


The Effect of Multiple Representation-Based Learning on Student Learning Outcomes: The Role of Learning Styles

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ABSTRACT

This study aims to examine the impact of instruction using multiple representations on student learning outcomes and to investigate patterns related to learning styles. This research is motivated by the limited number of studies that combine various types of mathematical representation with the use of technology, especially the use of Python as an exploratory and contextual learning tool. A quantitative method with a one-group pretest-posttest design was applied in this study, which involved 72 students. Data were collected through pretest and posttest scores, learning style categorization, and information on dominant representations, which were subsequently analyzed using R-Studio. The results indicate a significant improvement in student academic performance following the implementation of instruction based on diverse representations. The mean score increased from 64.79 in the pre-test to 80.37 in the post-test (mean difference = 15.58), with a paired t-test showing significance ($p < 0.001$). Additionally, an ANOVA analysis revealed no significant differences in learning outcomes based on learning styles. Network analysis suggests that students utilize various types of representations in a flexible manner, without being confined to a specific learning style. Visual representations appeared to be more dominant, but all learning styles were interrelated with various forms of representation. Overall, the results of this study indicate that multiple-representation-based instruction is effective in improving learning outcomes and supporting a more flexible learning process. This approach creates a more adaptive learning environment compared to methods that rely solely on learning style preferences.

Keywords: Effect, Multiple Representation, Learning Outcomes, Learning Styles.

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Introduction

Education is a vital pillar of human life. Education paves the way for a better life. However, education is currently undergoing a massive transformation driven by the technological revolution, social changes, and global disparities—whether in terms of digitalization, social issues, or the economy (Rohayati, 2024; Timotheou et al., 2023). Furthermore, a major challenge in the field of education is how to foster deep conceptual understanding and skills in students. This ensures that students possess more than just procedural skills or abilities, particularly in mathematics education. Students are not merely expected to understand formulas and abstract them into mathematical symbols or models; rather, they must be able to grasp the meaning behind those formulas or symbols (Chan et al., 2021). The PISA framework also emphasizes that learning should not focus solely on memorization but on adaptability, problem-solving skills, and reasoning (Golla & Reyes, 2022; Thomson et al., 2013). With strong mastery of these skills and abilities, students will have a solid foundation.

Therefore, it can be said that conceptual understanding is crucial to develop and should be a priority in educational innovation, particularly in mathematics education. One approach that can be used to help students understand concepts in mathematics is instruction that encourages students to recognize what is being represented (Mainali, 2021). Representation is a crucial activity in mathematical problem-solving (Susanti et al., 2023, 2024; Taufik & Susanti, 2022). With appropriate representations, students will be better able to interpret and express mathematical ideas through various forms, such as symbolic, graphical, verbal, and contextual representations. Research conducted by (Rexigel et al., 2024) indicates that with appropriate instructional design, learning through diverse representations helps students understand complex mathematical problems. Mainali (2021) also states that learning mathematics that uses various representations not only deepens students' conceptual understanding, but also encourages them to associate various forms of representation when solving problems. Hwang et al. (2007) in their research also state that students' skills in multiple representations are key to the mathematical problem-solving process. In their study, they state that learning activities involving various collaborative interactions and the use of technology can strengthen students' representational abilities. Thus, it can be said that mathematics instruction is effective in promoting conceptual understanding depending on how students can construct and integrate various representations. These diverse representations foster creativity and enhance students' flexibility in thinking when solving mathematical problems (Stieff et al., 2011). By integrating appropriate technology and media, learning design gives students the opportunity to explore diverse representations and participate in more meaningful learning processes. However, in practice, mathematics instruction in the field tends to be fragmented and has not yet been linked to meaningful learning experiences.

Most mathematics instruction in schools often relies on a single approach or has not yet integrated various media and learning resources. In fact, traditional approaches still dominate, such as conventional explanations of mathematical concepts, the use of learning resources that are still limited to textbooks, and a lack of learning interactions that directly involve students (Khasawneh et al., 2022; Martin-Alguacil et al., 2024). While these instructional approaches have indeed prompted the emergence of some mathematical representations, they have not comprehensively provided students with opportunities to generate, connect, and interpret the various representations used. Furthermore, there has been limited prior research on how technology can facilitate learning to elicit diverse types of representations (Kaite J. Carstens et al., 2021). Consequently, students' understanding remains superficial, and their ability to transfer their knowledge into real-world contexts remains very limited. Therefore, it is

essential to innovate in learning by utilizing technology that can enrich and strengthen students' representational processes. For example, by utilizing media as a learning aid. One application of technology in developing educational media is the use of Python (Bati, 2022; Dainamang et al., 2024; Ilham, 2024). Python is an accessible and flexible programming language. Python has capabilities in symbolic computation, numerical processing, and graphical visualization that can help students understand various mathematical concepts (Harris et al., 2020; Ranjan et al., 2023). Some Python libraries for mathematical computation and data visualization include Streamlit, NumPy, Matplotlib, and others. By using these libraries, educators and students can visualize abstract mathematical concepts—such as functions, geometry, or calculus—in a more dynamic way. Additionally, students can observe the relationships between symbolic, graphical, and numerical representations. Through Python, students will also develop logical thinking and apply various approaches to mathematical problem-solving (Bai et al., 2021). As demonstrated by the research conducted by Sadeghi et al. (2019), modern visualization technology can help students understand difficult concepts, making learning more engaging and interactive. Thus, it can be said that Python is not merely a technological tool but a constructive medium capable of connecting various forms of mathematical representation.

In a learning activity that supports multiple representations, the focus is not limited to the use of technology-based learning media; rather, a meaningful pedagogical design or framework is required. Learning becomes more meaningful when it is oriented toward students' real-world experiences (Andrews et al., 2023; Mystakidis, 2021). Therefore, there is a need to design learning based on contextual problems or contextual projects (Project-Based Learning – PjBL). PjBL offers students a variety of learning experiences, such as learning through exploration, collaboration, and reflection. These experiences encourage them to understand concepts deeply by positioning them as active participants who can design and complete projects relevant to their daily lives in the classroom (Gómez-García et al., 2020; Taufik & Susanti, 2023). Additionally, contextual problem-based learning also reduces students' misconceptions (Widarti et al., 2017). This type of instructional design is certainly aligned with the principle of multiple representations. Since a contextual learning approach allows students to utilize various representations, the integration of multiple representations, Python, and project-based learning will create a supportive learning environment that facilitates meaningful conceptual understanding.

Rexigel et al. (2024), Jupri et al. (2020), Mainali (2021), Sunyono & Meristin (2018), and Triantafyllou & Timcenko (2013), have conducted research on various representations in mathematics education. However, none of these studies have integrated project-based learning, let alone contextual projects. Most previous studies currently treat

multiple representations as a classroom teaching method without connecting them to contextual, real-world projects. However, connecting mathematical concepts to real-world situations and utilizing technology can deepen students' understanding of the concepts. Therefore, this study seeks to combine multiple representations, contextual project-based learning, and the use of Python in a single learning design.

In university mathematics education, challenges persist in facilitating students' understanding of abstract concepts and relating them to real-world situations. Many students tend to rely on procedures without mastering in-depth conceptual understanding, which in turn impacts their problem-solving abilities and academic achievement. This difficulty is evident when students are unable to transform mathematical ideas into various forms of representation, such as from symbolic notation to graphs or real-world applications. Furthermore, the diversity of student learning styles—visual, auditory, and kinesthetic—is not fully accommodated because teaching methods remain uniform. This suggests that the use of multiple representations and technological media, such as Python, has not been optimized to serve the diverse characteristics of students.

This study introduces the innovative use of Python as a learning tool to explore various forms of mathematical representation in students' conceptual thinking, while combining it with a contextual project-based learning approach. This approach is expected to produce a deeper and more meaningful learning experience through students' active participation in building and linking various representations. Although a number of studies have examined the application of multiple representations in mathematics teaching, there is still little research that specifically integrates Python-based technology within a contextual learning framework to support the exploration of diverse representations. Therefore, this study attempts to fill this gap by examining how Python-based learning media can facilitate various forms of representation in the context of project-based learning. Based on the explanation above, the problem formulation in this study includes: (1) how does multiple representation-based learning impact student learning achievement, and (2) what is the pattern of the relationship between learning styles and learning outcomes in this learning context.

Methods

This study is a quantitative study employing a one-group pretest-posttest design. This design was chosen to examine changes in students' learning outcomes following the use of multiple-representation-based instructional media. Additionally, the study analyzes the relationships and differences based on various learning styles (auditory, kinesthetic, and visual) and examines the patterns of association between learning

styles and the dominant representations used by students in solving mathematical problems. Although the one-group pretest–posttest design provides researchers with the opportunity to assess changes in learning outcomes between before and after an intervention, this design is limited because it does not include a control group, so external factors that may influence the results cannot be fully controlled.

Participants or Data Sources

The research subjects consisted of 72 students at a private university in Indonesia. The subjects consisted of 5th semester students who had all completed the algebra course as a prerequisite. The sample was selected based on the students' engagement in the learning process. They were then grouped into three learning styles: auditory, visual, and kinesthetic.

Research Instruments

This study used tests and questionnaires to collect data. Tests were used to assess learning outcomes (both pretest and posttest) as well as the representations used in mathematical problem-solving. The test instrument is designed according to indicators of mathematical problem-solving ability which include the phases of understanding the problem, planning a solution, implementing the strategy, and assessing the results. The test instrument has been validated by experts. Its reliability was tested using Cronbach's alpha coefficient, with values of 0.78 for the pretest and 0.76 for the posttest, indicating that the instrument is reliable.

Questionnaires, on the other hand, were used to identify learning styles. The measurement of learning styles in this study used the VAK (Visual, Auditory, Kinesthetic) model which was adapted from instruments that had been used in previous research (Fitkov-Norris & Yeghiazarian, 2015).

Research Procedures

The learning process is conducted over several sessions, using Python as a tool to present mathematical concepts in various forms, including symbolic, graphical, and numerical. Learning activities are designed as contextual projects that encourage students to actively explore, visualize, and communicate mathematical ideas. Each session includes exploration of concepts using Python, group discussions, and contextual project work based on multiple representations.

The data collection procedure was conducted in several stages. The first stage involved administering a pretest to assess the students' initial proficiency. Next, a learning style questionnaire was distributed. Subsequently, instruction was conducted using Python

to facilitate various representations that might arise in mathematical problem-solving. Finally, students took a posttest to measure the final outcomes of the instruction.

Data Analysis Techniques

Data analysis in this study was conducted using R-Studio, both for statistical analysis and data visualization. Descriptive statistics were used to analyze and describe the characteristics of the data (mean, standard deviation, minimum, and maximum values). Subsequently, assumption tests (Shapiro-Wilk and Levene's tests) were used to perform further analysis of the collected data. The Shapiro-Wilk method was chosen for the normality test because the sample in this study was relatively small ($n < 100$), so it is more recommended and has higher test power than Kolmogorov-Smirnov.

The paired t-test is used to assess the difference in learning outcomes between the pretest and posttest stages. Then, ANOVA analysis was used to assess variations in learning outcomes according to learning styles. And Tukey's Post Hoc test to assess the influence of each student's learning style. Comparing pretest and posttest scores aims to find changes in student learning achievement after the intervention, while further analysis is aimed at assessing the relationship with learning style types. The analysis focused on improving learning outcomes and differences influenced by learning style characteristics, not on comparisons between experimental and control groups.

To analyze the patterns of relationships between learning styles and the representations used by students, network analysis was subsequently employed and visualized using R-Studio. This network analysis was used to visualize how learning styles are interconnected with the various representations that emerge or are utilized by students in solving mathematical problems.

Result and Discussions

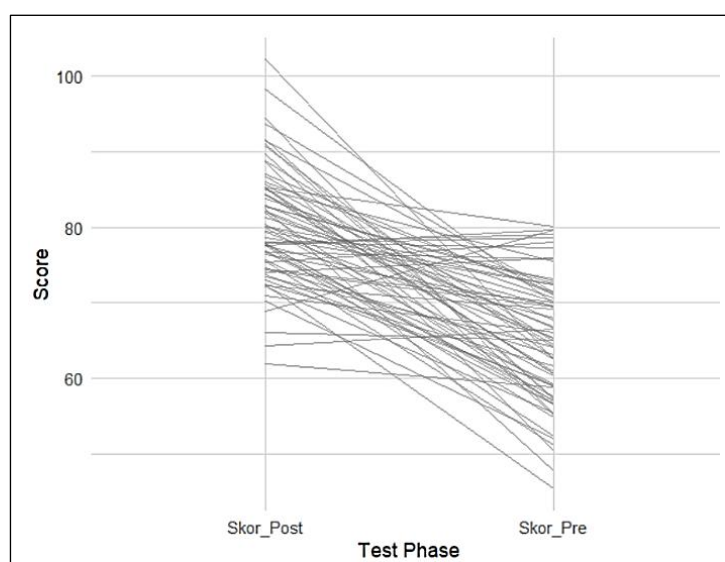
This study examines the effect of multiple-representation-based learning media using a contextual project approach with Python on students' understanding of mathematical concepts. The learning media used integrates various forms of representation, such as tables, verbal, digital, symbolic, contextual, and diagrams, into learning activities. To assess the impact of implementing these media, the researcher conducted measurements using pretests and posttests. [Table 1](#) presents the results of the descriptive statistics from the conducted study. This step was taken to provide an overview of the characteristics of the research data.

Table 1. Descriptive Statistics of Research Variables

Variable	N	Mean	SD	Min	Max
Pretest Score	72	64.79	8.38	45.30	80.12
Posttest Score	72	80.37	7.60	61.91	102.25

Based on the statistical analysis results presented in [Table 1](#), it can be concluded that there was an increase in the average scores from the pretest to the posttest, specifically from 64.79 to 80.37. This indicates that the use of Python-based media in instruction has a positive impact.

[Figure 1](#) also shows that students' scores tended to increase from the pretest to the posttest. This indicates that after participating in the learning process, many students experienced an improvement in their scores. Although there were some minor changes, the general trend in score changes was upward.

**Figure 1.** Improvement Pretest and Posttest Individual Score

[Figure 1](#) shows that the majority of the lines slope downward from pretest to posttest scores, indicating an improvement in learning outcomes after the treatment. This pattern indicates that nearly all students experienced positive changes, as evidenced by the shift in the lines to higher scores. Quantitatively, this improvement is supported by a significant difference in the average pretest and posttest scores, confirming that Python-assisted multiple representation learning consistently improves student learning outcomes. Variations in the slope of the lines across individuals reflect differences in the level of improvement, but the overall trend remains positive. Through contextual project-based learning activities, students not only receive theoretical material but also visualize mathematical concepts through programming. These activities help students understand concepts through various forms of

representation, resulting in a more comprehensive understanding. Furthermore, the process of exploring concepts through projects provides students with the opportunity to connect theory to more contextual situations. Student engagement in the modeling and visualization process also allows them to build a deeper conceptual understanding. Thus, the increase in scores shown in the graph may indicate that the use of this learning medium has a positive influence on students' understanding of mathematical concepts.

Furthermore, to determine whether the use of media has an effect on various types of student learning styles, normality and homogeneity of variance tests were first conducted. Table 2 shows the results of the normality assumption test for pretest and posttest scores using the Shapiro-Wilk test.

Table 2. Normality Test (Shapiro-Wilk)

Variable	W	p-value	Interpretation
Pretest Score	0.98124	0.3583	Normal
Posttest Score	0.98929	0.8046	Normal

Based on the analysis results presented in Table 2, it can be seen that the p-values for both variables are greater than 0.05; therefore, it can be concluded that the data are normally distributed. Next, a test of homogeneity of variances was conducted. Table 3 shows the results of the homogeneity analysis on the posttest regarding learning styles using Levene's Test. The results of the homogeneity test indicate that the p-values are greater than 0.05. Thus, it can be concluded that the data are homogeneous.

Table 3. Homogeneity Test (Levene's Test)

Dependent Variable	Group	F	p-value	Interpretation
Posttest Score	Learning Style	1.9653	0.1479	Homogeneous

It can therefore be concluded that the research data meet the assumptions for the normality and homogeneity of variance tests. Consequently, parametric statistical tests can be conducted to determine the relationships among the variables in this study.

Next, an analysis was conducted to determine the effectiveness of multiple representation-based learning in improving students' overall academic performance. Table 4 presents the results of the paired-sample t-test comparing pretest and posttest scores.

Table 4. Paired Sample T-test

Comparison	Mean Difference	T	df	p-value	Interpretation
Pretest vs Posttest	-15.578	-11.645	71	< 0.001	Significant

Using a 95% confidence interval, a p-value of 0.001—less than 0.05—was obtained. Thus, it can be concluded that, in general, learning using multiple-representation-based media has a significant effect on learning outcomes. Other factors, such as the learning experience during instruction, may also influence students' learning achievements. The implementation of multiple-representation-based learning media provides students with the opportunity to understand concepts through various methods. Students can utilize visualizations, modeling, and concept exploration through Python programming. These activities help students build a more active understanding of concepts. Thus, the increase in posttest scores is not only related to students' initial abilities but also to the learning experiences gained during the learning process.

This study used a single-group design with a pretest and posttest to assess changes in learning outcomes before and after the implementation of multiple representation-based learning. This design was chosen because it is suitable for assessing the initial effectiveness of a learning innovation in a real-life classroom setting. Although only a single group was involved, this approach can still identify improvements in learning outcomes internally within the same participants. However, to broaden the generalizability of the findings, further research is recommended using a design with a control group and a larger sample size.

Furthermore, an ANOVA test was conducted to examine differences between learning styles. This test was used to determine whether there were significant differences between students' learning styles and learning outcomes. Figure 2 presents the distribution of students' learning styles in this study.

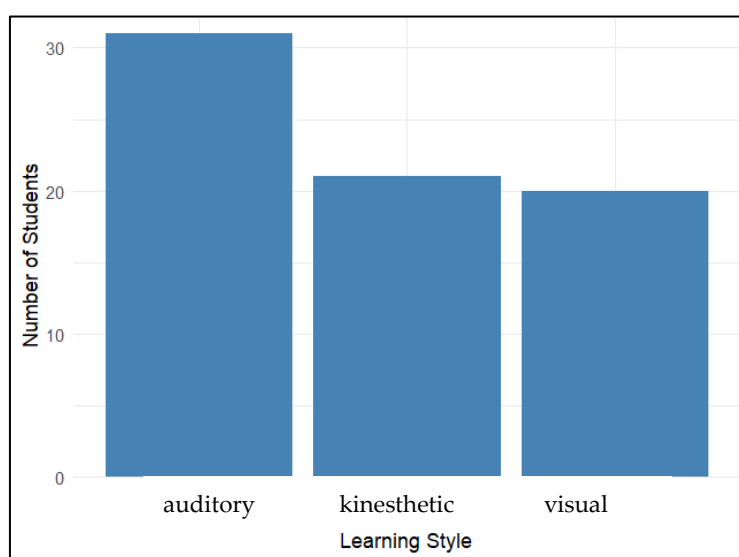


Figure 2. Distribution of Students Learning Style

The distribution diagram of students' learning styles presented in Figure 2 shows the number of students based on their learning styles. The bar graph indicates that students have three types of learning styles: auditory, kinesthetic, and visual. The number of students with an auditory learning style is higher compared to the other two categories. This difference in numbers indicates variations in the learning characteristics possessed by students. Such variations are one of the factors that need to be considered in the learning process.

Understanding this distribution of learning styles is important because each student has a different way of receiving and processing information. Therefore, the use of learning media based on multiple representations becomes relevant to accommodate this diversity. By presenting various forms of representation, students can understand mathematical concepts in ways that align with their learning characteristics. This distribution provides insight into the diversity of learning characteristics among the students involved in the study. These differences in learning styles are a key consideration in designing learning materials. By utilizing multiple representations, learning content can be presented in various forms, making it easier for students with different learning styles to understand.

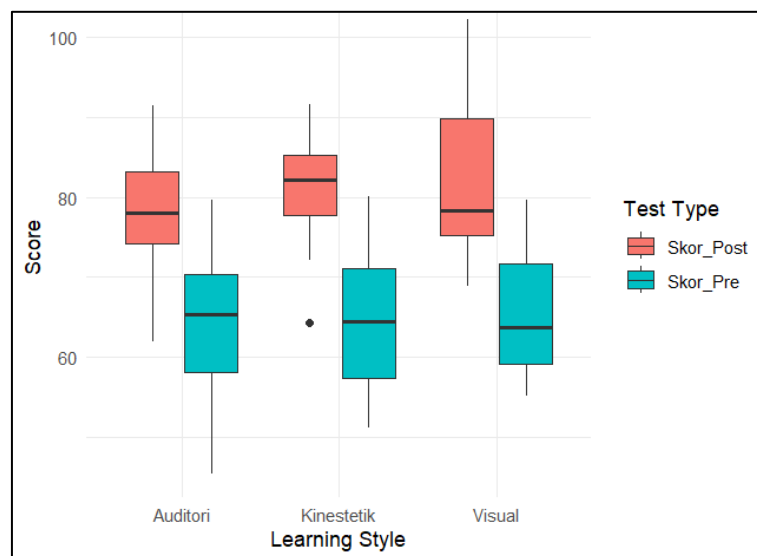


Figure 3. Distribution of Pretest and Posttest scores by learning styles

Figure 3 shows a comparison of pretest and posttest scores based on students' learning styles, which include auditory, kinesthetic, and visual. This graph uses a boxplot to illustrate the distribution of scores within each learning style group. The graph indicates that posttest scores for each learning style group tend to be higher than pretest scores. The median of the posttest scores also appears to be at a higher value than that of the pretest scores. The median position of the posttest scores also appears to be at a higher value than the pretest scores. Additionally, the range of values on the

posttest appears to be in a higher range than the pretest values. This indicates that an improvement in mathematical concept understanding occurred across all learning style groups. This improvement suggests that the learning process had a fairly uniform impact on various student characteristics.

This indicates that improved understanding of mathematical concepts occurs across various types of student learning styles. With diverse representations in learning materials, students with different learning characteristics can still grasp the concepts being studied. Students with a visual learning style can utilize graphs, diagrams, and tables generated using Python. Meanwhile, students with a kinesthetic learning style can become more engaged through exploratory project activities. Students with an auditory learning style can also gain understanding through verbal explanations and discussions during the learning process. Thus, the use of multiple representations allows learning materials to be delivered in various ways so that they can meet the diverse learning needs of students.

Research data based on assumption tests indicate that the data are normally distributed and homogeneous; therefore, the next step is to compare the means of the pretest scores and the students' learning style groups. Table 5 presents the results of the ANOVA test.

Table 5. ANOVA Result

Source	df	F	p-value	Interpretation
Learning Style	2	1.728	0.185	Not significant

The results of the ANOVA test presented in Table 5 show a p-value of 0.185 (>0.05), indicating that there is no significant difference in learning outcomes among the student learning style groups. In general, it can be concluded that learning outcomes did improve, but the individual learning styles of the students did not have a significant impact.

Next, a more in-depth analysis was conducted by examining the comparisons between pairs within the learning style groups in greater detail. In this case, Tukey's Post Hoc Test was used. Table 6 presents the results of the Tukey's Post Hoc Test that was conducted.

Table 6. Post Hoc Tukey Test

Comparison	Mean Diff	p-value	Interpretation
Kinesthetic vs Auditory	2.72	0.411	Not significant
Visual vs Auditory	3.77	0.196	Not significant
Visual vs Kinesthetic	1.04	0.897	Not significant

Based on the test results in Table 6, p-values were obtained for each pair. These values were as follows: kinesthetic and auditory with a p-value of 0.411, visual and auditory with a p-value of 0.196, and visual and kinesthetic with a p-value of 0.897. For all three pairs, the p-values were greater than 0.05, indicating that there were no significant differences. Learning styles do have an influence, but they do not result in significant differences in student learning outcomes. This could be attributed to various factors. Based on the statistical analysis conducted, it can be concluded that there is indeed an improvement in student learning outcomes. However, the learning styles possessed by the students do not have a significant impact. To examine how various representations are used by students in problem-solving, a network analysis was conducted using R-Studio. This analysis aimed to explore the relationship between each learning style and various types of mathematical representations. The representations used for exploration included audio, diagrams, digital, kinesthetic, contextual, symbolic, tables, visual, and verbal.

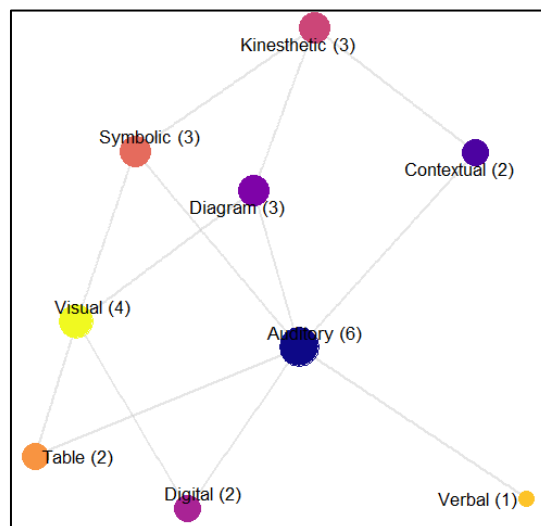


Figure 4. Network Learning Styles and Respresentasi Mathematics

Figure 4 presents a network of relationships between students' learning styles and the dominant learning representations they use. This graph shows several nodes representing learning styles—namely visual, auditory, and kinesthetic—as well as various types of representations such as verbal, symbolic, digital, contextual, diagrams, and tables. The lines connecting these nodes indicate a relationship between learning styles and the types of representations used in learning. This graph illustrates how various forms of representation are interrelated with the characteristics of students' learning styles. These relationships indicate that the learning process does not involve just one form of representation. Instead, learning utilizes various representations in an integrated manner.

The network diagram shows that each learning style tends to be associated with specific representations. The visual learning style appears to be linked to symbolic, diagrammatic, tabular, and digital representations. Meanwhile, the auditory learning style is more closely linked to a variety of representations, such as verbal, symbolic, diagrammatic, contextual, tabular, and digital. The kinesthetic learning style shows a connection to symbolic, contextual, and diagrammatic representations. These relationships indicate that students utilize various forms of representation in understanding mathematical concepts (Lisna et al., 2020). Based on these connections, it can be said that auditory and visual learning styles have the most significant relationship compared to other pairs of learning styles. This is also consistent with the results of the Tukey Post Hoc test. This is also evident in the types of representations used; there are four types of representations that are indeed equally frequently used by these two learning styles, namely symbolic, diagrammatic, tabular, and digital.

Furthermore, the predominance of the auditory learning style is associated with the various types of representations used in solving mathematical problems. This finding is also supported by research conducted by (Gunawan et al., 2020), which states that students with an auditory learning style tend to follow a more comprehensive process when solving mathematical problems. Research by (Santosa & Khotimah, 2023) also indicates that students with an auditory learning style demonstrate greater consistency in solving mathematical problems. It can be said that students often require several techniques when solving problems to understand the problem and translate it into a mathematical model. And this is typically done by students with an auditory learning style when they grasp concepts through verbal explanations or by speaking and listening. Students with an auditory learning style often speak to themselves internally, which supports the development of strategies for determining the steps to solve a problem. However, this study also contradicts research conducted by (Yunus et al., 2021), which showed that students with a kinesthetic learning style have better representational abilities compared to the other two learning styles.

This study revealed that students utilize multiple representations when solving mathematical problems, which contributes to broadening their understanding of concepts. The combination of symbolic, visual, and contextual representations allows students to establish connections between concepts and enhance their mathematical thinking flexibility. These findings are consistent with previous studies highlighting that the use of multiple representations can deepen conceptual understanding and problem-solving skills (Rexigel et al., 2024; Mainali, 2021). These results are also supported by recent studies indicating that using multiple representations can improve conceptual understanding and mathematical problem-solving abilities (Saepullah et al., 2023). Based on these findings, mathematics learning designs should

systematically incorporate multiple representations to accommodate students' diverse learning characteristics. Furthermore, the use of technologies such as Python can enrich the exploration of mathematical representations and provide a more meaningful learning experience. This not only improves learning outcomes but also fosters the development of more flexible and adaptive mathematical thinking skills.

Conclusion

The research results show an increase in pretest and posttest scores. Therefore, the multiple-representation-based learning has a positive impact on student learning outcomes. This indicates that students have improved their understanding of mathematical problem-solving.

However, based on the statistical analysis, there was no significant difference in learning outcomes based on the learning styles of individual students. This suggests that learning using various types of representations is able to accommodate visual, kinesthetic, and auditory learning styles equally. In other words, there are no specific characteristics or particular advantages associated with any specific learning style. Network analysis results also indicate that auditory and visual learners tend to use a greater variety of representations when solving mathematical problems. However, this does not imply that a particular learning style is limited to a specific form of representation.

Overall, it can be concluded that the use of media based on multiple representations in learning is indeed effective in improving student learning outcomes. It also provides students with the opportunity to develop various representations that may be used in the process of solving mathematical problems. Thus, this study can serve as a relevant alternative in mathematics education.

Practically, the findings of this study suggest that educators should not focus on a single learning style, but rather design learning that incorporates various types of representation—visual, symbolic, verbal, and contextual—to more effectively reach diverse student characteristics. Furthermore, the use of technologies such as Python in the learning process has been shown to facilitate the exploration of representations in a more flexible and interactive manner. The insignificant effect of learning styles on academic achievement in this study may be due to several factors. First, the multiple representation learning approach allows students to understand mathematical concepts through various forms (visual, symbolic, verbal, and contextual), making differences between learning style groups less visible. Second, students tend to combine various learning strategies rather than focusing on one particular style. Third,

the relatively small sample size for each learning style category may reduce the ability of statistical analysis to detect significant differences.

Future research is expected to conduct a qualitative study and identify the causal factors supporting the results of this study. Therefore, it is recommended that future research investigate other factors that could potentially influence learning achievement, such as basic abilities, learning motivation, or students' level of participation in technology use. Further studies could also employ a mixed methods approach to gain a more comprehensive understanding of how multiple representations play a role in the mathematics learning process.

Author's Declaration

Author Contribution	:	Author 1: Formulated the concept, developed the methodology, collected and analyzed data, and prepared the first draft. Author 2: Assisted in the implementation of the research, ensured the validity of the findings, and participated in the writing and revision of the manuscript. Author 3: Reviewed and edited the manuscript and provided conceptual suggestions. Author 4: Reviewed and edited the manuscript.
Funding Statement	:	This research received no external funding and was conducted independently by the authors.
Conflict of Interest	:	The authors declare no conflict of interest.
Additional Information	:	Additional data and materials related to this study are available from the corresponding author upon reasonable request.

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