

Enhancing Matrix Multiplication Learning in Grade XI: A Design Thinking Approach with Talking Stick and Row-by-Column Techniques

Wawan Fauzi¹, Lukman Harun^{2*}, Nizaruddin³

^{1,2*,3}Mathematics Education, Universitas PGRI Semarang
Jalan Sidodadi Timur Jalan Dokter Cipto No.24, Semarang, Central Java, Indonesia
2*ajisakatranslation@gmail.com

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Abstrak

Penelitian ini mengungkap penerapan konsep tongkat bicara dan teknik kolom-kali-baris untuk pembelajaran perkalian matriks siswa kelas XI dengan pendekatan desain berpikir. Penelitian kuantitatif deskriptif ini melibatkan guru mata pelajaran dan 32 peserta didik XI F 1 sebagai subjek penelitian. Penelitian ini diawali dengan observasi awal, diikuti dengan pelatihan teknik, metode, dan pendekatan gabungan, dan kemudian penerapan teknik gabungan oleh guru. Metode pengumpulan data dan instrumen yang diterapkan adalah lembar observasi untuk mengamati situasi sebelum dan sesudah guru saat menggunakan teknik, proses, dan pendekatan gabungan yang telah ditentukan. Para peneliti menganalisis data yang terkumpul menggunakan analisis deskriptif kuantitatif untuk mengidentifikasi perubahan yang paling efektif. Hasilnya menemukan bahwa teknik, metode, dan pendekatan gabungan memiliki pembelajaran perkalian matriks yang lebih baik. Kombinasi yang diterapkan menciptakan suasana belajar yang terstruktur dan interaktif untuk mendorong tanggung jawab dan kolaborasi. Para siswa dapat menjelaskan konsep matriks, memberikan solusi, dan berkolaborasi dengan teman sebayanya. Temuan-temuan ini menunjukkan bahwa memadukan konsep tongkat bicara dengan teknik kolom dikalikan baris melalui pendekatan desain berpikir dapat berfungsi sebagai model pedagogis yang efektif untuk meningkatkan keterlibatan siswa, pemahaman konseptual, dan pemecahan masalah kolaboratif dalam pembelajaran perkalian matriks.

Kata Kunci: Pembelajaran Kooperatif; Operasi Matriks; Perkalian Matriks; Berpikir Desain

Abstract

This research revealed the implementation of the talking-stick concept and column-multiplied-by-row technique for matrix multiplication learning of XI graders with a thinking design approach. This descriptive quantitative research involved the course teacher and 32 learners of XI F 1 as the research subjects. This research began with preliminary observation, followed by training in the combined technique, method, and approach, and then implementation of the combined technique by the teacher. The method of collecting data and the applied instruments were an observation sheet to observe the pre- and post-situations of the teacher while using the predetermined combined technique, process, and approach. The researchers analyzed the collected data using a quantitative descriptive analysis to identify the most effective changes. The results found that the combined technique, method, and approach had better matrix multiplication learning. The applied combination created structured and interactive learning atmospheres to encourage responsibility and collaboration. The students could explain the matrix concept, provide a solution, and collaborate with their peers. These findings suggest that integrating the talking-stick concept with the column-multiplied-by-row technique through a thinking design approach can serve as an effective pedagogical model to enhance student engagement, conceptual understanding, and collaborative problem-solving in matrix multiplication learning.

Keywords: Cooperative Learning; Matrix Operation; Matrix Multiplication; Design Thinking

I. INTRODUCTION

Various aspects of life have changed due to rapid advancements in science and technology. Consequently, educational institutions must actively and effectively implement learning processes to improve their outcomes. Continuous improvement in education is essential because enhancing its quality is expected to produce highly competitive graduates who can face the rigorous challenges of the job market (Schleicher, 2018). A learning process that systematically and progressively develops students' knowledge, skills, values, and attitudes is crucial for educational success. Innovations in teaching methods, particularly in mathematics, are indispensable, especially for topics often perceived as challenging, such as matrix multiplication. Many students struggle to grasp the fundamentals of matrix multiplication due to its abstract nature and complexity, which sets it apart from other basic math operations (Ningrum et al., 2022; Pattimukay et al., 2024). Without appropriate approaches, students often struggle to understand matrix multiplication, which requires a grasp of rows, columns, and operational order.

The challenges students face in comprehending the rows, columns, and operational order of matrices often hinder their ability to understand matrix multiplication. Matrix multiplication differs from basic mathematical operations such as addition or scalar multiplication because it necessitates a more profound understanding of the arrangement of elements within matrices and the relationships between these elements during the multiplication process (Oo &

Chaikan, 2021). Each element resulting from matrix multiplication is formed by multiplying the rows of the first matrix with the columns of the second matrix, which must be performed sequentially and accurately to yield correct values (Duan et al., 2023; Strang, 2016). Students tend to make repeated procedural errors if they fail to comprehend these fundamental principles. Furthermore, the abstract nature of matrices exacerbates the challenges students encounter. Many students find it difficult to visualise the process of transferring elements between rows and columns when learning matrix multiplication without visual aids or concrete representations (Hermanto & Susilawati, 2023). Lacking conceptual understanding, students often rely on rote memorisation of procedures, failing to fully comprehend the mechanics and reasoning behind these operations. Marfu'ah & Heriyati (2023) identified several other issues, including insufficient attention to detail when understanding problems, poor time management during tasks, difficulty focusing, incomplete understanding of concepts, formulas, and calculation steps, and inadequate proficiency in basic math operations.

Both male and female students exhibit conceptual errors, such as misunderstanding matrix multiplication formulas, errors in multiplication concepts, inverses, and adjoints, as well as mistakes in calculation and result simplification. Fausan et al. (2019) also identified procedural errors, such as omitting operation signs in matrices and failing to simplify results. In their study, male students made more errors than their

female counterparts. This disparity was attributed to male students' tendency to be less meticulous and hastier in solving matrix problems, whereas female students made fewer errors due to their more careful and thorough approach. When students encounter problems that are slightly different from the memorised examples, their limited understanding makes them prone to errors.

Teachers must adopt more interactive and contextual learning approaches to help students overcome these challenges. When students are learning how rows and columns work together in matrix multiplication (Dündar-Coecke et al., 2023), using concrete models or visual aids like matrix blocks or diagrams can help them understand. Liana et al. (2024) and Siswanto et al. (2024) explain that context-based approaches can help students understand how matrices are used in the real world, which makes them less abstract.

Matrix multiplication presents a significant challenge in secondary mathematics due to its abstract procedures and students' limited conceptual understanding (Kartini & Alawiyah, 2023). To address this issue, the present study integrates the design thinking approach—a structured, student-centered instructional model comprising empathy, definition, ideation, prototyping, and testing stages—into mathematics education. This approach enhances students' creativity, critical thinking, and real-world problem-solving abilities (Curtis et al., 2023). Through this iterative process, students frame mathematical problems, experiment with

strategies, and refine their understanding collaboratively (Nursidrati et al., 2023).

Within the design thinking framework, this study combines two pedagogical strategies: the row-by-column technique and the Talking Stick method. The row-by-column technique offers a systematic, easy-to-follow process for multiplying matrices by guiding students in aligning rows of one matrix with columns of another (Nursidrati et al., 2023). This structured method supports procedural fluency and reinforces how each element in the resulting matrix is derived, making abstract operations more accessible.

Meanwhile, the Talking Stick method fosters collaboration and student engagement by using a physical object to designate who may speak during discussions (Beyer, 2016; Zega et al., 2024). This strategy promotes orderly communication, encourages all students to participate, and increases classroom interaction. When applied to matrix operations, the Talking Stick method has shown meaningful results. Saputri et al. (2021) reported that it improved group collaboration and increased mastery learning to 80.76%. Similarly, Dewi et al. (2022) found that student mastery improved from 13.6% to 63.6% after two instructional cycles, as students actively participated in answering questions, discussing, and completing tasks. Unggu B et al. (2020) also found the cooperative Talking Stick model enhanced learning outcomes by combining audiovisual tools, relay-based Q&A sessions, and collaborative evaluation strategies. While these studies confirm the individual

effectiveness of both methods, little research has examined their combined application within a design thinking framework. This study seeks to fill that gap by exploring how the integration of algorithmic structure and interactive communication—framed through design thinking—can deepen students' understanding of matrix multiplication and improve learning outcomes. Preliminary observations at SMA Muhammadiyah Kudus (Grade XI F1) revealed weak student performance in matrix multiplication, with only 67% achieving mastery and an average class score of 67.33. These findings suggest that traditional instruction fails to motivate student engagement or promote conceptual clarity. In response, this study proposes an instructional model that leverages the strengths of design thinking, procedural scaffolding, and collaborative learning. Based on this context, the study tests two hypotheses: (1) Integrating the row-by-column technique and the Talking Stick method within a design thinking framework significantly improves students' performance in matrix multiplication. (2) Students taught with this integrated approach will demonstrate higher engagement, conceptual understanding, and collaborative problem-solving skills than those taught using conventional methods. By testing these hypotheses, this research aims to contribute a practical, evidence-based instructional strategy that improves mathematics learning through structured innovation and student-centered pedagogy.

This research aims to explore students' learning outcomes for matrix multiplication taught using the Talking Stick method and

the row-by-column technique. Combining the Talking Stick method with the row-by-column technique fosters interaction, collaboration, and quick thinking, enabling students to effectively share knowledge with their peers.

II. METHOD

This quantitative descriptive research examined the application of the Talking Stick Concept with the Row-by-Column Technique in Matrix Multiplication for Grade XI students using a design thinking approach. Savin-Baden & Major (2013) explain that the primary goal of this method is to evaluate the depth and complexity of the learning experience by comparing pre- and post-instructional strategies to determine their impact on student engagement, attitudes, and behavior during the learning process. The applied method is more appropriate than an actual experiment because it allows the intervention to be implemented within an existing classroom setting without disrupting the natural grouping of students. Unlike authentic experimental designs, this approach respects the school's ethical and logistical constraints by not randomly assigning students to control and experimental groups. This method enabled the teacher to deliver instruction using the integrated strategy (Talking Stick and Row-by-Column technique) to the whole class, ensuring fairness and inclusivity.

In this research, the researchers observed the implementation of the row-by-column multiplication technique in matrix multiplication lessons delivered using the Talking Stick strategy combined with the design thinking approach.

Table 1.
Talking Stick and Design Thinking Syntaxes

No.	Steps	Realized students' activities
1	Material introduction and empathy	Associating the mathematics topics with the real-world situation; understanding the basic concept of row-by-column multiplication; comprehending the benefits for the materials
2	Passing the stick and defining	Passing the class the stick while defining the introduced and associated materials
3	Active participation and ideation	Thinking to find ideas and approaches against the problem in step 1
4	Developing the prototype by practical interaction	Creating the simple model by practicing the row-by-column multiplication technique; presenting the prototype or the obtained solutions
5	Feedback, reflection, and examination	Sharing feedbacks by observing the superior aspects and revised aspects
6	Concluding and implementing	Revising the presented solution; concluding; implementing the final solution to solve problems

The research began with preliminary observations made before the teacher employed the row-by-column multiplication method, combined with the Talking Stick strategy and the design thinking approach. Next, the researchers provided the math teacher with brief training on combining the method, strategy, and approach. Finally, observations were made while the teacher used this combination.

Prior to conducting the research, the researchers obtained formal permission from the school principal and the

classroom teacher to carry out observations during regular mathematics lessons. All participants, including students and the teacher, were informed of the research objectives, procedures, and the non-intrusive nature of the data collection process. Given that the study involved systematic observation without disrupting classroom routines or introducing experimental groupings, consent was obtained in the form of passive parental consent, which is commonly applied in classroom-based educational research (Savin-Baden & Howell Major, 2023). Students' identities were anonymized, and data were coded to protect confidentiality. The researchers ensured that participation posed no risk to the students and that all activities were part of the regular instructional process. Moreover, the teacher received brief training on the integrated instructional method before the observation, with a complete understanding and voluntary participation in the implementation process.

During the study, the researchers served as observers, employing systematic observation, which uses rubrics to consistently and structurally track behaviours, skills, or progress indicators (Marroun & Young, 2018). Table 2 illustrates the applied observation rubric.

Table 2.
The Observation Rubrics of Row-by-Column Matrix Multiplication Learning

Aspects and Domains	Realized and expected activities on students	Scores
Material introduction (empathy)	Associating the ideas of matrix multiplication and real-world situations Example: mentioning	1-5

Aspects and Domains	Realized and expected activities on students	Scores	Aspects and Domains	Realized and expected activities on students	Scores
	real-life applications; explaining the meaning of multiplying matrices			solutions or ideas about the matrix multiplication	
Defining problems	Defining the matrix multiplication, finding problems, and explaining the objectives Example: stating the problem clearly; identifying the matters to solve	1-5	Collaboration and cooperation	Working effectively in groups Example: contributing to team efforts; clarifying others' misunderstanding; sharing turns respectfully	1-5
Ideation	Actively participating and discussing ideas, sharing ideas to solve problems, and discussing other solutions Example: sharing original ideas; providing at least one suggested method to solve the problem	1-5	Practical implementation and iteration	Utilizing tools to support problem-solving Example: Examining and iterating the solutions accurately, finding the errors, and revising	1-5
Prototyping	Using auxiliaries such as diagrams, physic objects, digital tools, and visual representation about the matrix multiplication Example: drawing diagrams; using objects or software to visualize matrix operation	1-5	Using tools and sources	Using tools to support problem-solving Example: using calculators or physical aids correctly and appropriately	1-5
Feedback and Reflection (Examination)	Listening to the teacher's feedbacks and peer-classmates; combining the suggestions to revise their solutions Example: listening attentively to peer or teachers' input; revising answers based on feedback	1-5	Personal reflection	Evaluating their own understanding and strategy Example: stating the difficult part; suggesting the solution to improve or solve the task differently in the future	1-5
Active participation (Talking Stick)	Communicating ideas clearly during discussion Example: Holding the stick and speaking clearly; sharing the explanation about the	1-5			

Table 2 presents the aspects and domains, the expected student activities, the examples of the activities, and the corresponding scores. Scores of 1–2 indicate that students are either unable or inactive in achieving the expected activities in the specified aspects and domains. A score of 3 suggests that students are moderately capable or active in achieving the expected activities, though there remains room for improvement. A score of 4 indicates that students are capable or active in meeting the expected activities,

while a score of 5 demonstrates that pupils are competent and actively engaged in achieving the expected activities in the specified aspects and domains.

To ensure the reliability of the observation rubric, two independent raters were trained to use the scoring guide based on the realized and expected student activities. They jointly observed and independently rated a randomly selected 20% of the total student participants across all rubric domains. The level of agreement between raters was measured using Cohen's Kappa. The results, presented in Table 3, indicate a high level of consistency across all domains, with Kappa values ranging from 0.74 to 0.89, suggesting substantial to almost perfect agreement (Landis & Koch, 1977).

Table 3.
Inter-Rater Reliability of Rubric based on Cohen's Kappa

Aspects and Domains	Cohen's Kappa
Material introduction (empathy)	0.82
Defining problems	0.79
Ideation	0.74
Prototyping	0.85
Feedback and Reflection (Examination)	0.78
Active participation (Talking Stick)	0.88
Collaboration and cooperation	0.86
Practical implementation and iteration	0.81
Using tools and sources	0.89
Personal reflection	0.80

According to Landis & Koch's (1977) interpretation, Kappa values between 0.61 and 0.80 represent substantial agreement, and values between 0.81 and 1.00 reflect almost perfect agreement, indicating that

the rubric was applied consistently by both raters.

Following the collection of data, the researchers detailed the variations in the execution of the anticipated student activities. The data analysis included two parts: 1) finding out what the differences are between using the Talking Stick Concept and the Row-by-Column Technique to teach Grade 11 students matrix multiplication compared to traditional learning, as shown by the Matrix Multiplication Learning Observation scores; and 2) finding out if using the Talking Stick Concept and the Row-by-Column Technique to teach matrix multiplication with a design thinking approach is more effective than traditional learning.

The researchers also employed the N-gain test on the observation results to identify which activities demonstrated significant improvement. The N-gain categorisation, widely used in educational research to measure learning effectiveness, was applied. The researchers utilised a standardised formula (Hake, 1998):

$$g = \frac{\text{Posttest score} - \text{Pretest score}}{\text{Maximum score} - \text{Pretest score}}$$

The applied learning is effective if the g-value is higher than 7; moderately effective if the g-value falls between 0.3 and 0.7; and ineffective if the g-value is lower than 3.

The use of systematic observation and N-gain analysis compensates for the lack of randomization, making this method suitable for evaluating educational effectiveness in real classrooms.

III. RESULT AND DISCUSSION

Researchers conducted two observations: before teachers were trained to use the combined technique, strategy, and approach (involving row-column matrix multiplication, the Talking Stick strategy, and design thinking), and after teachers received the training and applied it in research classrooms. The study was conducted in Class XI F 1, consisting of 32 students. The analysis results of Table 4 are also consistent with the following recapitulation. Table 4 shows the sum for all 32 students, before and after.

Table 4.
The Descriptive Statistics of Pretest-Posttest Scores

The realizations of the expected results	Pre-observation	Post-observation
Associating the ideas of matrix multiplication and the related real situations	68	100
Defining the problems of matrix multiplication, finding problems, and providing explanation about the objectives	68	100
Actively participating in discussing the ideas, sharing the ideas to find solution, and discussing other solutions	79	111
Using auxiliaries such as diagram, physical object, or digital tool; creating visual representation of the matrix multiplication	64	96
Listening to the teacher's and peer	73	105

The realizations of the expected results	Pre-observation	Post-observation
feedbacks and combining the suggestions to improve the solutions		
Holding the talking sticks; clearly speaking; providing explanation about the solution and notion of the matrix multiplication; and contributing to the discussion	80	112
Constructively collaborating with peers to find solutions, share ideas, and discuss different arguments	88	120
Examining and integrating the solutions accurately to find excellent results; finding errors; and revising	64	96
Effectively understanding and solving the problems with various sources such as calculators, software, and physical manipulation	64	96
Having the capability to reflect the learning process, identifying the strength and drawbacks of the applied method, and finding solution to improve the problem solutions	111	156

Based on Table 4, prior to the intervention, students' performance across

the ten observed domains ranged from 64 to 111, with particularly low scores in areas such as using visual aids and tools (64), engaging in feedback and reflection (73), and associating matrix concepts with real-life contexts (68). After the intervention, all areas showed notable gains, with post-observation scores ranging from 96 to 156. The most substantial improvement was observed in students' ability to reflect on the learning process and identify strengths and weaknesses, which increased from 111 to 156. Similarly, students' collaborative skills (from 88 to 120) and active participation in discussions (from 79 to 111) also demonstrated marked enhancements. These results suggest that the applied instructional approach effectively supported student engagement, conceptual understanding, collaboration, and critical reflection.

The researchers attempted to ensure the improvement between pretest and posttest with another statistical analysis. Table 5 shows the paired sample statistics.

Table 5.
Paired Sample Statistic Results

Pair 1		Mean	N	Std. Deviation	Std. Error Mean
		Pretest	75.9000	10	14.76821
	Posttest	109.2000	10	18.34121	5.80000

The table presents the results of a paired-samples statistical analysis comparing performance across ten observed domains before and after a learning intervention. The pre-observation (pretest) mean score was 75.90 with a standard deviation of 14.77, while the post-observation (posttest) mean score increased significantly to 109.20 with a standard deviation of 18.34. These figures indicate that, on average, the realization of expected learning behaviors across the domains improved following the intervention. The standard error of the mean was 4.67 for the pretest and 5.80 for the posttest, suggesting a slight increase in variability after the intervention.

The results of Table 6 are consistent with paired-sample test results. Table 5 shows the results of the paired-sample test.

Table 6.
The Paired Sample T-Test

Pair 1	Pretest - Posttest	Paired Differences				t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower Upper			
		-33.30000	4.11096	1.30000	-36.24080 -30.35920	-25.615	9	.000

The Sig. (2-tailed) value in the paired samples t-test result is .000, which indicates a highly significant difference between the pre-observation and post-observation scores. Since this p-value is well below the conventional alpha level of 0.05, it can be concluded with substantial

confidence that the observed improvement in scores is not due to chance. In other words, the intervention had a statistically significant effect on students' performance across the observed domains.

The researchers elaborated on the details of the improvement, as shown in

Table 7. Table 7 shows the observation results in detail.

Table 7.
Observation Results

The realizations of the expected results	Pre-observation	Post-observation
Associating the ideas of matrix multiplication and the related real situations	2.1	3.1
Defining the problems of matrix multiplication, finding problems, and providing explanation about the objectives	2.1	3.1
Actively participating in discussing the ideas, sharing the ideas to find solution, and discussing other solutions	2.5	3.5
Using auxiliaries such as diagram, physical object, or digital tool; creating visual representation of the matrix multiplication	2.0	3.0
Listening to the teacher's and peer feedbacks and combining the suggestions to improve the solutions	2.3	3.3
Holding the talking sticks; clearly speaking; providing explanation about the solution and notion of the matrix multiplication; and contributing to the discussion	2.5	3.5
Constructively collaborating with	3.0	4.0

The realizations of the expected results	Pre-observation	Post-observation
peers to find solutions, share ideas, and discuss different arguments		
Examining and integrating the solutions accurately to find excellent results; finding errors; and revising	2.0	3.0
Effectively understanding and solving the problems with various sources such as calculators, software, and physical manipulation	2.0	3.0
Having the capability to reflect the learning process, identifying the strength and drawbacks of the applied method, and finding solution to improve the problem solutions	3.5	4.5

Table 7 shows the results of pre- and post-observation learning using a combination of the matrix row-column multiplication technique, the Talking Stick strategy, and the design thinking approach for matrix multiplication lessons. Researchers found that students were able to relate the concept of matrix multiplication to relevant real-world situations. Initially, students were not actively linking the concept of matrix multiplication to real-world situations, as evidenced by a score of 2.1 on the observation rubric. However, after teachers

were trained and used the mix of techniques, strategies, and approaches, students did a pretty good job of applying the idea of matrix multiplication to real-life situations, as shown by their 3.1 score on the observation rubric.

In the second aspect and domain, students were initially not active in defining matrix multiplication problems, identifying issues, and explaining the objectives of those problems. A pre-observation score of 2.1 demonstrates this. After the observation, students did a good job of connecting the idea of matrix multiplication to real-life situations, as shown by their score of 3.1 on the observation rubric.

In the third aspect and domain, students were not active in participating in discussions about ideas, solutions, and alternative problems, as evidenced by a score of 2.5. After receiving lessons from trained teachers, students appeared fairly active in participating in discussions about ideas, solutions, and alternative problems, as evidenced by a score of 3.5.

In the fourth area and aspect, students initially did not actively use tools like diagrams, physical objects, or digital devices to create visual representations of the concept of matrix multiplication. An activity level of 2.0 demonstrates this. Then, their activeness became fairly active, as evidenced by a post-observation result of 3.0.

In the fifth aspect and domain, students were not sufficiently active in attentively listening to feedback from teachers and peers, and could not use the feedback to create better solutions. Subsequently, in the post-observation, students appeared

actively listening to feedback from teachers and peers and were quite capable of using that feedback to create better solutions. Pre-observation results of 2.3 and post-observation results of 3.3 demonstrate this.

In the sixth aspect and domain, students were not sufficiently active in speaking and contributing to class discussions by providing clear explanations of matrix multiplication problems and their ideas about them. A pre-observation score of 2.5 demonstrates this. Then, the post-observation results showed that students were active in speaking and contributing to class discussions by providing clear explanations of matrix multiplication problems and their ideas about those problems. This finding is evidenced by a post-observation score of 3.5.

In the seventh aspect and domain, students were able to collaborate constructively with their peers to solve problems, share ideas, and discuss differing opinions. The level of achievement increased from 3 in the pre-observation to 4 in the post-observation. This value indicates that students were able to collaborate constructively with their peers to solve problems, share ideas, and discuss differing opinions.

In the eighth aspect and domain, students initially could not test and evaluate the solutions they made, identify errors, and improve them. An activity achievement level of 2.0 demonstrates this. Afterwards, the score rose to 3.0 during the post-observation period. This score indicates that students became able to test and evaluate the solutions they made, identify errors, and improve them.

In the ninth aspect and domain, students initially were not active in using tools such as software and physical manipulatives to understand and solve problems. A pre-observation score of 2.0 supports this finding. Then, the students' activeness increased, as evidenced by a score of 3.0 in the post-observation.

In the tenth aspect and domain, students initially could not reflect on their learning processes, identify the strengths and weaknesses of their approaches, and find better solutions to problems. In the post-observation, this activity showed a significant increase from 3.5 in the pre-observation to 4.5.

Initial research on SMA Muhammadiyah Kudus class XI F1 students reveals ongoing issues with the current math teaching methods, particularly in the area of learning matrix multiplication. Inappropriate teaching methods cause these shortcomings. These methods made learning insufficiently engaging and challenging to enhance student activeness (Cui et al., 2022; Yan et al., 2023). This is evident in the low student scores in all aspects observed by the researchers.

The observation scores in Table 3 indicate that the teacher's conventional teaching of matrix multiplication material did not achieve optimal realization of expected activities. This is because the average observation results for each aspect of the expected activity realization for each student did not reach an average score of 3. However, after the teacher implemented the combination of techniques, strategies, and learning methods designed by the researchers, the average observation results for each aspect of the expected

activity realization exceeded or equalled 3. This suggests that implementing a combination of techniques, strategies, and methods could enhance students' participation in cooperative learning. Other evidence can be seen in Table 8 regarding the results of the N-gain test.

Table 8.
The N-Gain Test Results

The realizations of expected activities	Pre-Post	Max Score-Pre	N-gain
Associating the ideas of matrix multiplication and the related real situations	32.0	92.0	0.35
Defining the problems of matrix multiplication, finding problems, and providing explanation about the objectives	32.0	92.0	0.35
Actively participating in discussing the ideas, sharing the ideas to find solution, and discussing other solutions	32.0	81.0	0.40
Using auxiliaries such as diagram, physical object, or digital tool; creating visual representation of the matrix multiplication	32.0	96.0	0.33
Listening to the teacher's and peer feedbacks and combining the suggestions to improve the solutions	32.0	87.0	0.37
Holding the talking sticks; clearly speaking; providing explanation about the solution and notion of the matrix multiplication; and contributing to the discussion	32.0	80.0	0.40
Constructively collaborating with peers to find solutions, share ideas, and discuss different arguments	32.0	72.0	0.44
Examining and integrating the solutions	32.0	96.0	0.33

The realizations of expected activities	Pre-Post	Max Score-Pre	N-gain
accurately to find excellent results; finding errors; and revising			
Effectively understanding and solving the problems with various sources such as calculators, software, and physical manipulation	32.0	96.0	0.33
Having the capability to reflect the learning process, identifying the strength and drawbacks of the applied method, and finding solution to improve the problem solutions	32.0	49.0	0.65

The Table 8 shows that various activities are deemed effective in enhancing student learning based on the N-gain scale. Activities such as linking matrix multiplication to real-world situations, defining problems, and setting objectives for matrix multiplication achieved an N-gain value of 0.35, indicating a moderate improvement in students' ability to connect mathematical concepts with practical applications and problem-solving skills.

Active participation in idea discussions recorded an N-gain of 0.40. reflecting a significant improvement in student engagement and their ability to articulate problem-solving strategies and solution ideas. Additionally, communication activities during discussions showed the same N-gain value, indicating an increase in students' ability to effectively convey and share ideas.

Using visual aids to demonstrate matrix multiplication resulted in a moderate N-

gain of 0.33, signifying a moderate improvement in students' conceptual understanding. Students also showed moderate improvement in integrating feedback from teachers and peers to refine their solutions, with an N-gain of 0.37. Collaborative problem-solving activities recorded the highest N-gain in the moderate category, at 0.44. This highlights the effectiveness of working together to find solutions, share ideas, and discuss differing opinions.

The use of external resources such as calculators and software (N-gain: 0.33), as well as other activities like testing and iterating solutions (N-gain: 0.33), showed similar improvements in helping students understand and solve problems. Reflective learning activities, with an N-gain of 0.65, nearly reached the high category. This indicates their high effectiveness in fostering students' critical thinking and evaluation of the strengths and weaknesses of their own methods.

Except for reflective practices, which nearly reached the high category, all activities showed moderate improvements based on the N-gain scale. The most effective activities for enhancing student learning outcomes are reflection and collaboration.

Mathematics can actually be applied in daily life to solve various practical problems. However, students are not yet fully aware of the importance of understanding mathematical concepts in various fields of life. Students' interest in mathematics is relatively low, resulting in very few students truly grasping mathematical concepts and applications.

To date, many teachers still rely on conventional teaching methods such as lectures, rote memorization, and recall of study materials. Teachers who lack skills and creativity in teaching mathematics make students feel bored and disengaged (Derakhshan et al., 2021; Smedsrud et al., 2022; Tam et al., 2020). This leads students to be distracted, such as playing on their own, chatting with desk mates, disturbing others focused on the teacher's explanations, and more. As a result, they struggle to respond to teachers' questions.

One of the topics that class XI students must master in mathematics is matrix multiplication. Matrices are one of the topics in mathematics that can be implemented in everyday life, such as in economics to facilitate analysis of economic problems involving various variables, and in mining to solve issues in oil exploration operations (Hartman, 2010). This material is essential in daily life and requires a thorough understanding. Solving matrix problems requires high precision due to the complex structure of matrices in columns. Additionally, matrix addition and multiplication involve different operations. Thus, this topic can also develop students' creativity.

Addressing these challenges in mathematics learning requires cooperative learning models. This model allows students to interact actively in cooperative groups and assist each other in completing tasks. Hunanyan & Unanyan (2020), Loh & Ang (2020), and Trung & Truong (2023) explain that students become more active in learning activities when working in cooperative groups. In this context, the talking stick strategy is considered

appropriate because it enables students to collaborate in groups and answer questions about the material being studied, all contributing to improving their learning outcomes (Suseno et al., 2020; Twiningsih & Elisanti, 2021). One reason for choosing this learning model is its simplicity and suitability for the subject and the demographics of high school students.

In this study, the implementation of the talking stick method with the row-by-column technique encouraged students to address problems or questions that were challenging, discuss and solve them in pairs with desk mates, and present their findings to the class. The talking stick method with the row-by-column technique is a learning system that emphasizes teamwork, interaction, quick thinking, and sharing knowledge with peers.

In addition to these techniques and strategies, this study also combined design thinking. Design thinking is a collaborative method that gathers diverse ideas from various disciplines to develop solutions, aiming to make the teaching and learning process more interactive so that students can better absorb the material. Design thinking is one method that can be used to solve complex user problems by discovering appropriate innovations.

IV. CONCLUSION

This study showed that students learned matrix multiplication more effectively when using the Talking Stick method, row-by-column approach, and design thinking model. The Talking Stick strategy structured peer interaction and encouraged student responsibility and collaboration, while manipulatives and

digital tools supported problem-solving and self-evaluation. Students became more confident in explaining concepts, proposing solutions, and engaging with peers. Traditional instruction yielded average observation scores of only 3, whereas the researcher-designed combination raised them to 3 or higher. N-gain test results confirmed that these integrated techniques were more effective than conventional methods. Given these outcomes, the model is suitable for scaling to other schools and comparing with cooperative strategies like Think-Pair-Share or Jigsaw to assess relative effectiveness. For teachers, this study highlights the importance of structuring interaction, integrating tools, and combining cooperative learning with design thinking. Encouraging student reflection and revision also leads to deeper understanding and better learning outcomes.

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