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Integration and Applications of Linear Algebra in STEM Programmes: A Case Study of Ghanaian Universities

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Abstract: Linear algebra serves as a critical tool in propelling Science, Technology, Engineering, and Mathematics. So, this study aims to explore the level of integration into university curricula, its applications, and challenges. The study adopts the systems theory and linear system theory frameworks to provide a structural and analytical perspective on the integration and application. A cross-sectional research design was employed to gather data from two University undergraduate students pursuing the domain in Ghana. The findings revealed the disparity between theoretical instruction and practical application, as 41.3% affirmed the perception, emphasizing the need for curriculum reforms, increased use of computational tools, and interdisciplinary collaborations. It was therefore recommended that stakeholders strive to improve pedagogical strategies, strengthen industry collaboration, and invest in modern technology tools to enhance the application of linear algebra education.

INTRODUCTION

Linear Algebra focuses on structure, order, and relation, derived from (Juraev & Bozorov, 2024). This provides a framework for studying systems of linear equations, vectors, matrices, and transformations (Veith et al., 2023). Research (Ankita, Brahmani & Patta, 2021; Juraev & Bozorov, 2024; Veith et al., 2023) shows that Linear Algebra can generally be applied to daily life sciences, namely, but not limited to: Game Theory, Graph Theory, Image Processing, Data Science, Engineering, Physics, Mathematics.

In mathematics, Systems of linear functions are relations between dependent and independent variables, mathematically represented as:

$$f(x) = mx + c \quad (1)$$

In (1), the 'x' is the independent variable, and f(x) is the dependent variable. The graph of f(x) = mx + c is an increasing line when $m > 0$, a decreasing line when $m < 0$, and a horizontal line when $m = 0$ (Ankita et al., 2021). This can also represent vectors such as displacement, velocity, acceleration, force, and momentum to understand the behaviour of directional quantities in two-dimensional and three-dimensional spaces (Stewart et al., 2019).

Another representation is matrices in any dimensions, arranged in rows and columns (Lay et al., 2020). Matrices are fundamental for representing linear transformations, solving systems of linear equations, and facilitating explicit calculations in square, rectangular, diagonal, identity, zero, and symmetric forms. Matrices and vectors are closely related: single-column matrices are called column vectors, and single-row matrices are called row vectors (Lay et al., 2020). Matrices can be used to perform vector operations, as well as vector spaces, eigenvalues, eigenvectors, singular value decomposition, and linear transformations (Debnath, 2014).

Statement of the Problem

Even though the integration and applications of Linear algebra influence a wide range of fields, its integration and use in real Science, Technology, Engineering, and Mathematics (STEM) contexts remain limited, posing significant challenges to a nation's progress (Bardoe et al., 2023). Despite the theoretical knowledge of tertiary education students, there are still substantial gaps in the practical applications (Kadbadayi, 2021) due to a lack of computational tools, software, and new technologies. This disconnect hinders graduates' ability to apply Linear Algebra in problem-solving skills and innovation potential.

Also, the lack of advanced computational tools and resources restricts the scope and content of applications of Linear Algebra (Breiding et al., 2023). University students struggle with modern mathematics laboratory, facilities, and support for research activities. These gaps curtail the ability of students to explore and implement cutting-edge Linear Algebra techniques (Donkoh et al., 2023).

Again, the practical application of Linear Algebra in industry is often underutilized, culminating in missed opportunities for optimizing processes, product development, and innovations in STEM fields (Acheampong et al., 2024). This lack of collaboration and synergy hinders scientific research and technology development, exacerbates opportunities for practical experiences, and focuses more on theory (Danquah et al., 2020).

Other Challenges of Linear Algebra in STEM Programmes

Challenges of integration and applications persist in curriculum development, teaching methods, computational resources, and industry collaboration (Breiding et al., 2023; Supriyadi et al., 2024; Wang et al., 2020). Wang et al. (2020) found that Linear Algebra still lags behind rigid curricula that often fail to keep pace with technological advancements and their applications. Donkoh et al. (2023) discovered mainly theory without sufficiently linking theory to practical applications in STEM programmes.

Also, Wang et al. (2020) found a shortage of qualified instructors who have both deep mathematical knowledge and pedagogical skills. Many Faculty members have strong theoretical backgrounds but lack training in modern teaching methods that emphasize active learning, problem-solving, and the use of technology. So, it is not uncommon to find traditional lecture-based instruction, to the detriment of problem-solving skills.

Again, research (Supriyadi et al., 2024) revealed that research in linear algebra requires significant funding to acquire computational resources, software licenses, and training. Research funding is often limited, and the allocation of funds is sometimes skewed towards non-scientific and non-STEM fields. This limitation constrains research on applications and innovative solutions. And researchers who are willing to finance projects in the field are confronted with computational infrastructure to support machine learning, optimisation, and data analysis (Acheampong et al., 2024).

Furthermore, research (Ankita et al., 2021; Bardoe et al., 2023) revealed that Linear Algebra has not been synergised with the local industry, such as agriculture, finance, telecommunications, and healthcare. For instance, Ankita et al. (2021) discovered that optimising agricultural linear regression models and financial risk management through matrix-based approaches has bridged the gaps between theory and practice (Donkoh et al., 2023). Supriyad et al. (2024) found that interdisciplinary collaboration in STEM fields creates a more holistic learning environment for students to make practical applications and develop the ability to work in diverse teams to foster innovation and the development of new technologies that address local challenges (Koskinen & Pitkaniemi, 2022).

Theoretical Framework

This study applied the Linear System Theory in modelling, analysing, and designing the Linear Equations (Strang, 2016). The goal is to find values for variables that satisfy all the equations simultaneously. This theory has widespread applications in various STEM fields. A system of 'm' linear equations in 'n' variables is a collection of 'm' equations, each containing a linear combination of the same 'n' variables summing to a scalar as expressed in the form:

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \dots\dots + a_{1n}x_n &= b_1 \\ a_{21}x_1 + a_{22}x_2 + \dots\dots + a_{2n}x_n &= b_2 \\ \vdots \quad\quad \vdots \quad\quad\quad\quad \vdots \quad &\quad \vdots \\ a_{m1}x_1 + a_{m2}x_2 + \dots\dots + a_{mn}x_n &= b_m \end{aligned} \tag{2}$$

In (2), x_1, $x_2 \ldots, x_n$ are variables, a_{ij} are coefficients, and b_i are constants (Debnath, 2014).

Also, the matrices can compactly represent the systems as:

$$Ax = b \tag{3}$$

In (3), A is an m × n matrix of coefficients $[a_{ij}]$, x is an n × 1 column vector of variables $[x_i]$, b is an m × 1 column vector of constants $[b_i]$. In this sense, Matrix Decomposition can be applied to solve linear systems, eigenvalue problems, and optimization tasks using numerical analysis, computer graphics, machine learning, and scientific computing (Debnath, 2014). The Eigenvalues represent the scaling factor, while eigenvectors indicate the directions that remain unchanged under the transformation as applied in differential equations, principal component analysis (PCA), and quantum mechanics (Lay et al., 2020).

Again, the Singular Value Decomposition (SVD) can compute the pseudo-inverse of non-square matrices, providing solutions to underdetermined or overdetermined matrix equations. Even the Least Squares Method in numerical analysis can minimise the sum of squared differences between observed and predicted values for overdetermined systems, fitting data to models, and analysing regression problems, with applications spanning science, engineering, and economics (Strang, 2016). Therefore, the following research questions guided the study: (1) How can linear algebra be integrated into STEM programmes? (2) What are the perceived applications of linear algebra in STEM programmes? (3) What challenges do students and faculty members encounter in STEM programmes?

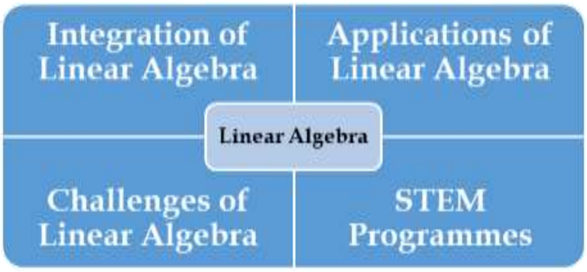

Figure 1. A 2x2 Matrix of the Conceptual Framework

Integration of Linear Algebra into STEM Programmes

The integration of linear algebra in STEM programmes has evolved over the years, reflecting both advancements in the field and the increasing demand for its applications across multiple disciplines (Alrajeh & Shindel, 2020; Veith et al., 2023). The integration of Linear Algebra into undergraduate and graduate curricula revealed numerous benefits and challenges (Bardoe et al., 2023). Lay et al. (2020) integrated Linear Algebra into Core Mathematics and Science Programmes and linked the course to abstract algebra, numerical analysis, differential equations, quantum mechanics, and relativity (Strang, 2016).

Also, Lay et al. (2020) applied the concept to electrical, mechanical, and civil engineering for analysing systems, control theory, signal processing, and computer-aided design. For instance, it was revealed that eigenvalues and eigenvectors came to stability in the systems, and solved network equations in electrical circuits (Lay et al., 2020).

Again, Muller and Guido (2016) utilized the knowledge in understanding algorithms, graphics, computer vision, and machine learning. They performed matrix transformations in scaling, rotation, translation of objects, linear regression, dimensionality reduction, and neural networks, and extended to statistical modeling and data manipulation, as well as optimizations, equilibrium problems, population dynamics, and biological networks (Aggarwal, 2020; Lay et al., 2020).

Perceived Applications of Linear Algebra in STEM Programmes

In Mathematics Education, Strang (2023) found that Linear Algebra is the cornerstone of advanced mathematics, the basis for more specialised abstract algebra, functional analysis, differential equations, vector spaces, matrix theory, and linear transformations. This is even applied in physics, engineering, economics, and computer science (Strang, 2023).

In Engineering Education, research (Strang, 2023) discovered that Linear Algebra is indispensable for systems and signals, control theory, robotics, structural analysis, and circuit design. They analysed electrical circuits, solved mechanical stress problems, and optimised control systems. They also modeled and simulated physical systems, analyzed structural integrity, and optimized mechanical, civil, electrical, and aerospace topics (Strang, 2023).

In computer science, Goodfellow et al. (2023) modelled computer graphics, machine learning, cryptography, and data analysis. They used matrices and eigenvectors to perform transformations, algorithms, and multidimensional data in machine learning and artificial intelligence (Maanu et al., 2025). All the areas seek to enable students to understand mathematical problems, models, and interpretations (Maulani, 2024). Therefore, understanding Linear Algebra problems helps to build efficient algorithms to solve real-world problems in software engineering (Goodfellow et al., 2016).

METHOD

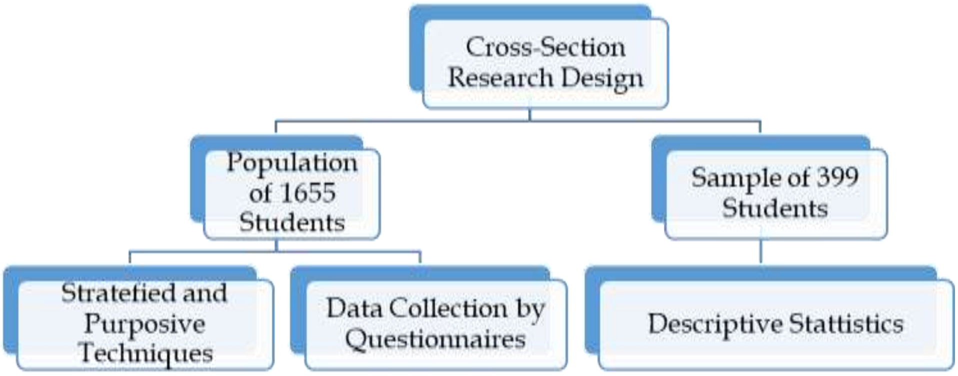

Figure 2. Framework of Descriptive Cross-Sectional Design

Research Design

The quantitative cross-sectional descriptive survey design aimed at systematically investigating the integration and applications of Linear Algebra into STEM programmes. This design was chosen to allow the researchers to collect, analyse, and interpret quantitative data in a structured manner to provide a comprehensive understanding of the phenomenon under investigation (Creswell & Creswell, 2018). The descriptive survey design allowed the researchers to describe the state of affairs or assess characteristics of the phenomenon (Cohen, Manion, & Morrison, 2018).

Again, the design was employed on a large sample (305), ensuring the results are representative and applicable to a wider population. The data ranged from students (e.g., undergraduates, graduates) and faculty (e.g., lecturers, professors), Integration, Applications, and Challenges. This enabled us to gain insights into its relevance in solving real-world problems (Canonigo & Joaquin, 2024).

Even though the design offered a large sample to enhance the generalizability of the findings and ensure consistency and comparability of data across respondents, the design was limited in its ability to explore in-depth contextual factors and the complexities of individual experiences (Creswell & Creswell, 2018). Despite these limitations, the design provided a solid foundation for understanding Linear Algebra in STEM programmes.

Population

The target population for the study included faculty members and students of the departments in selected universities. A stratified random sampling technique was used to ensure that all relevant subgroups, such as different academic departments, were adequately represented in the sample. This method minimised sampling bias and enhances the reliability and validity of the findings (Creswell & Plano Clark, 2018).

The research population included students and faculty members in STEM programmes. These programmes included mathematics, engineering, computer science, physics, and chemistry. However, Linear Algebra is deeply embedded in mathematics and engineering programmes, functioning as a critical foundation for both theoretical concepts and practical applications (Strang, 2016). Therefore, the respondents were drawn mainly from the mathematics and engineering departments. The choice was to foster direct engagement with Linear Algebra and its applications to make them well-positioned to provide relevant data.

The selection of respondents also provided a comprehensive understanding of how Linear Algebra contributes to STEM programmes. So, the population was drawn from one public and one private university to ensure that data collection and analysis are more feasible and practical. The research population was 1,655, as shown in Table 1.

Table 1. Population Distribution

University	Students	Faculty	Total
UNIA	1050	62	1112
UNIB	520	23	543
Total	**1570**	**85**	**1655**

Source: Field work, 2024

Sample Size

The sample size was determined based on the total number of students and faculty members within the selected universities, ensuring it is large enough to achieve statistical significance. This allowed for the generalisation of findings to the broader population of similar academic institutions. According to Adam (2020), the Yamane formula is an approximation of the known sample size formula, such as the Cochran formula for proportion at a 95% confidence level and population proportion of 0.5 (Adam, 2020). These statistical formulas determined the optimal sample size while considering the confidence level and margin of error.

In addition, the researchers selected two Universities, offering STEM programmes, and Linear Algebra was a core component of the curricula. This ensured that the two institutions used and applied linear algebra in pertinent and prominent areas. The two universities were denoted as University A (UNIA) and University B (UNIB), for the sake of anonymity and ease of analysis. The researchers also selected respondents randomly to ensure representativeness and generalizability to reflect the different educational contexts.

Furthermore, a sample of no less than 20% of the targeted population was considered wide and inclusive. This was statistically significant and provided a robust basis for concluding on the integration and application of Linear Algebra in STEM programmes, to allow for meaningful subgroup analysis.

On the whole, the sample size was feasible given time, resources, and logistical constraints, while still being large enough to capture diverse and meaningful insights. The stratification of the sample allowed for detailed comparative analysis and understanding of different viewpoints, and further justifications for representativeness, statistical significance, and alignment with the objectives. Therefore, the sample size is shown in Table 2.

Table 2. Sample Size

University	Students	Faculty
	Sample Size	Sample Size
UNIA	131	27
UNIB	114	23
Total	**245**	**60**

Source: Field work (2024)

Sampling Techniques

The sample size of not less than 20% of the population was calculated using Yamane's formula:

$$n = \frac{N}{1 + N \cdot e^2} \quad (4)$$

In (4), 'n' is the sample size, 'N' is the Total population size, and 'e' is the Margin of error (also called sampling error). For a more inclusive sample, a smaller margin of error was preferred, such as 0.05 (5%). To ensure the sample size was at least 20% of the population, we checked: $n \geq 0.2 \times N$. If n' calculated from the formula, is less than $0.2 \times N$, we adjust it to $n = 0.2 \times N$.

The researchers combined stratified and purposive techniques to select the respondents to ensure a diverse and representative sample, capturing a broad spectrum of experiences and contexts related to teaching and applying Linear Algebra in STEM programmes (Creswell & Plano Clark, 2018). The purposive sampling technique allowed the researchers to intentionally select universities, faculty members, and students who were directly involved in Linear Algebra courses. In this technique, the researchers focused on individuals most relevant to the research objectives and who had sufficient knowledge and experience in the subject.

Additionally, stratified sampling by gender, age, and department was used to ensure that the specific subgroups were well represented in the sample (Boateng, 2024). This helped achieve balanced representation across different subpopulations, fostered a more comprehensive understanding of the role of linear algebra in STEM (Creswell, 2018), reduced sampling bias, and increased the reliability of the findings (Cohen, Manion, & Morrison, 2018).

Data Collection Procedure

The data collection procedure involved several steps to ensure the accuracy and reliability of the data collected. First, permission was sought from the relevant authorities in the selected universities to administer the questionnaires. Confidentiality and anonymity are key ethical principles in research that ensure respondents provide informed consent by assuring them of the privacy and protection of their data. (Kang & Hwang, 2023). The data collection process took place over three weeks, with follow-up reminders sent to respondents who had not yet completed the survey to improve the response rate. The researchers distributed the questionnaires and achieved a higher response rate.

Additionally, to complement the self-administered questionnaires, the researcher also utilised Google Forms for both students and faculty members. The distribution of the questionnaires across the selected universities was guided by the calculated sample size determined for both groups.

Data Analysis Techniques

The researchers retrieved 305 out of the 355 respondents (rate of retrieval = 86%) to make meaningful insights and support the research objectives. The data analysis involved applying statistical techniques to systematically evaluate and interpret the 305 responses. These provided a comprehensive understanding of the integration and impact of the applications (Creswell & Creswell, 2018).

Also, the researchers used SPSS to process and analyse the coded data (Pallant, 2020). This addresses all facets of the analytical process from data preparation and management to data analysis and reporting to uncovering trends, relationships, and patterns associated with the use of linear algebra in STEM programmes (Pallant, 2020).

Again, the researchers employed descriptive statistics (percentages) to present and analyse the data (Rahman & Muktadir, 2021). These statistics are fundamental in describing the relationships between variables in the population (Creswell & Creswell, 2018).

Furthermore, the demographic variables were gender, age, academic rank, and department. The independent variables were integration, applications, and challenges in learning and teaching STEM programmes (Bardoe et al., 2023). The trends and patterns of the independent variables helped to address the research problem (Pallant, 2020).

Validity and Reliability

The validity of research instruments and data collection methods was crucial to establishing the reliability and credibility of the study. Reliable and appropriate procedures ensure that the findings align with the research objectives. To establish validity, the researchers validated the instruments for accuracy before administering them to the respondents (Creswell & Creswell, 2018).

Also, Cronbach's alpha was used to assess the internal consistency of the questionnaire items. Cohen et al. (2018) explain that a high Cronbach's alpha value (typically above 0.7) indicates good internal consistency and ensures that a scale measures the same underlying construct. By employing these statistical measures, the researchers ensured that the questionnaires and data collected were valid, reliable, and credible, and provided relevant information on the integration and application of Linear Algebra in STEM programmes (Creswell & Creswell, 2018).

Again, to ensure that the instruments and data collection methods were well-designed and reliable, the researchers conducted a pilot test with students and faculty members from another University. The pre-testing was conducted on thirty (30) students and five (5) faculty members. The questionnaires were pre-tested for characteristics similar to those of the study population. The Cronbach's alpha value was above 0.7, too (Creswell & Creswell, 2018).

Ethical Considerations

The ethical considerations were of paramount importance to ensure that the rights, dignity, and welfare of the respondents were respected. This helped safeguard against potential harm and ensure the integrity of the research process. Obtaining informed consent ensures that respondents have a full understanding of what they are consenting to and can make an autonomous decision. The researchers ensured that respondents were fully aware of the nature, purpose, risks, and benefits of the study before agreeing to participate (Creswell & Creswell, 2018).

Furthermore, the anonymity of the surveys encouraged respondents to provide more honest and accurate responses, enabling the researcher to obtain reliable data while minimising ambiguous answers. This allowed for a thorough assessment of the integration of linear algebra education and the challenges they face, enabling the collection of extensive and measurable data in a short period.

Additionally, the survey method was cost-effective, as it did not require direct interaction between the researcher and respondents, thus helping to avoid or limit personal biases (Creswell & Creswell, 2018). The researchers ensured the confidentiality of respondents by safeguarding their personal information and securely storing any data collected.

Again, anonymity was maintained unless respondents explicitly agreed to have their identities disclosed. It was essential to ethically minimise the risk of harm to respondents. They were not forced, pressured, or deceived into participating. The researchers respected the autonomy of the respondents, allowing them to make informed decisions about their participation in the study.

RESULTS AND DISCUSSION

Table 3. Gender Distribution of Respondents

University	Gender					
	Male		Female		Total	
	Frequency	%	Frequency	%	Frequency	%
UNIA	140	67.6	67	32.4	207	67.9
UNIB	66	67.3	32	32.7	98	32.1
Total	**206**	**67.5**	**99**	**32.5**	**305**	**100.0**

Table 3 presents the gender distribution of students across two universities, UNI (A) and UNI (B), with a total sample size of 305 students. The overall gender representation shows that 206 out of 305 students (67.5%) are male, while 99 (32.5%) are female. At UNI (A), 140 out of 207 students (67.6%) are male, and 67 (32.4%) are female. Similarly, at UNI (B), 66 out of 98 students (67.3%) are male, and 32 (32.7%) are female. The male-to-female ratio at both universities remains relatively consistent, with male students forming the majority in both institutions.

Table 4. Age Distribution of Respondents

Age	University				Total	
	UNIA		UNIB			
	Frequency	%	Frequency	%	Frequency	%
16–20	68	32.9	23	23.5	91	29.8
21–25	51	24.6	38	38.8	89	29.2
26–30	31	14.9	13	13.3	44	14.4

Age	University				Total	
	UNIA		UNIB			
	Frequency	%	Frequency	%	Frequency	%
31–35	12	5.8	4	4.1	16	5.2
36–40	7	3.4	6	6.1	13	4.3
41+	38	18.4	14	14.2	52	17.1
Total	**207**	**100.0**	**98**	**100.0**	**305**	**100.0**

Table 4 presents the age distribution of respondents across two universities, UNI (A) and UNI (B), with a total sample size of 305, comprising both students and faculty members. The largest age group across both universities is 16–20 years, representing 29.8% of the total population. UNI (A) has a higher proportion of students in this age group (32.9%) compared to UNI (B) (23.5%), suggesting that UNI (A) may have a younger student enrolment. But, UNI (B) has a higher percentage of students in the 21–25 age group (38.8%) than UNI (A) (24.6%). However, numbers decline in the 31–35 and 36–40 age categories, with UNI (A) having a slightly higher proportion than UNI (B).

Table 5. Academic Position/Rank Distribution

Academic Position	Frequency	%
Undergraduate	168	55.1
Graduate	77	25.2
Lecturer	58	19.0
Professor	2	0.7
Total	**305**	**100.0**

Table 5 shows that the majority of respondents were undergraduate students (55.1%). Among Faculty, lecturers made up 19.0%, and Professors formed the smallest category, with only 2 respondents (0.7%). Overall, the data highlight the predominance of students in both undergraduate and graduate programmes within the academic setting.

Table 6. Departmental Distribution

Department	Undergraduate		Graduate		Lecturer		Professor		Total	
	Freq.	%	Freq.	%	Freq.		Freq.	%	Freq.	%
Mathematics	58	34.5	21	27.3	13	22.4	-	-	92	30.2
Engineering	110	65.5	56	72.7	45	77.6	2	100	213	69.8
Total	168	100.0	77	100.0	58	100.0	2	100	305	100.0

Table 6 shows that Engineering was the dominant field (69.8%), significantly outnumbering those in Mathematics (30.2%). Among undergraduate students, Engineering had the highest representation (65.5%), compared to Mathematics (34.5%). Similarly, in the graduate programmes, Engineering was higher (72.7%) compared to Mathematics (27.3%). The faculty distribution followed the same trend, with 77.6% in Engineering and only 22.4% of lecturers in Mathematics. Notably, Engineering had two professors, while Mathematics had none.

Integration of Linear Algebra in the Curriculum

Table 7. Level of Integration of Linear Algebra

Levels	Students		Faculty members		Total	
	Freq.	%	Freq.	%	Freq.	%
Not at all	2	0.8	-	-	2	0.7
Slightly	22	9.0	-	-	22	7.2

Levels	Students		Faculty members		Total	
	Freq.	%	Freq.	%	Freq.	%
Moderately	118	48.2	11	18.3	129	42.3
Highly	100	40.8	40	66.7	140	45.9
Fully	3	1.2	9	15.0	12	3.9
Total	**245**	**100.0**	**60**	**100.0**	**305**	**100.0**

Group	**Students**	**Faculty**
Mean	49.0	20.0
Variance	55.7	17.3
Observations	245	100
df	343	-
t-Stat paired	5.10	-
p-value	<0.0001	

Table 7 shows that 45.9% highly integrated in Linear Algebra. This consisted of students (40.8%) and faculty members (66.7%), suggesting that both groups recognize the integration of Linear Algebra. Additionally, 42.3% of students and 48.2% of faculty members reported moderate integration. This suggests that faculty members were more likely to pursue full integration than students.

Table 8. Dearth of Integration of Linear Algebra

Depth of Coverage	Students		Faculty members		Total	
	Frequency	**%**	**Frequency**	**%**	**Frequency**	**%**
Superficial	17	6.9	-	-	17	5.6
Adequate	166	67.8	1	1.7	167	54.8
In-depth	62	25.3	47	78.3	109	35.7
Very in-depth	-	-	12	20.0	12	3.9
Total	**245**	**100.0**	**60**	**100.0**	**305**	**100.0**

Table 8 revealed that students (67.8%) and one faculty member (1.7%) considered the coverage of Linear Algebra to be adequate. Interestingly, 6.9% of students perceived the coverage as superficial, with no faculty members sharing this view. This suggests that most academic programmes provide a moderate level of exposure. Furthermore, 20% of faculty members rated the coverage as very in-depth, whereas no students reported this depth. This suggests that faculty members may have a different perspective, likely due to their broader knowledge of advanced applications and research opportunities.

Table 9. Areas of Integration of Linear Algebra

Areas	Students		Faculty members		Total	
	Frequency	**%**	**Frequency**	**%**	**Frequency**	**%**
Matrices	211	86.1	52	86.7	263	86.2
Vector spaces	189	77.1	48	80	237	77.7
Eigenvalues and Eigenvectors	160	65.3	44	73.3	204	66.9
Linear transformations	196	80	49	81.7	245	80.3
Applications in STEM	46	18.8	38	63.3	84	27.5
Total		**327.3**		**385.0**		**338.4**

Table 9 shows that 86.1% of students and 86.7% of faculty members confirm that Matrices were their focus, followed by Linear transformations (80.3%), Vector Spaces (77.7%), and Eigenvalues and Eigenvectors (66.9%). In contrast, applications of Linear Algebra in STEM received considerably less emphasis (27.5%), and only 18.8% of students recognized the applications in STEM.

Table 10. Alignment of Linear Algebra with Industry Needs

Alignment	Students		Faculty members		Total	
	Frequency	%	Frequency	%	Frequency	%
Poorly aligned	11	4.5	-	-	11	3.6
Moderately aligned	143	58.4	12	20.0	155	50.8
Well aligned	88	35.9	43	71.7	131	43.0
Very well aligned	3	1.2	5	8.3	8	2.6
Total	**245**	**100.0**	**60**	**100.0**	**305**	**100.0**

The results in Table 10 show that 3.6% believed that the linear algebra curriculum was poorly aligned with industry needs. This suggests that while some students perceived a gap between theoretical instruction and industry demands, faculty members generally believed the curriculum maintained at least some level of relevance. The highest is Moderate alignment (50.8%): students (58.4%) and faculty members (20.0%). This means many students and faculty members acknowledge a gap between academic instruction and real-world applications. However, 43.0% said it is well aligned, and only 2.6% perceived the curriculum as very well aligned with industry needs. Interestingly, faculty members were more likely to hold this view (8.3%) than students (1.2%). This was a noticeable difference in their disparity.

Table 11. The Balance Between Theory and Application by Students and Faculty

Balance	Undergraduate		Graduate		Lecturer		Professor		Total	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Entirely theoretical	26	15.5	13	16.9	-	-	-	-	39	12.8
Mostly theoretical	80	47.6	33	42.9	13	22.4	-	-	126	41.3
Balanced	49	29.2	26	33.8	18	31.0	1	50	94	30.8
Mostly applied	13	7.7	5	6.4	27	46.6	1	50	46	15.1
Total	**168**	**100.0**	**77**	**100.0**	**58**	**100.0**	**2**	**100**	**305**	**100.0**

Table 11 revealed that 12.8% believed that the curriculum was entirely theoretical. This perception was primarily held by undergraduate students (15.5%) and graduate students (16.9%), while no faculty member associated themselves with the view. About 41.3% perceived the curriculum as mostly theoretical. This view was more prevalent among undergraduate students (47.6%) and graduate students (42.9%), whereas lecturers only 22.4% shared this perspective. These suggest that students perceive a stronger emphasis on theory than on application. Furthermore, 30.8% considered the curriculum balanced between undergraduate (29.2%) and graduate students (33.8%) perceptions were lower than lecturers (31.0%) and professors (50%). However, only 15.1% perceived the curriculum as mostly applied, with only 7.7% of undergraduates and 6.4% of graduate students holding this view, as compared to a significantly higher proportion of lecturers (46.6%) and professors (50%).

Table 12. The Balance Between Theory and Applications in Departments

Balance	Mathematics		Engineering		Total	
	Frequency	%	Frequency	%	Frequency	%
Entirely theoretical	22	23.9	17	8.0	39	12.8
Mostly theoretical	70	76.1	56	26.3	126	41.3
Balanced	-	-	94	44.1	94	30.8
Mostly applied	-	-	46	21.6	46	15.1

Balance	Mathematics		Engineering		Total	
	Frequency	%	Frequency	%	Frequency	%
Total	**92**	**100.0**	**213**	**100.0**	**305**	**100.0**

Table 12 shows that 12.8% perceived the curriculum as entirely theoretical. This perception was higher in Mathematics (23.9%) than in Engineering (8.0%). These suggest that linear algebra in Mathematics was heavily focused on theoretical foundations, whereas Engineering integrated the concepts. Moreover, 41.3% considered the curriculum to be mostly theoretical, with Mathematics (76.1%) being more theoretical than Engineering (26.3%). This shows that Mathematics is too abstract, remote, and unused as compared to Engineering. Additionally, 30.8% believed there was a balance between theory and applications, with Mathematics at 0% and Engineering at 44.1%. However, 15.1% considered the curriculum to be mostly applications, and interestingly, no respondents from Mathematics held this view, as opposed to Engineering (21.6%).

Table 13. Integration of Linear Algebra in Selected Courses

Courses	Students		Faculty members		Total	
	Frequency	%	Frequency	%	Frequency	%
Mathematics	245	100	60	100	305	100
Computer Science	158	64.5	38	63.3	196	64.3
Engineering	223	91.0	49	81.7	272	89.2
Physics	130	53.1	32	53.3	162	53.1
Data Science	146	59.6	42	70.0	188	61.6
Economics	62	25.3	23	38.3	85	27.9
Environmental Science	3	1.2	2	3.3	5	1.6

Table 13 shows that Linear Algebra is a fundamental component of mathematics (100%), Engineering (89.2%), and computer science (64.3%). It declined in Physics (53.1%), Data Science (61.6%), Economics (27.9%), and Environmental Science (1.6%).

Table 14. Industry-Relevant Case Studies in Linear Algebra

Industry-Relevance	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Total
Undergraduate	4(2.4%)	3(1.8%)	16(9.5%)	63(37.5%)	82(48.8%)	168
Graduate	-	1(1.3%)	5(6.5%)	33(42.9%)	38(49.4%)	77
Lecturer	-	-	2(3.4%)	39(67.2%)	17(29.3%)	58
Professor	-	-	-	-	2(100%)	2
Total	**4(1.3%)**	**4(1.3%)**	**23(7.5%)**	**135(44.3%)**	**139(45.6%)**	**305**

Table 14 shows that 89.9% either agreed (44.3%) or strongly agreed (45.6%) that incorporating industry-relevant case studies enhances student applications of Linear Algebra. Lecturers overwhelmingly endorsed the inclusion of industry-relevant case studies (96.6%), and the two professors unanimously supported the idea, reinforcing the notion that higher-level educators recognize the value of applications. Opposition was minimal, strongly disagreeing and disagreeing. The 7.5% neutrality indicates a saddle situation.

Applications of Linear Algebra in STEM Programmes

Table 15. Familiarity with Applications of Linear Algebra

Familiarity	Students		Faculty members		Total	
	Frequency	%	Frequency	%	Frequency	%
Not familiar	21	8.6	-	-	21	6.9
Slightly familiar	55	22.4	-	-	55	18.0

Familiarity	Students		Faculty members		Total	
	Frequency	%	Frequency	%	Frequency	%
Moderately familiar	110	44.9	16	26.7	126	41.3
Very familiar	52	21.2	29	48.3	81	26.6
Extremely familiar	7	2.9	15	25.0	22	7.2
Total	**245**	**100.0**	**60**	**100.0**	**305**	**100.0**

Table 15 shows that 41.3% were moderately familiar, 26.6% were Familiar, and 7.2% were Extremely Familiar. Presumably, about 75% demonstrated a strong understanding of applications of Linear Algebra in STEM Programmes. However, nearly 25% were slightly familiar/not familiar, highlighting a notable gap in familiarity with Linear Algebra.

Table 16. Areas of Applications of Linear Algebra

Areas	Students		Faculty		Total	
	Frequency	%	Frequency	%	Frequency	%
Machine learning	161	65.7	44	73.3	205	67.2
Image processing	106	43.3	36	60.0	142	46.6
Signal processing	70	28.6	32	53.3	102	33.4
Control systems	33	13.5	29	48.3	62	20.3
Optimization	18	7.3	25	41.7	43	14.1
Data Science	110	44.9	38	63.3	148	48.5
Computational physics	15	6.1	12	20.0	27	8.9
Total		**209.4**		**359.9**		**239.0**

Table 16 shows that 67.2% identified Machine Learning, 48.5% Data Science, and 46.6% Image Processing as the three most applied areas of Linear Algebra in STEM programmes. The least applied areas were recorded in Signal Processing (33.4%), Control systems (20.3%), Optimization (14.1%), and Computational Physics (8.9). This suggests that students may have limited exposure to optimization techniques that heavily rely on Linear Algebra, such as linear programming.

Table 17. Impact of Integration of Linear Algebra

Impact	Students		Faculty		Total	
	Frequency	%	Frequency	%	Frequency	%
No impact	7	2.9	-	-	7	2.3
Low impact	57	23.3	-	-	57	18.7
Moderate impact	114	46.5	16	26.7	130	42.6
High impact	67	27.3	39	65.0	106	34.8
Very high impact	-	-	5	8.3	5	1.6
Total	**245**	**100.0**	**60**	**100.0**	**305**	**100.0**

Table 17 shows that 42.6% rated the “Moderate Impact”, 34.8% “High Impact”, and 1.6% “Very High”. This suggests that respondents overwhelmingly (78%) recognize the impact of linear algebra applications in STEM. Despite this resounding impact, 22% believed its impact was low.

Table 18. Real-World Applications of Linear Algebra

Problems	Undergraduate		Graduate		Lecturer		Professor		Total	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Never	36	21.4	13	16.9	-	-	-	-	49	16.1
Rarely	57	33.9	29	37.7	11	19.0	-	-	97	31.8
Sometimes	56	33.3	23	29.9	16	27.6	-	-	95	31.1
Often	15	9.0	10	13.0	29	50.0	1	50	55	18.0

Problems	Undergraduate		Graduate		Lecturer		Professor		Total	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Always	4	2.4	2	2.6	2	3.4	1	50	9	3.0
Total	**168**	**100.0**	**77**	**100.0**	**58**	**100.0**	**2**	**100**	**305**	**100**

In Table 18, 16.1% never, and 31.8% rarely encountered real-world applications. However. Lecturers (53.4%) and professors (100%) reported a higher frequency of incorporating real-world problems, and this could be attributed to the gap between instruction and applications.

Table 19. Applications of Software Tools for Linear Algebra

Software	Undergraduate		Graduate		Lecturer		Professor		Total	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Never	9	5.4	1	1.3	-	-	-	-	10	3.3
Rarely	40	23.8	15	19.5	3	5.2	-	-	57	18.7
Occasionally	81	48.2	41	53.2	35	60.3	-	-	158	51.8
Frequently	35	20.8	16	20.8	18	31.1	-	-	69	22.6
Always	3	1.8	4	5.2	2	3.4	2	100	11	3.6
Total	**168**	**100.0**	**77**	**100.0**	**58**	**100.0**	**2**	**100**	**305**	**100**

In Table 19, 78% have either occasionally or frequently, or always used software tools for Linear Algebra. Interestingly, both professors' surveys (100%) reported always using software tools. The results largely show that many students and Faculty recognize the value of computational software tools. Regrettably, 22% who have either never or rarely used software tools came from the students.

Table 20. Commonly Used Software Tools for Applications of Linear Algebra

Tools	Students		Faculty		Total	
	Frequency	%	Frequency	%	Frequency	%
MATLAB	135	44.2	46	15.1	181	59.3
Python	147	48.2	43	14.1	190	62.3
R	22	2.9	12	3.9	34	6.8
GeoGebra	69	22.6	22	7.2	91	29.8
Mathematica	14	4.6	4	1.3	18	5.9

In Table 20, Python (62.3%) and MATLAB (59.3%) were the most commonly used software tools. However, faculty showed a stronger preference for MATLAB (15.1%) over Python (14.1%). GeoGebra (29.8%), R 6.8%, and Mathematica (5.9%) were moderately used for utilizing, visualizing, and exploring linear algebra concepts. It must be pointed out that respondents could select multiple tools, and this made selection NOT mutually exclusive.

Challenges in Teaching and Learning Linear Algebra

Table 21. Levels of Difficulty in Linear Algebra

Difficulty Level	Students		Faculty		Total	
	Freq.	%	Freq.	%	Freq.	%
No difficulty	21	8.6	5	8.3	26	8.5
Slight difficulty	44	18.0	32	53.3	76	24.9
Moderate difficulty	125	51.0	15	25.0	140	45.9
Very difficult	50	20.4	7	11.7	57	18.7
Extremely difficult	5	2.0	1	1.7	6	2.0
Total	**245**	**100.0**	**60**	**100.0**	**305**	**100.0**

In Table 21, about 91.5% found linear algebra slightly to extremely difficult, and only 8.5% reported no difficulty in learning Linear Algebra. About 91.4% of the students found Linear Algebra challenging as compared to the faculty (91.7%). In contrast, about 13.4% of Faculty, as compared to 22% of students, considered it very to extremely difficult.

Table 22. Reasons for Challenges in Linear Algebra

Reasons	Students		Faculty		Total	
	Freq	%	Freq	%	Freq	%
Lack of foundational knowledge	75	30.6	16	26.7	91	29.8
Difficulty with abstract concepts	139	56.7	24	40.0	163	53.4
Limited real-world application	212	86.5	46	76.7	258	84.6
Lack of computational tools use	122	49.8	33	55.0	155	50.8
Insufficient learning resources	51	20.8	12	20.0	63	20.7

In Table 22, the three most prominent reasons were Limited real-world application (84.6%), difficulty with abstract concepts (53.4%), and Lack of computational tools use (50.8%). The reasons were more pervasive for students than for Faculty, as 86.5% and 56.7% got stuck in Limited real-world applications and Difficulty with abstract concepts, respectively. Clearly, one can appreciate the disconnect between theory and practice, and low application of linear algebra in Mathematics as compared to Engineering. However, the selection was NOT mutually exclusive because respondents could select multiple key challenges.

Integration of Linear Algebra into STEM Programmes

The findings on Tables 7 and 8 generally show that Linear Algebra is moderately to highly integrated into the curricula, even though the faculty was more likely to integrate Linear Algebra than students. These findings align with Stewart et al. (2019), which emphasize the importance of embedding linear algebra concepts deeply within STEM Programmes to facilitate interdisciplinary and transdisciplinary applications (Veith et al., 2023). This explains the reasons for the deep coverage of Linear Algebra, even though students might not perceive the depth of coverage as strongly due to differences in engagement, instructional methods, or assessment structures. There is therefore a need for curricular improvements to enhance the integration of linear algebra in STEM programmes, as embedding more practical applications and computational tools could bridge the gaps between theoretical knowledge and real-world problem-solving (De Coninck et al., 2019). Ultimately, by incorporating industry-relevant case studies and interdisciplinary approaches, this could improve student engagement and perceptions of linear algebra's importance.

Also, the findings in Tables 9, 13, and 16 revealed that certain topics receive more emphasis than others. Paramount among these were matrices and linear transformations, reflecting their foundational role in various applications, including engineering, physics, and data science (Strang, 2023). However, the low applications of Linear Algebra suggest there is a need for curriculum enhancement to better integrate applied contexts, reinforcing the practical importance of linear algebra in scientific advancements (Goodfellow et al., 2016).

This can be addressed by including more hands-on learning experiences, computational tools, and interdisciplinary collaborations (Wang et al., 2020).

Furthermore, the findings show that incorporating industry-relevant case studies would enhance student engagement in linear algebra. In particular, the Professors demonstrated a strong preference for industry-relevant case studies. This underscores real-world applications in mathematics to increase student motivation and comprehension, and drive into industry-related problems to bridge the yawning gaps between theoretical knowledge and practical application (De Coninck et al., 2019), and reinforce the relevance of linear algebra in STEM Programmes (Strang, 2016).

Applications of Linear Algebra in STEM Programmes

The findings show that participation in linear algebra research remained relatively low, with only a small proportion of students engaging in research activities. This suggests a need for greater emphasis on research opportunities that explore the real-world applications of linear algebra. This was influenced by their familiarity with the practical applications. This reinforces the need to enhance curriculum design to apply Linear Algebra in coursework and allow students to gain a deeper understanding of its relevance in real-world scenarios. This finding aligns with research emphasizing the need for better foundational instruction in linear algebra to improve comprehension and practical application. This is one way academic and research experiences could advance applications, pedagogy, and curriculum design.

In addition, the findings identified several domains where Linear Algebra could be widely applied, with machine learning, data science, and image processing emerging as the most prominent. This growing dependence on linear algebra in training models and optimizing algorithms could even support artificial intelligence (Goodfellow et al., 2016; Maanu et al., 2025). The areas of Image Processing and Signal Processing could transform visual and audio data, as students and Faculty leverage matrix operations and eigenvalue decomposition in medical imaging and telecommunications. Wang et al. (2020) assert that the disparity between students and Faculty suggests a gap in awareness or practical exposure to some applications, particularly in control systems and optimization. Despite this gap, Faculty expertise and student comprehension may improve pedagogical strategies (Aggarwal, 2020).

Furthermore, the findings showed that students and Faculty displayed different levels of knowledge of the impacts of the applications. Faculty rated the impact as high or very high, indicating a stronger acknowledgment of its significance compared to students. This finding emphasizes the critical role of enhancing problem-solving skills and analytical thinking (Strang, 2023). To maximize the impact of linear algebra, educational institutions should consider integrating more applied learning approaches, emphasizing real-world applications that resonate with students' experiences. Another way is to embed real-world applications into curricula and incorporate more industry-relevant case studies and project-based learning approaches to bridge the gap between theory and practice (Donkoh et al., 2023; Koskinen & Pitkaniemi, 2022).

Moreover, a substantial number of students reported encountering real-world problems. Higher education often emphasizes procedural knowledge over conceptual understanding, limiting students' opportunities to engage in real-world and problem-solving experiences. Software tools could be fully integrated into their academic practices (Borba et al., 2016) to increase engagement and meet instructional and research-related demands, and even implement more structured training programs and emphasize the importance of digital literacy in academic and research contexts.

Challenges in Teaching and Learning Linear Algebra

The findings revealed several challenges emanating from a lack of foundational knowledge, conceptual difficulties, limited real-world applications, insufficient computational tools, and inadequate learning resources. These difficulties can be attributed to students' general perceptions of STEM Programmes, which often correlate with their prior knowledge, engagement, and instructional methods (Alrajeh & Shindel, 2020). In contrast, the faculty generally have expertise and familiarity with the programmes. This discrepancy suggests that instructors identify students' challenges, address the less demanding areas before grasping complex concepts.

Again, the observed differences in perception emphasize the need for instructional strategies that bridge the gap between faculty expectations and student experiences (Canonigo & Joaquin, 2024). Incorporating active learning techniques, contextual examples, and scaffolded learning opportunities could enhance student comprehension and reduce perceived difficulty. On one hand, Faculty awareness of students' challenges could lead to improved teaching practices and support student learning more effectively (Sevimli & Unal, 2022). On the other hand, prior research could lessen the depth of abstract concepts, as Faculty could plan for case studies, simulations, and project-based learning (Alrajeh & Shindel, 2020).

In addition, difficulty in abstract concepts requires higher-order cognitive skills, and inviting urgent attention in visual aids, interactive demonstrations, and step-by-step problem-solving strategies to address the lack of foundational knowledge (Joyce & Cartwright, 2019), and stronger preparatory coursework, diagnostic assessments, and remedial support (Sevimli & Unal, 2022). The inclusion of modern computational tools could enhance understanding by providing training and increasing access to these tools to significantly improve learning outcomes.

Moreover, access to high-quality textbooks, online resources, and well-equipped laboratories plays a crucial role in academic success (Alrajeh & Shindel, 2020). Investing more modern digital and physical resources to support the canker. Continuous professional development programs could enhance complex lesson delivery (Alrajeh & Shindel, 2020) and provide opportunities for faculty to learn innovative teaching strategies, incorporate new technologies, and share best practices with peers. The practice of contextualizing mathematical concepts through real-world applications could increase student engagement and comprehension, and practical applications.

Lastly, Access to software tools could enhance their understanding to improve problem-solving skills and analytical thinking. This cannot be achieved without interdisciplinary, multidisciplinary, and transdisciplinary collaborations to foster a more holistic learning experience (Joyce & Cartwright, 2019; Koskinen & Pitkaniemi, 2022; Wang et al., 2020). This ensures that an updated curriculum could be aligned with industry needs and technological advancements in STEM Programmes (Sevimli & Unal, 2022), compelling curriculum revisions to merge machine learning, data analytics, and computational mathematics to ensure relevance in today's job market (Alrajeh & Shindel, 2020).

CONCLUSION AND SUGGESTIONS

Linear Algebra is still dreaded by students, even though it abounds in many applications in STEM Programmes if well integrated. The smooth integration is only possible if the numerous challenges are addressed.

Based on the findings and the conclusion, the following recommendations were drawn: Several recommendations were drawn: (1) Curriculum revision should place greater emphasis on the practical applications of linear algebra, and not the theory; (2) Institutions should acquire more modern software tools, workshops, and seminars to unearth emerging applications of Linear Algebra; (3) Faculty and students should undertake more joint research projects, multidisciplinary, interdisciplinary, and transdisciplinary in STEM Programmes to gain Collaborations, research initiatives, valuable hands-on experience, and real-world applications of Linear Algebra.

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