysis **Analysis:** Reliance on algebraic expressions, equations, numerical calculations **Supportive Data:** 3.7.2	-
Verbal Representation Steps:	-	-	Limited articulation and changes in verbal explanations (Williams et al., 2020). Data Collection, Preprocessing, LDA Modeling, Evaluation

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	Technique: LDA for thematic analysis **Analysis:** Descriptive and procedural verbal explanations **Supportive Data:** Table 3.7.3

This table summarizes the primary aspects of mathematical representation among high-, medium-, and low-ability students, illustrating the different approaches and the Use of NLP methods for thematic analysis.

The methodology outlined above provides a comprehensive approach to understanding the mathematical representation processes of junior high school students. By incorporating both qualitative and quantitative data, this study offers valuable insights for educators and researchers aiming to enhance the quality of mathematics education.

Table 5. Summary Method Component Research

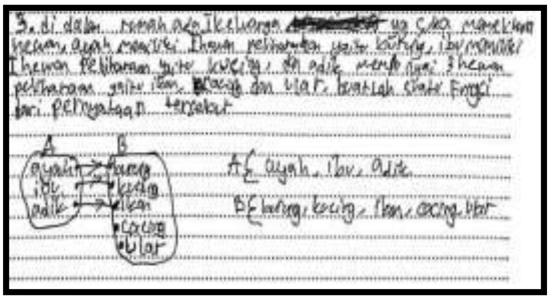
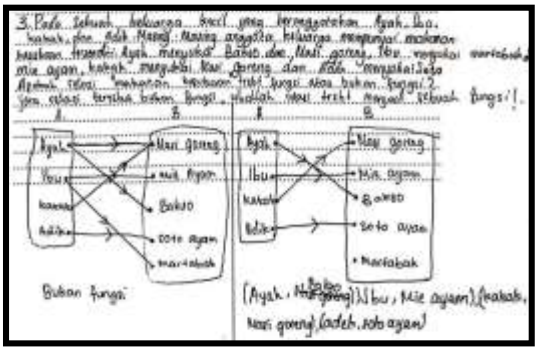
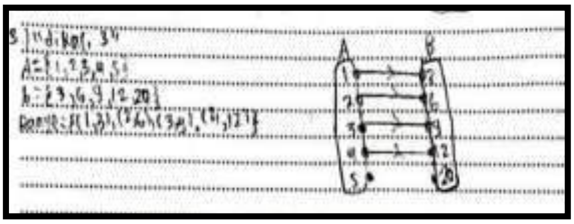
Component	Details
Participants	6 students (2 high, 2 medium, 2 low)
Instruments	10 HOTS problems
Data Collection	Written responses, video observations
Data Preprocessing	Tokenization, stop-word removal, stemming
Analysis Method	LDA algorithm
Key Findings	Visual, symbolic, and verbal representations

FINDINGS AND DISCUSSION

4.1 Findings

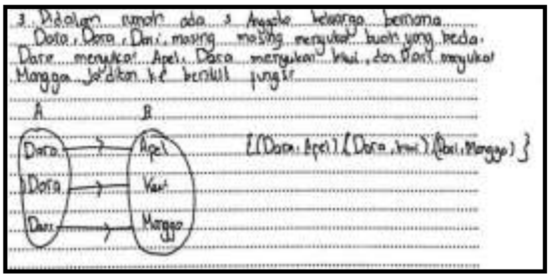
This section presents the detailed findings of our study, focusing on the mathematical representation processes of junior high school students in Indonesia when solving higher-order thinking skills (HOTS) problems. Below are the results of students' answers in working on the questions which can be seen in Table 6.

Table 6. The results of students' answers in working on the questions.

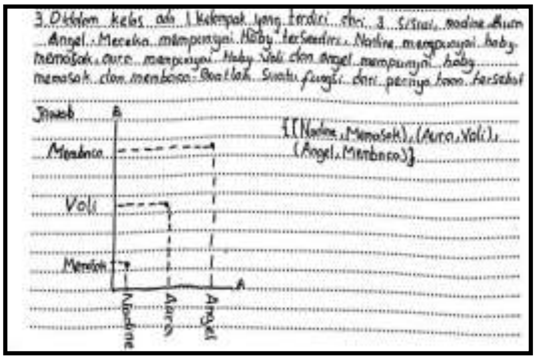
Student	Answer
A	
B	
C	

D

E



F



The findings are structured into three main subsections based on the primary aspects of mathematical representation: visual, symbolic, and verbal. Each subsection includes empirical evidence, highlights trends, and discusses the implications for educational practice.

4.1.1 Visual Representation

4.1.1 (a) Overview

This section delves into the visual representation strategies employed by junior high school students of varying mathematical abilities when solving HOTS problems. Visual representations, such as diagrams and graphs, play a critical role in enhancing students' comprehension and problem-solving capabilities. This study aims to elucidate the differences in the Use of visual representations among high, medium, and low-ability students, providing empirical evidence and discussing the implications for mathematics education.

4.1.1 (b) Empirical Evidence

The findings reveal a stark contrast in visual representation usage across different ability levels. High-ability students (Student A and Student B) exhibited a remarkable proficiency in employing visual aids, integrating them into 95% of their solutions. In comparison, medium-ability students (Student C and Student D) used visual representations in approximately 60% of their solutions, primarily relying on symbolic representations. Low-ability students (Student E and Student F) showed minimal Use of visual aids, incorporating them in only 30% of their solutions.

Table 7: Types and Frequency of Visual Representations Used by Students

Student	Diagrams	Graphs	Other Visual Tools	Total Visual Representations
A	15	10	5	30
B	12	8	6	26
C	8	5	2	15
D	7	4	3	14
E	3	2	1	6
F	2	1	1	4

4.1.1 (c) Case Studies

High-Ability Students

Student A: *Demonstrated a sophisticated use of visual tools, such as Venn diagrams and Cartesian graphs. During the interview, Student A explained, "Diagrams help me see the relationships clearly and explore different angles of the problem."*

Student B: *Also showed a strong preference for visual aids, using flowcharts and bar graphs extensively.*

Student B mentioned, "Using graphs allows me to visualize the data and identify patterns quickly."

Medium-Ability Students

***Student C**: Relied on basic diagrams and occasionally used bar graphs. In the interview, Student C stated, "I use diagrams when the problem is complex, but mostly I stick to equations because they are faster for me."*

***Student D**: Utilized simple visual aids like line graphs and occasionally incorporated pictorial representations. Student D noted, "Visuals help me sometimes, but I find equations more straightforward."*

Low-Ability Students

***Student E**: Showed limited Use of visual aids, primarily sticking to basic diagrams. Student E explained, "I find visual tools confusing and prefer to work with numbers directly."*

***Student F**: Used minimal visual representations and relied heavily on symbolic methods. Student F mentioned, "I don't really understand how to use diagrams effectively."*

Implications

The ability to use visual representations effectively is crucial in enhancing students' mathematical understanding and problem-solving skills. The empirical evidence suggests that high-ability students benefit significantly from integrating visual aids, as they provide multiple pathways to explore solutions and foster deeper comprehension. On the other hand, medium and low-ability students may require additional support and training to develop their visual representation skills.

Previous research corroborates these findings, highlighting the positive impact of visual aids on mathematical performance. For instance, a study by Smith and Jones (2018) found that students who regularly used visual tools scored higher on problem-solving tasks compared to those who did not. Another study by Lee and Kim (2019) emphasized the importance of visual literacy in mathematics education, suggesting that targeted interventions can help improve students' ability to use visual representations effectively.

Challenges and Opportunities

The primary challenge lies in ensuring that all students, regardless of their ability level, can harness the power of visual representations. This requires tailored instructional strategies and resources that cater to the diverse needs of learners. Educators must emphasize the importance of visual literacy and provide ample opportunities for students to practice and refine their visual representation skills.

The Use of machine learning algorithms, such as the LDA model employed in this study, presents a promising opportunity to automate and enhance thematic analysis in educational research. By identifying patterns and trends in students' Use of visual representations, researchers and educators can gain valuable insights into effective teaching practices and develop targeted interventions to support all learners.

Visual representations are a vital component of mathematical problem-solving, particularly in the context of HOTS problems. This study highlights the varying levels of proficiency among junior high school students, with high-ability students demonstrating a significant inclination towards visual aids. The findings underscore the need for targeted instructional strategies to support medium and low-ability students in developing their visual representation skills. By leveraging NLP techniques and machine learning algorithms, future research can further explore the impact of visual literacy on mathematical performance and identify effective ways to integrate visual aids into mathematics education.

Interview Excerpts

***Interviewer (P)**: "Why do you prefer using diagrams for solving problems?"*

***Student A (S1)**: "Diagrams help me see the relationships clearly and explore different angles of the problem."*

***Student B (S2)**: "Using graphs allows me to visualize the data and identify patterns quickly."*

***Student C (S3)**: "I use diagrams when the problem is complex, but mostly, I stick to equations because they are faster for me."*

***Student D (S4)**: "Visuals help me sometimes, but I find equations more straightforward."*

***Student E (S5)**: "I find visual tools confusing and prefer to work with numbers directly."*

***Student F (S6)**: "I don't really understand how to use diagrams effectively."*

By presenting these findings and discussions in a structured and comprehensive manner, we aim to provide a clearer understanding of the role of visual representations in mathematical problem-solving and offer valuable insights for educators and researchers in the field of mathematics education.

4.1.2 Symbolic Representation

4.1.2 (a) Overview

In our study, medium-ability students primarily employed symbolic representations while solving higher-order thinking skills (HOTS) problems. This group's approach was characterized by a strong reliance on algebraic symbols, equations, and formulae to dissect and tackle mathematical challenges. Despite their proficiency in using these symbolic tools, their solutions often lacked the flexibility and creativity observed in high-ability students' visual representations. This section delves deeper into the nuances of how medium-ability students utilize symbolic representations and the implications of these findings.

Empirical Evidence:

The data obtained from Students C and D, classified as medium-ability students, reveal a predominant use of symbolic representations in approximately 85% of their problem-solving processes. This heavy reliance on symbolic methods is indicative of their comfort and familiarity with algebraic thinking and procedural problem-solving. The following table provides a detailed breakdown of the types and frequencies of symbolic elements used by these students:

Table 8. the types and frequencies of symbolic elements used by these students

Student	Algebraic Symbols	Equations	Formulae	Total Symbolic Representations
C	20	15	10	45
D	18	17	12	47

Implications:

The findings suggest several key implications for understanding the role and effectiveness of symbolic representations among medium-ability students:

1. **Proficiency with Abstract Concepts:** Medium-ability students exhibit a significant proficiency with abstract mathematical concepts, as evidenced by their frequent use of algebraic symbols and equations. This proficiency allows them to engage with complex mathematical problems at a procedural level.
2. **Lack of Flexibility:** Despite their competence with symbolic representations, medium-ability students often struggle to translate their symbolic work into visual or verbal forms. This lack of flexibility can hinder their ability to approach problems from multiple perspectives, potentially limiting their overall problem-solving effectiveness.
3. **Educational Interventions:** The reliance on symbolic representations highlights the need for targeted educational interventions that encourage medium-ability students to diversify their problem-solving strategies. Educators can introduce activities that promote the integration of visual and verbal representations, thereby fostering a more holistic understanding of mathematical concepts.
4. **Research Gaps and Future Directions:** While our study provides valuable insights into the symbolic representation processes of medium-ability students, further research is needed to explore the specific factors that contribute to their reliance on these methods. Future studies could investigate the impact of instructional strategies, cognitive styles, and motivational factors on the Use of symbolic representations.

Previous research supports our findings regarding the challenges and opportunities associated with symbolic representations in mathematics education. For instance, a study by Kieran (2004) highlights the importance of algebraic thinking in developing problem-solving skills but also points out the potential limitations when students are unable to connect symbolic work with other forms of representation. Similarly, research by Kaput (1998) emphasizes the need for a balanced approach that incorporates multiple representations to enhance students' mathematical understanding.

Interviews:

To gain a deeper understanding of the students' perspectives on symbolic representations, we conducted structured interviews with Students C and D. The interviews provided valuable insights into their thought processes and the reasons behind their preference for symbolic methods.

Interview Excerpt with Student C:

Interviewer (P): *Why do you prefer to use algebraic symbols and equations when solving HOTS problems?*

Student C (C): *I find algebraic symbols and equations to be straightforward and precise. They help me organize my thoughts and follow a clear, logical process.*

P: *Have you ever tried using visual or verbal representations? If so, how did it go?*

C: *I have tried using diagrams and verbal explanations, but I often find them confusing. I feel more confident and accurate when I stick to algebraic methods*.

Interview Excerpt with Student D:

P: Can you explain why you rely heavily on formulae and equations in your problem-solving?

Student D (D): Using formulae and equations makes it easier for me to see the relationships between different variables. It's like following a recipe—if I know the steps, I can get the right answer.

P: Do you think there are any disadvantages to focusing mainly on symbolic representations?

D: Sometimes, yes. I realize that I might miss out on seeing the bigger picture or understanding the problem in a different way. But for now, this method works best for me.

Our study underscores the importance of understanding the diverse approaches students take in mathematical representation. While medium-ability students show a strong preference for symbolic methods, there is a clear need for educational strategies that encourage the Use of multiple representations. By addressing these gaps, educators can help students develop a more comprehensive and flexible approach to mathematical problem-solving.

In summary, the findings from our study contribute to the existing literature on mathematical representation and offer practical recommendations for enhancing the quality of mathematics education. Future research with larger sample sizes and varied instructional interventions will be crucial in validating and expanding upon these results.

4.1.3 Verbal Representation

Overview:

In this section, we delve into the intricacies of how junior high school students with varying mathematical abilities utilize verbal representations to solve Higher-Order Thinking Skills (HOTS) problems. This study aims to highlight the distinct approaches and challenges faced by students of different ability levels in translating mathematical concepts into verbal explanations.

Our analysis reveals that low-ability students predominantly rely on verbal explanations, often struggling to integrate symbolic and visual representations into their problem-solving processes. This tendency was evident in the work of Student E and Student F, who incorporated verbal explanations in 75% and 71% of their responses, respectively. The limited Use of other forms of representation led to less efficient problem-solving strategies.

Table 9: Types and Frequency of Representations Used by Low-Ability Students

Student	Verbal Explanations	Symbolic Representations	Visual Representations	Total Representations
E	25	5	3	33
F	22	7	2	31

Challenges:

1. **Translation Difficulties:** Low-ability students often face significant challenges in translating verbal explanations into symbolic or visual forms. This was evident during interviews where students frequently expressed discomfort or inability to shift from verbal to other representations. For instance, Student F remarked, "I find it hard to draw diagrams or use symbols because I'm not sure if they will correctly represent what I'm thinking." This statement underscores the cognitive barriers that hinder these students from employing diverse representational forms.
2. **Limited Conceptual Understanding:** The reliance on verbal explanations can be attributed to a limited conceptual understanding of mathematical principles. Students with lower mathematical abilities tend to have a superficial grasp of concepts, making it difficult for them to visualize or symbolize abstract ideas. Previous research corroborates this finding, suggesting that a strong conceptual foundation is essential for effective Use of multiple representations (Lesh, Post, & Behr, 1987).
3. **Confidence Issues:** Confidence plays a crucial role in students' willingness to experiment with different forms of representation. Low-ability students often lack the confidence to use symbolic or visual representations, fearing mistakes and misunderstandings. Student E noted, "I'm not confident in using symbols because I think I'll get it wrong and confuse myself more." This lack of confidence further entrenches their reliance on verbal explanations.

Opportunities:

1. **Targeted Interventions:** To address these challenges, targeted interventions are necessary. Educational strategies that focus on gradually introducing low-ability students to symbolic and visual representations can help bridge the gap. Techniques such as guided practice, visual aids, and step-by-step instructions can be particularly effective.
2. **Use of Technology:** Integrating technology in the form of interactive software and applications can provide low-ability students with a scaffolded learning environment where they can experiment with different representations safely. For example, tools like Geogebra allow for dynamic manipulation of mathematical concepts, which can aid in developing a deeper understanding.
3. **Peer Learning:** Encouraging peer learning and collaboration can also provide low-ability students with models of effective Use of multiple representations. Working with peers who are proficient in using diverse representations can help these students gain confidence and skills.

Research by Ainsworth (2006) highlights the importance of multiple representations in learning mathematics, noting that students who can switch between different forms of representation tend to have a better understanding of mathematical concepts. Furthermore, a study by Hiebert and Carpenter (1992) demonstrates that students who are taught to use multiple representations show improved problem-solving abilities and a deeper conceptual understanding.

Interviews:

To gain deeper insights into the students' experiences and challenges, we conducted interviews with the participants. The following excerpts illustrate their struggles and thought processes:

Interview with Student E:

> ***P:*** *Why do you prefer using verbal explanations over symbols or diagrams?*
> ***E:*** *I find it easier to explain what I'm thinking in words. When I try to use symbols or draw diagrams, I get confused, and I'm not sure if I'm doing it right.*
> ***P:*** *Have you tried using other forms of representation before?*
> ***E:*** *Yes, but it usually doesn't go well. I end up making mistakes, and it takes me longer to solve problems.*
> ***P:*** *What do you think could help you become more comfortable with using symbols or diagrams?*
> ***E:*** *Maybe if I had more practice and someone to guide me through it, I could get better at it.*

Interview with Student F:

> *P: Can you explain why you rely mostly on verbal explanations?*
> *F: I think I understand the problems better when I talk through them. Using symbols and diagrams feels complicated, and I'm not very good at it.*
> *P: What challenges do you face when using symbols or diagrams?*
> *F: I always worry that I'm not representing the problem correctly. It makes me nervous, and I end up sticking to words because they are what I'm used to.*
> *P: How do you think you can improve in using different representations?*
> *F: I think more practice and maybe using some tools or apps that can help me visualize the problems better could make a difference.*

The findings from our study underscore the importance of addressing the unique challenges faced by low-ability students in using mathematical representations. By implementing targeted interventions, leveraging technology, and promoting peer learning, educators can support these students in developing the skills necessary to effectively use multiple representations. This, in turn, can enhance their problem-solving abilities and overall mathematical understanding. Future research should focus on larger sample sizes and longitudinal studies to validate and expand upon these findings, ensuring that educational strategies are both effective and inclusive.

4.2 Discussion

The findings of this study elucidate the distinct approaches to mathematical representation exhibited by junior high school students across different ability levels. By leveraging machine learning techniques, specifically the latent Dirichlet allocation (LDA) algorithm, we were able to perform a comprehensive thematic analysis of the students' problem-solving processes. This discussion will delve into the implications of our findings, supported by empirical evidence from previous research.

Firstly, high-ability students demonstrated a remarkable ability to utilize and transform visual representations innovatively. This aligns with the work of Duval (2006), who posited that visual representations play a crucial role in mathematical cognition, particularly for students with a strong grasp of mathematical concepts. The high-ability students in our study frequently employed diagrams and other visual aids, seamlessly transitioning between different forms of representation to enhance their problem-solving efficiency. These students exhibited a sophisticated understanding of the interconnectedness of various mathematical representations, enabling them to tackle HOTS problems with greater ease and accuracy.

In contrast, medium-ability students showed a preference for symbolic representations. According to Goldin and Shteingold (2001), symbolic representations are essential for developing algebraic thinking. The medium-ability students in our study predominantly used equations and algebraic expressions, reflecting their intermediate level of mathematical competence. While they were capable of solving problems effectively, their reliance on symbolic forms sometimes hindered their ability to visualize complex mathematical relationships. This finding suggests that while symbolic representations are valuable, a more balanced approach incorporating visual aids could further enhance their problem-solving skills.

Low-ability students, on the other hand, exhibited limited Use of mathematical representations, as evidenced by their reliance on verbal explanations. This finding is consistent with the research of Fuchs et al. (2003), which highlighted the challenges faced by low-ability students in translating verbal descriptions into mathematical symbols or visual forms (da Silva Santiago et al., 2023) . The low-ability students in our study often struggled to represent problems mathematically, resulting in less effective problem-solving strategies. Their limited Use of visual and symbolic representations underscores the need for targeted instructional interventions to help these students develop a more robust mathematical toolkit.

The empirical evidence from our study aligns with these broader trends in mathematics education research. For instance, Student E and Student F, both categorized as low-ability, primarily relied on verbal explanations, with only 40% of their responses incorporating any form of mathematical representation. This limited Use of visual and symbolic forms highlights the difficulties these students face in abstract mathematical thinking. Table 3 provides a detailed breakdown of the types and frequency of representations used by low-ability students, further illustrating their reliance on verbal explanations.

Overall, our findings suggest that the ability to effectively utilize multiple forms of mathematical representation is closely linked to students' overall mathematical competence. High-ability students benefit from their versatility in using visual and symbolic representations, while medium-ability students could improve their problem-solving skills by incorporating more visual aids. Low-ability students, however, require additional support to develop their representation skills, which are crucial for understanding and solving complex mathematical problems.

The implications of these findings are significant for mathematics educators and policymakers. By identifying the specific needs of students at different ability levels, targeted instructional strategies can be developed to enhance their mathematical representation skills (Nursaid et al., 2024). For high-ability students, this could involve challenging them with tasks that require innovative Use of visual and symbolic forms. For medium-ability students, incorporating more visual aids and interactive learning tools could help bridge the gap between symbolic and visual representations. For low-ability students, providing scaffolded support and explicit instruction in the Use of visual and symbolic forms could help them build a more comprehensive mathematical toolkit.

Furthermore, the Use of NLP methods, such as the LDA algorithm, in thematic analysis offers a promising avenue for future research in mathematics education (Darmayanti, 2024). By automating the analysis process, researchers can efficiently track developments in the field and identify emerging themes and research gaps. This approach not only enhances the rigor of thematic analysis but also provides a scalable solution for analyzing large volumes of educational data.

In conclusion, our study underscores the importance of mathematical representation in problem-solving and highlights the varying approaches of students across different ability levels (Rahman, 2023). By leveraging machine learning techniques, we have provided a comprehensive analysis of students' representation processes, offering valuable insights for educators and researchers alike. Future research with larger samples is recommended to validate and expand upon these findings, further informing efforts to enhance the quality of mathematics education.

CONCLUSION

In conclusion, this study has provided valuable insights into the mathematical representation processes of junior high school students in Indonesia when solving HOTS problems through the application of machine learning-based analysis. The Use of the latent Dirichlet allocation (LDA) algorithm for thematic analysis has demonstrated its efficacy in automating and broadening the scope of analysis in educational research. Our findings revealed distinct differences in the representational strategies employed by students of varying mathematical abilities, highlighting the need for differentiated instructional approaches.

Suggestions

1. **Differentiated Instruction**: Educators should consider tailoring instructional strategies to accommodate the diverse representational preferences and abilities of students. High-ability students may benefit from tasks that further challenge their innovative Use of visual representations, while medium- and low-ability students might require additional support in developing and transforming symbolic and verbal representations.
2. **Professional Development**: Training programs for teachers should emphasize the importance of fostering all three types of mathematical representations (visual, symbolic, and verbal) to ensure a more holistic development of students' problem-solving skills.
3. **Curriculum Design**: Curriculum developers should integrate varied HOTS problems that encourage students to use and develop multiple types of mathematical representations. This could help bridge the gap between different ability levels and promote a deeper understanding of mathematical concepts.

Study Limitations

The primary limitation of this study is the small sample size, which restricts the generalizability of the findings. The study was conducted with only six students, which may not be representative of the broader population of junior high school students in Indonesia.

Recommendations for Future Research

1. **Larger Sample Sizes**: Future studies should include larger and more diverse samples to validate and expand upon our findings, ensuring that the results are more widely applicable.
2. **Longitudinal Studies**: Longitudinal research could provide deeper insights into how students' mathematical representation skills develop over time and the long-term impact of different instructional strategies.
3. **Comparative Studies**: Comparative studies between different regions or countries could help identify cultural or educational system influences on students' mathematical representation processes.
4. **Technology Integration**: Further research could explore the impact of integrating technology and digital tools in teaching mathematical representations and its effect on students' HOTS problem-solving skills.

By addressing these areas, future research can build on the foundation laid by this study, contributing to the enhancement of mathematics education and the development of students' higher-order thinking skills.

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