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Flow of Mental Activity in Developing Dominant Representations for Solving Convergent Sequence Problems: Supporting Quality Education (SDG 4)

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ABSTRACT

Objective: *To investigate the flow of mental activities involved in developing dominant representations when solving convergent sequence problems and to understand how students transform dominant representations into alternative forms to support mathematical understanding.* ***Method:*** *Employing a qualitative case study approach involving 12 Mathematics Education students from the Faculty of Education and Teacher Training, Datokarama State Islamic University, Palu, who had completed real analysis courses and understood the concept of convergent sequences. Data were collected through validated tests and semi-structured interviews. The research procedure followed the stages proposed by Fraenkel et al., including phenomenon identification, participant selection, data collection, analysis, and interpretation.* ***Results:*** *The findings revealed that the flow of mental activities in developing dominant representations consists of five stages: understanding the problem, identifying dominant representations, converting dominant representations into alternative representations, evaluating and revising solutions, and reflecting on the effectiveness of the chosen representations. Students with verbal, visual, and symbolic dominant representations demonstrated different approaches in solving convergent sequence problems but followed a similar cognitive flow when transforming representations.* ***Novelty:*** *A systematic flow of mental activities for developing dominant representations in mathematical problem-solving. The findings contribute to mathematics education literature by explaining how representation transformation supports conceptual understanding of convergent sequences and promotes more effective learning practices aligned with the goals of quality education (SDG 4).*

INTRODUCTION

The development of students' mathematical understanding is closely related to the achievement of Sustainable Development Goal (SDG) 4, which emphasizes inclusive and equitable quality education and the promotion of lifelong learning opportunities for all. In mathematics education, quality learning is reflected not only in students' ability to obtain correct answers but also in their capacity to construct meaning, use multiple representations, and engage in higher-order thinking processes. Understanding how students develop and transform mathematical representations is therefore essential for designing learning environments that foster conceptual understanding, critical thinking, and problem-solving skills, which are key competencies promoted under SDG 4.

Sequence limits are crucial in real analysis, describing infinite sequences' behavior as their elements approach certain values (Bartle & Sherbert, 2000; Royden & Fitzpatrick, 2010). Students must understand real number sequences, definitions, and related theorems to apply them in problem-solving (Çetin, 2009). Competencies include understanding form, notation, and connecting sequence limits with other concepts (Isnani et al., 2020). Complex and abstract applications require thinking skills (Wewe, 2020), and using mathematical representations can help students solve problems (Awofala et al., 2024; Nursupiamin, 2020).

Mathematical representation is a method of presenting mathematical concepts using symbols, images, or graphs, aiding in visualization, understanding, problem-solving, prediction, and communication (Mainali, 2021; Netti & Mastuti, 2021; Zulu & Mudaly, 2023). It enhances understanding and application in various contexts (Awaludin et al., 2021; Mainali, 2021; Sokolowski, 2018). The National Council of Teachers of Mathematics (NCTM) emphasizes the use of representations in mathematics learning to organize, record, and model phenomena (Novianti & Retnawati, 2019).

Research on representation in mathematics learning, particularly in real analysis courses (Afriyani et al., 2018; Cooper & Alibali, 2012; Mainali, 2021; Man & Sugiman, 2022; Netti & Mastuti, 2021), and results of observations conducted by researchers on November 3rd, 2023, and February 27th, 2024, shows that students generally have an initial understanding of answering questions. They identify key concepts and relationships related to the questions, resulting in solutions that require precision and strong understanding (Kartika et al., 2021). Students often provide solutions to convergent sequence problems verbally, visually, or symbolically, which aligns with their initial understanding.

Dominant representation is the preferred method for understanding and solving mathematical problems (Mainali, 2021; Pedersen et al., 2021), influenced by factors like learning style and problem characteristics (Wang & Han, 2021). It connects abstract concepts to concrete, facilitates communication, and influences problem solutions (Jones & Tiller, 2017; Juliyanto & Siswanto, 2021; Santos-Trigo, 2024). Students use representations based on their characteristics to understand the questions given, directing students to solve problems by involving activities to find answers (Afriyani et al., 2018; Beccone, 2020; Schoenherr & Schukajlow, 2024).

Cognitive processes involve information processing, problem restructuring, problem representation, problem-solving planning, estimating results, performing basic operations, and checking accuracy (Ekawati et al., 2019). Observable activities like eye movements and facial expressions influence learners' mental engagement and approach to problems, allowing them to communicate their understanding of mathematics (Amerstorfer & Freiin, 2021; Nursupiamin, 2020; Rosmala & Setyaningsih, 2021). Appropriate mental activity is essential for developing dominant representations for problem-solving (Juliyanto & Siswanto, 2021; Nursupiamin, 2020).

Research indicates that mental activities like problem understanding, planning, and reviewing results are closely linked to learners' dominant representations in understanding and manipulating information (Brata et al., 2022; Nurmala et al., 2024).

This study focuses on examining mental activities in developing dominant representations into other forms of representation. In this case and henceforth referred to as alternative representations. This aims to train students to develop creative thinking skills by conveying ideas in various ways. The ability to transform a representation into another form is an important component in conceptual understanding and solving more complex problems (Yumiati & Haji, 2019).

The study aims to explore the relationship between mental activity flow and dominant representation in solving convergent sequence problems. While previous research has highlighted the importance of mental activity and dominant representation in solving mathematical problems (Simbolon et al., 2018), there is a lack of specific exploration in this context. The study aims to fill this gap by understanding the relationship between mental activity flow and dominant representations, enabling the design of more effective learning strategies to facilitate students' understanding and problem-solving.

RESEARCH METHOD

This study employs a qualitative case study approach, involving 12 students from FTIK UIN Datokarama Palu's Mathematics Education Department who took real analysis courses. The selection process involved students who had studied sequence limits and were willing to contribute. Researchers use test instruments and interview guidelines. Two types of test instruments are used, namely the dominant representation identification test and the dominant representation development test. Both tests have met the logical and empirical validity tests (Nursupiamin, 2020). Meanwhile, the interview guidelines met the validity test with an average of 0.83 and a very high category by involving 2 experts in the field of learning evaluation.

The procedure for reviewing this research refers to the stages of Fraenkel et al., namely, identifying the phenomena that occur, identifying respondents, data collection, data analysis, interpretation, and conclusions (Rosmala & Setyaningsih, 2021).

RESULTS AND DISCUSSION

Results

Students have special characteristics and can differ based on their background, experience, and habits. These differences affect the way they think and act, including in solving problems and developing representation skills. Six respondents were selected to represent each representation category as shown in Table 1.

Table 1. Respondent categorization

Dominant Representation	Alternative Representation	Subject
Verbal	Visual	MJ
Verbal	Symbolic	HP
Visual	Verbal	NU
Visual	Symbolic	NI
Symbolic	Verbal	IN
Symbolic	Visual	TR

The dominant representation development test involves two stages: the first question, followed by an in-depth interview to explore the dominant representation and the students' ability to develop alternative representations; and the second question to gather supporting data about the students' activities. Here are the results of the development of the dominant representation from each respondent:

In the interview, MJ understood the first problem by determining the keywords and concluded that $\binom{b}{n} \to 0$ when $n \to \infty$. When trying to solve visually, MJ had some difficulty, especially in illustrating $\binom{c}{n} \to 0$, but after guidance from the researcher, MJ managed to improve the illustration. In the second problem, MJ was able to use visual representation better, connecting her verbal understanding with her final answer.

HP showed a good understanding of problem 1 and quickly determined the keywords showing that $\binom{b}{n} \to 0$ as $n \to \infty$. HP explained the problem sequentially and concluded that the value of b did not affect the result. When asked to solve the problem with a symbolic representation, HP had difficulty and needed guidance to connect her verbal understanding with the symbolism. With the help of the researcher, HP was able to show that $\binom{b}{n} \to 0$ and made some revisions to her answer. In problem 2, HP showed progress in using symbolic representation and was able to link his initial understanding with the definition of a convergent sequence.

NU, who had visual dominance, started solving problem 1 by initializing $(a_n) = \binom{b}{n}$ and using tabulation to illustrate the pattern of the sequence a_n. From the illustration, NU concluded that $\binom{b}{n} \to 0$ as $n \to \infty$, and the researcher noted that NU did not experience any problems in visual representation. When asked to solve the problem using verbal representation, NU analyzed the understanding from the illustration and transformed the form $\binom{b}{n}$ to conclude $\binom{b}{n} \to 0$. Although NU experienced initial difficulty in simplifying the form, he was able to overcome the obstacle when working on problem 2 more seriously, using verbal and visual representations effectively, and successfully showed that $\left(\frac{x_{n+1}}{x_n}\right) \to 1$.

NI, who had visual dominance, started solving problem 1 by focusing on the keyword $\binom{b}{n} \to 0$, assuming that the sequence would approach 0 as $n \to \infty$. Using tabulations and illustrations, NI plotted the points for each n and concluded that $\binom{b}{n} \to 0$ without experiencing any problem in visual representation. However, when asked to solve the problem with symbolic representation, NI experienced initial difficulties. After being prompted to remember how to prove the limit of a function, NI remodeled $(a_n) = \binom{b}{n}$ and immediately applied the definition of a convergent sequence, found $\left|1 - \frac{x_{n+1}}{x_n}\right|$, and showed $\binom{b}{n} \to 0$. At the next meeting, NI felt more confident in solving problem 2 despite initially struggling to determine the pattern x_n that fulfills $\left(\frac{x_{n+1}}{x_n}\right) \to 1$, trying to understand the application of the definition of a convergent sequence.

The interview results with IN, who has symbolic dominance, showed a very good understanding of the concept of convergent sequence. IN fluently and emphatically explained the steps to show that $\binom{b}{n} \to 0$, demonstrating proficiency in verbal representation. When asked to solve other problems with similar difficulty levels, IN was also able to do so without any problems. In the next meeting, despite feeling a little confused with problem 2, IN quickly determined x_n and clearly explained the idea underlying the determination of x_n that fulfills $\left(\frac{x_{n+1}}{x_n}\right) \to 1$.

The test results showed that TR understood the concept of convergent sequence despite not starting with a preliminary analysis. TR could show that $\binom{b}{n} \to 0$ using a symbolic representation, but had problems when asked to visualize the concept. The researcher provided additional problems with the same level of difficulty to help TR practice visualization, which TR rarely did manually, as he usually used the GeoGebra application. At the next meeting, TR showed confidence when working on problem 2, which he considered easy, by choosing $x_n = \frac{c}{n}$ (constant). When asked about other forms of x_n, TR acknowledged that there were four but could only mention $x_n = \frac{i}{n}$.

Based on the test results and interviews with six subjects, the researcher identified several important steps in
developing dominant representations to solve the convergent sequence:

1. Understanding the problem: Understanding and determining keywords to facilitate solving.

2. Identification of dominant representation: Presenting an initial representation that is easy to understand and relevant.
3. Changing the dominant representation to an alternative: Understanding the change from dominant to alternative representations.
4. Evaluation and revision: Evaluating the accuracy and relevance of alternative representations, and making revisions where necessary.
5. Reflection: Reflecting on the effectiveness of the alternative representation and the experience in improving understanding.

The five steps, in the study, the researcher mentioned as the flow of activities in developing dominant representation which can be described as follows:

Figure 1. The flow of mental activity in developing dominant representations

The flow of activities described serves as a reference for effective strategies in instilling an understanding of mathematical concepts in students, including problem identification, introduction of dominant representations, conversion to alternative representations, evaluation, and reflection. These findings indicate that students can recognize the presence of mathematics around them and learn to use new skills authentically, as well as integrate experiences into their learning (Bingham, 2017; Uyen et al., 2021). Additionally, it also trains students to develop creative thinking skills by conveying ideas in various ways, allowing for active engagement in problem-solving (Huinker, 2020; Yumiati & Haji, 2019). The constructivist approach is important in developing dominant representations, encouraging students to share knowledge and experiences related to mathematical concepts. This is expected to help students explore the relationship between questions and related concepts (Shah, 2019), thereby leading to the emergence of various forms of representation. Consistency is also important in developing dominant representations; through problem-solving exercises, students can identify potential obstacles to changing representations. Further research can explore how the constructivist approach enriches the understanding of mathematical concepts and facilitates the development of effective representations.

Discussion

The findings reveal that students with different dominant representations—verbal, visual, and symbolic—follow a similar flow of mental activities when solving convergent sequence problems. Regardless of their preferred representation, students began by understanding the problem and identifying key information before selecting a dominant representation. This finding supports the view that mathematical problem solving involves a sequence of cognitive processes, including information processing, problem representation, and solution verification (Ekawati et al., 2019). The results indicate that dominant representation serves as an entry point for understanding mathematical concepts, while the transformation into alternative representations strengthens conceptual understanding.

The study also demonstrates that students who were able to convert their dominant representations into alternative forms showed better understanding of convergent sequences. For example, students with verbal dominance initially relied on explanations and keywords before translating their understanding into visual or symbolic forms. Similarly, students with visual dominance used illustrations and tabulations to identify patterns before expressing their reasoning verbally or symbolically. These findings are consistent with previous studies emphasizing that multiple representations facilitate mathematical understanding and support problem-solving processes (Mainali, 2021; Sokolowski, 2018). The ability to move flexibly among representations enables students to view mathematical concepts from different perspectives and construct more comprehensive understanding.

Another important finding is that representation transformation was often accompanied by evaluation and revision activities. Several students experienced difficulties when changing representations but gradually refined their solutions through reflection and researcher guidance. This suggests that representation development is not a linear process but an iterative one involving continuous monitoring and reconstruction of understanding. Such findings support constructivist learning theory, which views knowledge construction as an active process in which learners continuously modify and reorganize their understanding through experience and reflection (Shah, 2019).

The identified flow consisting of understanding, identification, conversion, evaluation and revision, and reflection extends previous studies on dominant representation by providing a more systematic description of the mental activities involved in representation development. While previous research has highlighted the importance of representations in mathematical learning (Afriyani et al., 2018; Simbolon et al., 2018), this study explains how students develop and transform those representations during the process of solving convergent sequence problems. The findings therefore contribute to a deeper understanding of the cognitive mechanisms underlying mathematical representation and conceptual learning.

Implications for SDG 4 and quality mathematics education

The findings of this study have important implications for Sustainable Development Goal (SDG) 4, which aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. The identified flow of mental activities—understanding, identification, conversion, evaluation and revision, and reflection—provides a framework for supporting students' conceptual understanding in mathematics. The ability to develop dominant representations and transform them into alternative representations enables students to approach mathematical problems from multiple perspectives and construct deeper conceptual meaning.

The findings suggest that effective mathematics learning should encourage students not only to master mathematical procedures but also to actively engage in representational transformation and reflective thinking. Such learning experiences foster critical thinking, problem-solving, and conceptual understanding, which are essential competencies for quality education. Furthermore, the constructivist learning environment highlighted in this study aligns with the principles of SDG 4 by promoting active participation, meaningful learning, and the development of higher-order thinking skills. Therefore, integrating activities that support representation development and transformation into mathematics instruction may contribute to improving learning quality and enhancing students' understanding of abstract mathematical concepts such as convergent sequences.

CONCLUSION

Fundamental Finding: This study reveals that the development of dominant representations in understanding convergent sequences follows a systematic flow of mental activities consisting of understanding, identification, conversion, evaluation and revision, and reflection. Students initially identify the core problem and rely on their dominant representation visual, verbal, or symbolic to construct meaning. Subsequently, they convert the dominant representation into alternative forms to strengthen conceptual understanding and verify solutions. The findings indicate that successful problem solving is not solely determined by the dominant representation itself, but by students' ability to transform and connect multiple representations throughout the learning process. **Implication:** The findings suggest that mathematics instruction should encourage students to use and transform multiple representations rather than relying on a single representation. Teachers can design learning activities that facilitate transitions among visual, verbal, and symbolic representations to support deeper conceptual understanding of convergent sequences and other abstract mathematical concepts. Such learning practices are aligned with Sustainable Development Goal (SDG) 4, which emphasizes the provision of quality education through meaningful learning experiences, critical thinking, and problem-solving skills. By fostering students' ability to develop and transform representations, educators can enhance conceptual understanding, promote active learning, and support the development of higher-order thinking skills necessary for lifelong learning. **Limitation:** This study was conducted with a limited number of participants and focused specifically on the concept of convergent sequences. Therefore, the findings may not be generalized to all mathematical topics or student populations. **Future Research:** Future studies may involve larger and more diverse participant groups to validate the proposed flow of mental activities. Further research can also explore the development of dominant representations in other mathematical concepts, such as limits, continuity, and calculus, as well as investigate the role of digital learning tools in supporting representational transformation.

AUTHOR CONTRIBUTIONS

Nursupiamin Nursupiamin: Conceptualization, Methodology, Investigation, Formal Analysis, Writing – Original Draft, and Writing – Review & Editing. **Sukayasa:** Supervision, Validation, Methodology, and Writing – Review & Editing. **Muh. Rizal:** Data Curation, Investigation, Validation, and Writing – Review & Editing. **Muhammad Ikram:** Visualization, Project Administration, Literature Review, and Writing – Review & Editing. All authors have read, reviewed, and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

CONFLICT OF INTEREST STATEMENT

The authors state that no financial or personal conflicts of interest exist that may have affected the content or findings of this research.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors declare that no artificial intelligence (AI) tools or other digital writing assistants were used in the preparation, analysis, or writing of this manuscript. All stages of the research process, including data analysis, interpretation, and manuscript writing, were conducted solely by the authors. The authors take full responsibility for the originality, accuracy, and integrity of the content presented in this article.

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