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IMPROVING INFORMATICS STUDENTS' MATRIX ALGEBRA CONCEPTUAL UNDERSTANDING THROUGH A PYTHON-BASED LEARNING TRAJECTORY

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Abstract

In matrix algebra courses, conceptual understanding remains low. This is due to the lack of integration and relevance of mathematics learning to their competency, namely informatics engineering. Learning trajectory instruction, characterized by sequential learning and Python computing applications relevant to students, provides a solution to improve students' matrix algebra conceptual understanding. The purpose of this study was to examine students' understanding of mathematical concepts in algebra by implementing a Python-based learning trajectory model. This study was a quasi-experimental study with posttest-only control group design. The sample was taken using a random sampling technique. A sample size of 69 students was selected, consisting of 33 students from the experimental class and 36 students from the control class. The results of this study present the difference in the average test scores for understanding matrix algebra concepts between the experimental and control classes. The t-test showed that t-test (3.469) > t-table (1.997), with $\alpha = 0.05$ (df = 67), indicating that H_1 was accepted, stating that the Python-based Learning trajectory model is effective as an alternative learning strategy to strengthen students' matrix algebra conceptual understanding.

Keywords: Learning Trajectory; Python; Conceptual Understanding; Matrix Algebra

INTRODUCTION

Difficulty in studying mathematics: Students often struggle to learn concepts based on algebraic operations (Riastuti et al., 2023). Matrix algebra is an important topic in computer science, information technology, and applied mathematics. (Harahap et al., 2025). Basic concepts such as matrix operations, determinants, inverses, and their application in systems of linear equations play an important role in supporting the mastery of modern technology, from artificial intelligence, numerical modeling, to data analysis (Putra Hatoguan & Musllim Karo Karo, 2025). Mastery of matrix algebra provides a fundamental basis that enables students to engage with more advanced computational topics (Gultom et al., 2025) topics. However, phenomena and facts show that student experience difficulty in understand concepts with material that tends to nature abstract (Nur et al., 2024) Learning that tends to be centered on educators is based on memorizing formulas, making students less able to relate concepts to real applications (Dewimarni, 2017). This situation influences students' learning outcomes in the Linear Algebra and Matrix course, grade records from the previous semester indicate that more than 33% of students were still categorized at an adequate level.

On the other hand, the development of digital technology presents great opportunities in supporting mathematics learning (Sulhaliza et al., 2025). The Python programming language, with various libraries such as *NumPy* and *SymPy*, is known for its simplicity and flexibility and allows for practical visualization and exploration of matrix algebra operations (Oliphant, 2015). Using Python in learning not only gives students computational experience, but can also help them connect theory with practice (Surbakti et al., 2024).

Apart from that, the *Learning Trajectory (LT)* is defined as a structured and systematic learning pathway that describes the sequence of learning goals, instructional activities, and students' conceptual development from basic to more complex levels (Juana et al., 2022). Through this trajectory, learning is designed progressively, starting from foundational concepts and moving toward more complex implementations. Furthermore, the use of technology in mathematics learning can assist students in understanding concepts more effectively and solving more complex problems (Assegaf et al., 2023).

However, one of the important challenges in learning matrix algebra is the low motivation of students to learn, students prefer courses that are relevant to their field (Dewimarni et al., 2024). Algebra is a mathematics course which is abstract in nature, with many symbols (Mitchell J. Nathan, 2023). This makes students tend to think that matrix algebra is difficult material and not relevant to their professional needs, thus affecting their interest and involvement in the learning process. With use technology in learning mathematics, especially in the subject studying linear algebra and matrices, so that become solution for give something room new in learning that can be open road for increasing motivation Study student (Putra et al., 2023).

Previous studies have explored the use of Python in mathematics learning, particularly to support computational exploration and visualization of linear algebra concepts such as matrix operations, determinants, and systems of linear equations (Oliphant, 2015; Surbakti et al., 2024). These studies show that Python can facilitate numerical computation and provide students with practical experience in applying mathematical procedures. However, most of this research focuses primarily on Python as a computational tool and places limited emphasis on how it can support the development of students' conceptual understanding in abstract topics such as matrix algebra (Assegaf et al., 2023). Moreover, existing studies rarely integrate Python within a structured pedagogical framework that systematically guides students' conceptual learning processes. In particular, the potential of combining Python with a *Learning trajectory* approach, which organizes learning progressively from basic to advanced concepts, remains underexplored (Juana et al., 2022). Therefore, this study examines the effectiveness of a Python-based *Learning trajectory* model in improving students' conceptual understanding of matrix algebra.

METHODOLOGY

This study employed a quasi-experimental approach. According to sugiyono (2013), quasi-experimental research aims to examine the effect of a particular treatment on research subjects. This study employed a posttest-only control group design to examine the effectiveness of the Python-based Learning Trajectory model. The purpose of this study was to determine its impact on students' conceptual understanding of matrix algebra. The research population comprised all fifth-semester students of the Informatics Engineering Study Program at Putra Indonesia University (YPTK) Padang who were enrolled in the Linear Algebra and Matrix course in the 2025/2026 academic year. Samples were selected using a random sampling technique. In total, 69 students were involved in the study, including 33 students from class IF 3 as the experimental group and 36 students from class IF 3 US as the control group. The experimental group was instructed using a Python-based Learning Trajectory model, while the control group received conventional instruction. Data were collected using a matrix algebra conceptual understanding test. The instrument possessed construct validity and was reviewed by a mathematics expert, Mishbah Ulhusna, M.Si., to ensure the consistency between the course material, assessment items, and indicators used to evaluate students' conceptual understanding. The indicator of understanding the concept in this study is the ability of students to apply the concept in solving math problems correctly and precisely. The statistical test used was the t-test, with normality and homogeneity tests as prerequisite tests. The concept understanding ability test data was processed using SPSS software version 28.

RESULTS AND DISCUSSION

RESULTS

Statistical tests used to see The effectiveness of the Python-based *learning trajectory* model is tested using a t-test. First, a normality test is performed. as a pre-test condition main continued with the homogeneity test. The results of the normality test on the ability data understanding draft algebra the obtained matrix good class experiment and class control are presented in Figure 1 below.

Group Statistics

	Kelas	N	Mean	Std. Deviation	Std. Error Mean
Nilai	Kelas Experimen	33	77.76	14.528	2.529
	Kelas Konrtrol	36	65.31	15.220	2.537

Figure 1. Data on the ability to understand the concept of matrix algebra

The descriptive statistics indicated that the experimental group (n = 33) achieved a mean score of 77.76 on the matrix algebra conceptual understanding test with a standard deviation of 14.53. Meanwhile, the control group (n = 36) obtained a mean score of 65.31 with a standard deviation of 15.22.

Prior to hypothesis testing, prerequisite analyses were conducted to ensure that the data met the required assumptions. The first analysis involved a normality test to examine whether the distribution of students' conceptual understanding scores in both groups followed a normal distribution. The results of the normality test for the experimental and control groups are presented in Figure 2:

Figure 2. Results of the normality test of the conceptual understanding ability test data

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Kelas	Statistic	df	Sig.	Statistic	df	Sig.
Nilai	Kelas Experimen	.103	33	.200*	.958	33	.234
	Kelas Konrtrol	.111	36	.200*	.977	36	.651

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Figure 2. Results of the normality test of the conceptual understanding ability test data

Presented in Figure 2, the experimental class data can be interpreted with a Sig. 0.234 > 0.05, meaning the data is normally distributed. The control class conceptual understanding ability test data with a Sig. 0.651 > 0.05 means the data is normally distributed. The conclusion for the data distribution results of the mathematical concept understanding ability test data of students in the experimental class and the control class is normally distributed.

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Nilai	Based on Mean	.023	1	67	.881
	Based on Median	.049	1	67	.825
	Based on Median and with adjusted df	.049	1	63.021	.825
	Based on trimmed mean	.021	1	67	.885

Figure 3. Homogeneity Test Results of the Variance Between the Experimental Class and the Control Class

Based on Figure 3. presented homogeneity test results variance is sig. value **0.881 > 0.05** with thus concluding that second class own level the same homogeneity**.**

Prerequisite test first normality test to be continued with pre-test conditions second namely the homogeneity test has finished and concluded fulfilled. For carry out basic statistical tests further hypothesis that is using the **parametric** *t-test*. The results of the statistical test with the t-test are in Figure 4.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Nilai	Equal variances assumed	.023	.881	3.469	67	<,001	12.452	3.589	5.288	19.616
	Equal variances not assumed			3.476	66.883	<,001	12.452	3.582	5.302	19.602

Figure 4. T-test statistical test

Referring to Figure 4, the obtained t value is 3.469, which exceeds the critical t value of 1.997 at $\alpha = 0.05$ with *df* = 67. Because $t_{count} > t_{table}$, the null hypothesis (H_0) is rejected. This finding demonstrates that students who participated in the Python-based Learning Trajectory model achieved significantly higher conceptual understanding of matrix algebra compared with those who learned through conventional instruction.

DISCUSSION

The results of the data processing in the study showed that the implementation of the Python-based *Learning trajectory learning model* significantly influenced students' conceptual understanding of matrix algebra. The results of the average score on the mathematical concept comprehension test for matrix algebra in the experimental class were higher than those in the control class. This explains that the integration of Python into learning not only facilitates procedural understanding but can also deepen students' conceptual understanding of matrix algebra. This finding is not much different from the findings ofRais & Zhao (2024) which states that the integration of Python in learning plays a role in increasing students' understanding of the relationship between theory and practice through interactive visualization and numerical simulation.

The Learning trajectory model plays a crucial role in regularly building students' thought processes from simple concepts to higher levels of complexity. According to Eka PSB, et al. (2023)*Learning trajectory* provides a strong conceptual foundation because it emphasizes logical relationships between concepts and planned cognitive progression. By incorporating Python into this *learning trajectory model, students not only learn matrix algebra algorithms but also understand the relationships between concepts, processes*, and how these concepts are applied in real-world computing contexts, such as numerical programming and artificial intelligence. This finding aligns with that proposed by Firmasari et al., (2024) who discovered that *Hypothetical Learning trajectory* (HLT) is a systematic learning design to build students' mathematical and computational thinking skills.

In addition to the cognitive aspect, the research results also showed a significant difference in the learning motivation of students in the experimental class. This is because the *learning trajectory model* applied can link with practical applications of Python more in line with the needs and interests of Informatics Engineering students. As expressed by Almira R. Bayanova et al., (2023), learning motivation increases when students find learning where there is a connection between the material being studied and the competencies of their field of study. In the context of this research, Python acts as a bridge connecting abstract mathematical theory with real computational implementation, thus fostering students' curiosity and desire to explore further. This goes hand in hand with Puspitasari & Rayungsari, (2024) the fact that mathematics learning integrated with technology can increase students' learning interest.

During the learning sessions in the experimental class, the learning process tended to be more interactive and collaborative. Students participated in discussions, worked on matrix algebra problems using the Google Colab environment with the NumPy library, and reflected on the computational results obtained from their programming activities. These findings align with Charania et al., (2021) those stated *Technology-enhanced learning trajectories* can create a constructivist learning environment that encourages active and reflective participation.

In addition, the motivation in the experimental class is also consistent with the research, this is supported by data from the results of distributing the Learning Motivation questionnaire adapted from Manzano-León et al. (2021) which is presented in Table 1

Table 1. Data from the results of the Experimental Class Student Motivation Questionnaire.

Aspect	Percentage (%)	Category
Choice of tasks	87%	High
Effor	88%	High
Persistence	86%	High
Achievement	88%	High
Average	87%	High

Source Category: modification (Muthmainnah et al., 2021)

Rosadi et al., (2023) which shows that interactive learning media can strengthen self-confidence (self-efficacy) and motivation as well as belief in facing challenges in learning.

Furthermore, the findings of this study indicate that the effectiveness of the Python-based Learning Trajectory model lies in the integration between structured conceptual learning and computational exploration. Through the learning trajectory stages, students are guided to construct their understanding progressively, while Python functions as a tool that allows students to test, visualize, and verify mathematical concepts directly. This combination helps reduce the abstract nature of matrix algebra by transforming symbolic procedures into observable computational processes. As a result, students are able to connect mathematical theory with computational implementation more meaningfully. Previous studies indicate that learning trajectories help structure the development of students' mathematical understanding by aligning learning goals, instructional activities, and students' thinking processes in a coherent progression (Zapatera Llinares, 2022). In addition, the integration of technology in mathematics learning environments can facilitate computational exploration and support the development of computational thinking, which contributes to deeper conceptual understanding and improved problem-solving abilities (Wardani et al., 2022). Therefore, the integration of Python within a structured learning trajectory does not only support procedural skills but also strengthens conceptual understanding and computational thinking in learning matrix algebra.

CONCLUSION

The findings demonstrate that the implementation of the Python-based Learning Trajectory model contributes positively to improving students' conceptual understanding of matrix algebra. The experimental group achieved a higher average score than the control group, indicating better learning outcomes. In addition, the t-test analysis confirmed a statistically significant difference between the two groups (t = 3.469, $t_{critical}$ = 1.997, α = 0.05), suggesting that the learning model provides a meaningful impact on students' conceptual mastery. These results indicate that the integration of Python within a structured learning trajectory helps students connect abstract mathematical concepts with their computational representations, allowing them to develop a clearer and more meaningful understanding of matrix algebra.

From a practical perspective, the Python-based Learning Trajectory model can serve as an effective instructional strategy for mathematics learning in Informatics Engineering programs, particularly in courses related to linear algebra and computational mathematics. By integrating programming tools such as Python and libraries like NumPy in interactive environments such as Google Colab, instructors can create learning experiences that combine conceptual explanation, computational experimentation, and visualization. This approach not only supports conceptual understanding but also develops students' computational thinking skills, which are essential in the context of modern computing and data-driven disciplines.

However, this study has several limitations. First, the research was conducted on a limited sample within a single academic program, which may restrict the generalizability of the findings to broader educational contexts. Second, the study focused primarily on conceptual understanding and learning motivation, while other important aspects such as long-term retention, problem-solving ability, and higher-order computational skills were not examined. Therefore, future research is recommended to involve larger and more diverse samples, explore additional learning outcomes, and investigate the long-term impact of integrating Python-based learning trajectories in mathematics and computing education.

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