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Analysis of vector concept understanding and its correlation with basic mathematical abilities of prospective science teachers

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ABSTRACT

This study investigates the relationship between basic mathematical skills and the understanding of vector concepts among 54 prospective science teachers enrolled in basic physics and basic math courses. The research employed a descriptive and correlational quantitative approach, utilizing data from vector tests and basic mathematics assessments administered during the courses. Descriptive statistical analyses revealed that participants showed varying levels of proficiency in both vector understanding and basic mathematical abilities, with average scores indicating a moderate level of competence overall. Correlational analysis using Pearson correlation coefficients found a significant positive relationship ($r = 0.477, \rho = 0.001$) between basic mathematical skills and the understanding of vector concepts, suggesting that higher proficiency in basic mathematical skills corresponds to better understanding of vector concepts. Further analysis segmented by dimensions of vector operations indicated stronger correlations in two-dimensional vector understanding ($r = 0.503, \rho = 0.000$) compared to one-dimensional operations ($r = 0.348, \rho = 0.014$). Basic geometry emerged as the most influential predictor of understanding of vector concepts, exhibiting the highest correlation with both overall understanding of vector concepts ($r = 0.444, \rho = 0.001$) and 2D understanding of vector concepts ($r = 0.430, \rho = 0.0021$). These findings underscore the critical role of mathematical competence, particularly in geometric reasoning, in facilitating conceptual understanding in physics education. In conclusion, strengthening basic mathematics skills among prospective science teachers is essential for enhancing their ability to teach and understand physics, particularly in topics like vectors. Future research should explore instructional strategies to address gaps in math-physics integration.

Keywords: basic mathematical skills, conceptual understanding, correlation, physics, vector

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INTRODUCTION

One of the most challenging subjects for students is physics, largely due to the dominant presence of mathematics (Crowell, 2007; Putri & Pranata, 2023). The emphasis on calculations can sometimes overshadow the core ideas of physics itself (de Winter & Hardman, 2020). Students generally recognize the close connection between mathematics and physics, both in terms of content and real-life applications, and understand that mathematics is essential for supporting their comprehension of physics (Kapucu et al., 2016). However, other studies suggest that the negative perception students have toward physics is not necessarily caused by mathematics, but rather by lack of the identification math skills to applied in physics (Wilson, 2014) and the missing links between mathematics and physics (Michelsen, 2005). Understanding the scope of physics and how mathematical tools support the comprehension of these concepts is crucial.

Physics involves a chain of interconnected concepts, beginning with fundamental ideas that gradually build toward more complex theories. A deep understanding of vectors is particularly fundamental, as they form the basis for many key physical quantities that are characterized by both magnitude and direction, known as vector quantities. Examples of such quantities include displacement, velocity, acceleration, force, gravitational force, work, momentum, and torque. Mastery of vectors, therefore, becomes critical not only in kinematics and dynamics but also in many advanced areas of physics. Previous studies have shown that vector understanding is positively correlated with students' comprehension of motion, such as in projectile motion (Pranata & Seprianto, 2023). Vectors are often represented using arrows to show both magnitude and direction, which is why they are referred to as the "language of arrows" (TLA) (Heafner, 2015). Another study found that students' proficiency in vector representation correlates highly with the quality of free-body diagrams using arrows they produce when studying force in dynamics (Pranata & Lorita, 2023).

Despite the importance of vectors, various studies indicate that students' understanding of vector concepts, particularly basic vector operations, remains low (Pranata, 2023, 2024; Shaffer & McDermott, 2005). Students struggle with applying vectors in kinematics (Barniol & Zavala, 2014a; Shaffer & McDermott, 2005), highlighting the need to explore and analyze their understanding and the challenges they face in learning these concepts. Understanding how vector concepts relate to mathematics is a critical first step, as previous studies suggest. The process can then extend to applying these concepts in more complex physics topics.

Although mathematics is sometimes perceived as a challenge in learning physics, it remains an integral part of the discipline. Physics education must focus on conceptual understanding while using the necessary mathematical tools to achieve learning objectives, such as geometry in vector studies. Integrating mathematics into physics can help increase students' interest and self-efficacy (Béchard et al., 2021) if it is applied appropriately and not overly emphasized as the primary focus (de Winter & Hardman, 2020). The key focus should remain on physics concepts, such as vectors. As such, it is predicted that a strong relationship exists between vector comprehension and basic mathematical abilities.

The mathematical formula in physics is a key component of the subject. Mathematics are fundamental tools for representing physical variables and their relationships (National Research Council., 2012). This applies to many areas of physics, and the role of mathematics in physics often gives students the impression that physics is predominantly about equations and calculations (de Winter & Hardman, 2020). A positive linear relationship between mathematics achievement and physics performance has been established (Chen et al., 2021). Prior mathematical knowledge is also a significant predictor of students' problem-solving skills in physics (Djudin, 2023). While important, the difficulty some students face with mathematical skills can create barriers to success in physics, which must be navigated carefully.

Previous studies highlight that students often face difficulties in understanding vector concepts from both a mathematical and operational perspective (Pranata, 2023, 2024). Students tend to use mathematical formulas before grasping the underlying physics concepts. This approach can exacerbate their challenges, as they struggle to select and apply appropriate mathematical and physical laws and formulas (Meli et al., 2016). There is a recognized need to assess and improve these foundational skills, especially among prospective science teachers. Physics offers an excellent opportunity to help students learn how to apply mathematics to real-world contexts (Jensen et al., 2017), and vice versa, using mathematics as a tool to facilitate the learning of physics. Given the close relationship between the two, it is recommended that physics and mathematics be taught in tandem more frequently (Michelsen, 2015).

Students' understanding of vectors has been shown to significantly correlate with their basic mathematical skills, which are necessary for manipulating and applying vectors in physics problems. Mathematical operations that are easily handled in a mathematics class can become challenging when applied in a physics context (Meli et al., 2016). Moreover, students often have a simplified view that "maths explains physics," which experts argue can hinder their physics comprehension if students cannot identify the relevant mathematical concepts that may influence students' understanding in physics (Wilson, 2014).

Mastery of basic mathematical abilities is crucial for learning physics. Arons (1997) identified three foundational mathematical concepts necessary for introductory physics instruction: arithmetic reasoning, geometric scaling, and proportionality. Vector concepts in physics can be represented both visually (through arrows) and mathematically (using formulas) (Barniol & Zavala, 2014b; Hawkins et al., 2010; Knight, 1995). So we also need to explore mathematical concepts related to arrows that usually place in coordinate and equations. Based on these insights, we identified five essential mathematical concepts to include: number concepts, proportionality, coordinates, geometry, and equations. These concepts are important for solving physics problems and applying mathematical models, especially in vector analysis. Although research exists on students' understanding of vectors and mathematical skills, limited studies focus on prospective science teachers. Understanding how these individuals perceive and integrate these concepts is essential to developing targeted educational interventions.

The study of academic mathematics provides increasing opportunities to learn physics over the course of study (Neumann et al., 2021). Having interdisciplinary experiences in both physics and mathematics helps students develop a more meaningful understanding of these interconnected subjects (Liu & Liu, 2011). Evidence of the correlation between students' initial mathematical knowledge and their learning gains in physics is well-documented (Buick, 2007; Chen et al., 2021; Meltzer, 2002). However, few studies have systematically investigated the relationship between students' understanding of vector concepts and their proficiency in basic mathematics. Such a correlation is crucial for understanding predictors of success in physics education. Educators should recognize this relationship to improve students' performance and attitudes toward both subjects (Michelsen, 2015). Understanding this relationship will enable students to engage more effectively with both physics and mathematics.

This research has three main objectives:

(1) to describe the level of prospective science teachers' vector conceptual understanding (VCU),

(2) to investigate the relationship between their VCU and their basic mathematical abilities, and

(3) to identify potential predictors of success in VCU through students' mathematical proficiency.

These findings will contribute valuable insights for educators in designing effective instructional strategies for future science teachers.

METHODS

A quantitative research method with descriptive and correlational design was employed, aligning with the study's objective to examine students' VCU and mathematical skills individually and their interrelationship. The descriptive approach facilitated an in-depth analysis of students' comprehension of vector concepts and foundational mathematical abilities, while the correlational design enabled an assessment of potential connections between these two skill sets. The study adopted a total sampling method, meaning all students from the targeted population were included. This approach was chosen due to the relatively small and accessible population of 54 prospective science teachers enrolled in both basic physics and basic mathematics courses within the same academic term. These students provided a relevant population, as both courses integrate vector and mathematical concepts fundamental to understanding physics. The comprehensive inclusion of all available students enhances the validity of the findings within this specific educational context. However, generalizing the results to broader populations should be done cautiously, as this sample

Table 1. Student score categories

Score (S)	Category
80 ≤ S ≤ 100	A
65 ≤ S < 80	B
0 ≤ S < 65	C

Table 2. Interpretation of the strength of a relationship

Strength of a correlation	*r*
Much larger than typical	≥ 70
Large or larger than typical	0.50
Medium or typical	0.30
Small or smaller than typical	0.10

Table 3. Descriptive statistic

Variables	N	Range	Minimum	Maximum	Mean		Standard deviation	Skewness	
					Statistic	Standard error		Statistic	Standard error
VCU	49	66.67	33.33	100.00	75.30	2.42	16.94	–0.14	0.34
BMS	49	40.00	50.00	90.00	72.68	1.55	10.88	–0.14	0.34

reflects a particular cohort of pre-service science teachers in a single academic setting.

Data on students' understanding of vector concepts were collected using a vector test administered in the basic physics course. This test focused on fundamental vector operations, such as vector addition and subtraction in both one-dimension (1D) and two-dimension (2D). To ensure content validity, the vector test was reviewed by subject matter experts in physics education, who assessed whether the items effectively covered the essential concepts. To assess basic mathematical abilities, a test was administered in the basic math course, covering key topics such as basic number concepts, proportionality, coordinates, plane and solid figures, and equations. The math test was also developed and refined with input from mathematics education specialists to ensure it measured relevant competencies accurately. Both instruments underwent a validation process involving expert reviews and item analysis to confirm their appropriateness for assessing the intended skills.

Prior to data collection, all participants were informed about the purpose of the study, the voluntary nature of their participation, and their right to withdraw at any time without consequences. Informed consent was obtained from each participant, ensuring that they understood and agreed to the use of their data for research purposes. Confidentiality and anonymity were maintained throughout the study.

Out of the 54 participants, data from 5 students were excluded due to the responses, as a result of their absence from one of the tests. This left a sample of 49 students for analysis. Both sets of data were analyzed descriptively to provide an overview of the understanding of vector concepts and basic mathematical abilities. Students' scores were categorized based on a predefined scale, aligned with institutional standards, as shown in **Table 1**.

The relationship between the data sets was analyzed using Pearson's or Spearman's rho correlation tests. Pearson's correlation was applied when the data met the parametric requirements of normal distribution (assessed via skewness) and linearity (assessed via scatterplots) (Leech et al., 2005; Morgan et al., 2004). If these conditions were not met, Spearman's rho test was employed. The correlation coefficients were categorized based on a predefined scale, as shown in **Table 2** (Cohen, 1988). To further explore the relationship between students' understanding of vector concepts and their basic mathematical abilities, regression analysis was conducted. This analysis aimed to predict students' understanding of vector concepts based on their basic mathematical abilities, thereby identifying potential predictors and providing insights into the factors affecting these abilities.

RESULTS AND DISCUSSION

Descriptive Statistic

After collecting data through the vector test and the basic mathematics test, the data were analyzed descriptively using SPSS to answer first research questions. The results are presented in **Table 3**.

Based on the mean values of the two variables in **Table 3**, it can be observed that the score for vector understanding (75.30) is slightly higher than that for basic mathematical skills (72.68). Vector understanding is further divided into the understanding of vector operations in 1D and 2D, while basic mathematical skills are categorized into five parts: number concepts (M1), proportionality (M2), coordinates (M3), basic geometry (M4), and equations (M5). The mean score for each of these categories are presented in **Figure 1**. The complete descriptive statistical analysis is provided in **Appendix A**.

In terms of vector understanding, students demonstrated greater comprehension of 1D vectors (mean = 78.23) compared to 2D vectors (mean = 73.26). However, proficiency in 2D vectors is essential for grasping subsequent physics concepts, such as parabolic motion (Pranata & Seprianto, 2023), force analysis (Pranata & Lorita, 2023; Pranata et al., 2016), torque analysis (Pranata et al., 2017), and other concepts involving vector quantities. Similar patterns have been observed in previous studies conducted under various learning conditions, such as assignment-based learning (Pranata, 2023), blended learning (Pranata & Seprianto, 2023), and the use of PhET simulations (Pranata, 2023). These results align with the fact that the difficulty of vector manipulation increases with dimensional complexity.

Regarding basic mathematics skills (BMS), the highest score was achieved in coordinates (84.75), followed by number concepts (73.53) and proportionality (70.95). Basic geometry (68.96) and equations (65.22) had lower average scores. This distribution suggests that while students are proficient in spatial reasoning (as reflected by the high score in coordinates), they may encounter difficulties with more abstract mathematical operations, such as geometry and solving equations.

The distribution of students' scores for vector understanding and BMS was also analyzed. For vector understanding, students were evenly distributed across different score ranges, with 30.61% achieving the highest category (rank A), as shown in **Figure 2**. In contrast, for BMS, the majority of students (46.94%) fell into rank B, with fewer (24.49%) in rank A.

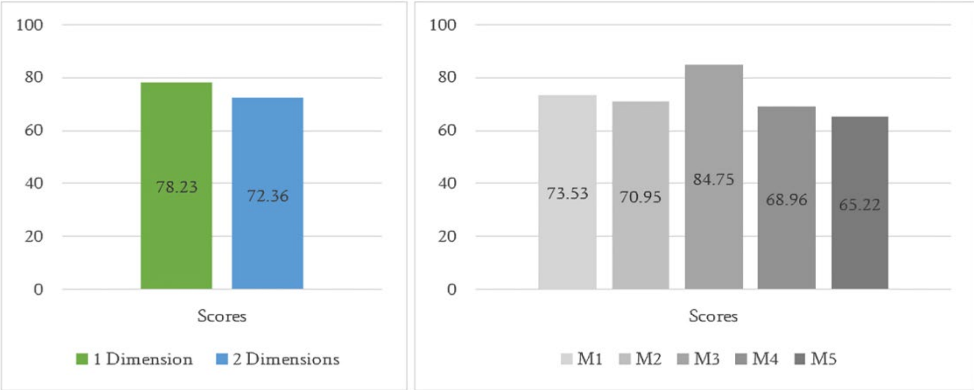

Figure 1. Scores distribution based on category: Vector Understanding (left) and Basic Math Skills (right) (Source: Author's own elaboration)

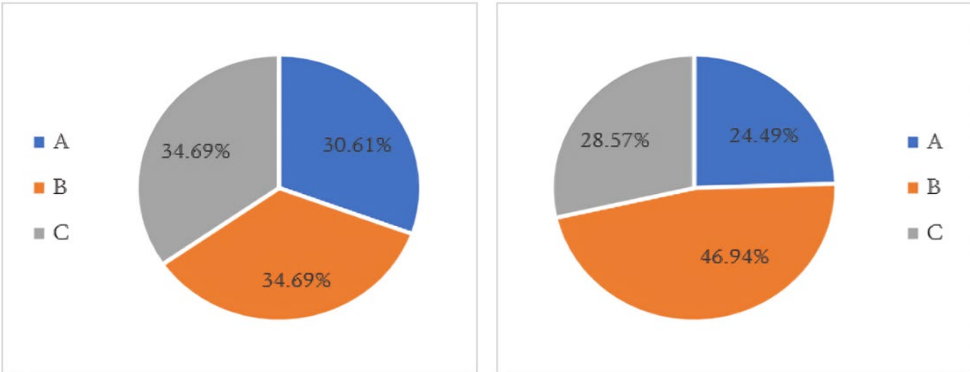

Figure 2. Scores distribution for each student: Vector Understanding (left) and Basic Math Skills (right) (Source: Author's own elaboration)

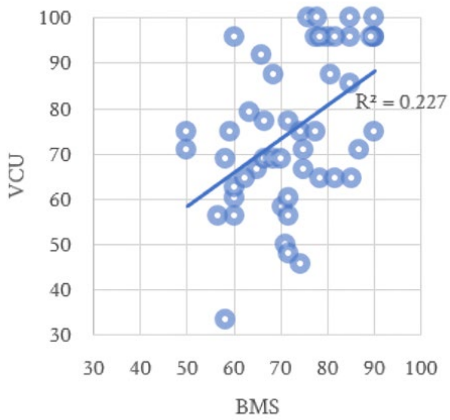

Figure 3. Scatterplot: BMS in x-axis and VCU in y-axis (Source: Author's own elaboration)

These descriptive findings offer a broad overview of students on both variables (VCU and BMS) and their respective sub-categories. However, further investigation is necessary to explore potential relationships between these variables and their sub-categories. Specifically, regression analysis can assess whether BMS serve as predictors for VCU.

Understanding Vector Concepts and Their Correlation with Basic Mathematical Skills

Vector concepts are deeply intertwined with basic mathematical skills. Mathematics serves as a foundational tool for understanding vectors, including operations related to coordinates, numbers, proportionality, geometric properties, and equations. Descriptive statistics show a normal distribution of the data, as indicated by skewness values within the acceptable range of –1 to +1 (see **Table 1** and **Appendix A**). Additionally, based on the scatterplot (**Figure 3**), a linear relationship between the two datasets–VCU and basic mathematical skills–is observed, meeting the conditions for Pearson correlation testing.

A Pearson correlation analysis was performed using SPSS. The results, summarized in **Table 4**, indicate a significant medium-level correlation ($r = 0.477, \rho = 0.001$) between BMS and vector understanding, approaching a high correlation threshold (Cohen, 1988). This suggests that students with higher proficiency in basic mathematics tend to have a better understanding of vectors. These findings align with previous research on the correlation between mathematical ability and physics comprehension (Chen et al., 2021; Neumann et al., 2021). Others studies also find the same results but focus on math and physics learning gains (Buick, 2007; Meltzer, 2002).

Further analysis revealed that BMS correlated more strongly with 2D vector understanding ($r = 0.503$) than with 1D vector understanding ($r = 0.348$), with both correlations statistically significant ($\rho = 0.000$ for 2D and $\rho = 0.014$ for 1D) (**Table 5**). This underscores the importance of solid mathematical skills, particularly when dealing with more complex vector operations in 2D.

Additionally, specific mathematical skills were examined for their correlation with vector understanding. Although coordinates scored the highest in BMS, their correlation with vector understanding was not statistically significant. In contrast, significant correlations were found between number concepts and 2D vector understanding, as well as between proportionality, equations, and vector comprehension, with

Table 4. Pearson correlation results-1

Variables		VCU	VCU 1D	VCU 2D
BMS	Pearson correlation	0.477**	0.348*	0.503**
	Sig. (2-tailed)	0.001	0.014	0.000

* Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed)

Table 5. Pearson correlation results-2

Variables		VCU	VCU 1D	VCU 2D
M1. Concepts of numbers	Pearson correlation	0.296*	0.131	0.392**
	Sig. (2-tailed)	0.039	0.370	0.005
M2. Proportionality	Pearson correlation	0.331*	0.274	0.320*
	Sig. (2-tailed)	0.020	0.057	0.025
M3. Coordinates	Pearson correlation	0.239	0.220	0.210
	Sig. (2-tailed)	0.098	0.128	0.148
M4. Basic geometry	Pearson correlation	0.444**	0.364*	0.430**
	Sig. (2-tailed)	0.001	0.010	0.002
M5. Equations	Pearson correlation	0.318*	0.203	0.363*
	Sig. (2-tailed)	0.026	0.162	0.010

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed)

basic geometry emerging as a key predictor for both 1D and 2D vector understanding.

Regression: How Basic Math Skills Predict Vector Understanding?

A simple regression analyses were conducted to examine how well BMS predict VCU across different dimensions and categories of mathematical content.

Overall predictive model

The overall regression model for predicting VCU based on BMS was statistically significant, $F(1,47) = 13.826, \rho = 0.001$ ($\rho < 0.01$). The derived equation to understand this relationship was

$$VCU\ score = 21.364 + 0.742\ (BMS\ score).$$

This indicates that for every unit increase in BMS score, VCU score is expected to increase by 0.742 units. The adjusted R-squared value of 0.211 suggests that 21.1% of the variance in VCU score is explained by BMS, categorized as a medium effect (Cohen, 1988). Detailed regression analysis results are provided in **Appendix B**.

Dimension-specific analysis

Simple regression was also conducted separately to investigate how well BMS predict VCU in 1D and D. The result were not statistically significant for 1D, $F(1,47) = 6.479, \rho = 0.014$ ($\rho > 0.01$) . In contrast, the result was statistically significant for 2D, $F(1,47) = 15.948, \rho = 0.000$ ($\rho > 0.01$). The identified equation to understand those relationship was

$$VCU\ 1D\ score = 35.851 + 0.583\ (BMS\ score).$$

$$VCU\ 2D\ score = 6.861 + 0.901\ (BMS\ score).$$

The adjusted R-squared value of 0.237 indicates that 23.7% of the variance in 2D VCU score is explained by BMS, also categorized as a medium effect. Detailed results are provided in **Appendix C** and **Appendix D**.

Mathematical category analysis

A multiple regression analysis was conducted to determine which category of BMS best predicts VCU. The overall model was statistically significant $F(5,43) = 3.3.671, \rho = 0.007$ ($\rho < 0.01$). The equation derived is

$$VCU\ score = C + 0.256\ (M1) + 0.023\ (M2) + 0.109\ (M3) + 0.517\ (M4) - 0.025\ (M5).$$

where $C = constant = 11.531$ and M1 to M5 represent categories of BMS.

Basic geometry (M4) emerged as the strongest predictor for VCU, with a regression equation indicating that higher scores in basic geometry correlate positively with VCU scores. Detailed results are provided in **Appendix E**. Basic geometry also demonstrated the highest correlation with both 1D and 2D VCU ($r = 0.364, p = 0.010$, and $r = 0.430, p = 0.002$, respectively) and strongest predictor form VCU in 1D and 2D, reinforcing its significance in understanding vector concepts (**Appendix F** and **Appendix G**). Concepts of numbers (M1) and coordinates (M3) also served as good predictors for VCU. Sample questions (originally in Indonesian) are provided in **Appendix H**.

These findings underscore the importance of basic mathematics, particularly basic geometry, in comprehending vector concepts. The integration of relevant mathematical content in physics education enhances conceptual understanding and supports learning objectives. However, overemphasizing computational aspects alone may obscure fundamental physics concepts. Therefore, aligning mathematical components with physics concepts is crucial for fostering meaningful learning experiences and avoiding educational fatigue.

In context of science education, integrating science and mathematics content can enhance students' interest and efficacy (Béchard et al., 2021). However, studies have shown varied responses regarding the integration of mathematics in biology (Ulandari et al., 2024), chemistry and physics, suggesting a need for tailored approaches. While mathematics plays a dominant role in physics and chemistry (Putri & Pranata, 2023), its relevance should be carefully considered to optimize learning outcomes without overwhelming students. When students recognize that mathematics can enhance their physics performance, they are more motivated to learn how to use mathematical knowledge to solve physics problems (Chen et al., 2021).

From a broader scientific perspective, mathematics is often considered the language of the universe. It is used to describe and explain natural phenomena through mathematical equations that represent patterns and relationships in the physical world. To deepen understanding in physics, studying mathematics alongside physics is highly beneficial (Crowell, 2007). The mathematical concepts must align with the physics content being taught, such as vectors, which require a grasp of basic geometry, number concepts, and equations. Addressing areas of mathematical difficulty can improve physics comprehension, and previous research confirms that integrating both subjects can enhance learning outcomes in teacher education (Neumann et al., 2021).

In science, mathematics and computation are powerful tools for representing physical variables and their relationships. They are used in simulations, statistical data analysis, and recognizing quantitative relationships (National Research Council, 2012). The conceptual understanding of quantitative relationships underlying scientific phenomena forms the basis for sensemaking in science from a mathematical perspective. This type of sensemaking–focusing on the deep conceptual understanding of quantitative relationships–can guide instruction, curriculum, and assessment development (Kaldaras & Wieman, 2023; Kuo et al., 2020; Zhao & Schuchardt, 2021).

In conclusion, mathematics plays a pivotal role in understanding the physical sciences, especially physics, when purposefully integrated with learning objectives. This approach ensures that mathematical concepts not only support but also enhance students' engagement and understanding in physics education. In alignment with the role of math in understanding the physical world, the results show a significant correlation between VCU and BMS. Thus, when teaching physics concepts like vectors, it is essential to identify and integrate relevant mathematical concepts. Instructors may consider adding math-focused sessions or workshops to the physics curriculum.

CONCLUSION

This study aimed to analyze prospective science teachers' understanding of vector concepts and examine its correlation with their basic mathematical abilities. The findings indicate a significant relationship between proficiency in basic mathematics, particularly geometry and number concepts, and comprehension of vector concepts. Prospective science teachers with stronger mathematical foundations were better equipped to grasp vector-related topics, crucial in physics education. Consequently, reinforcing these skills within teacher education programs could enhance the quality of physics instruction.

The study also highlights the need for an integrated approach to teaching physics and mathematics. Rather than focusing solely on computational methods, aligning mathematical tools with physics concepts can foster deeper conceptual understanding and reduce educational fatigue. As prospective science teachers play a critical role in shaping future generations' understanding of physics, strengthening their mathematical proficiency could have long-term positive impacts on science education. Targeted interventions aimed at developing these foundational skills are essential for preparing future teachers to convey both the mathematical and conceptual aspects of physics effectively.

It is important to note the study's limitations, as it was conducted in a single location with a relatively small sample, which may limit the generalizability of the findings. Further research across diverse settings and larger sample sizes is needed to explore the specific challenges prospective science teachers face when applying mathematical concepts to physics. Also, expanding the scope to investigate a broader range of mathematical abilities and their influence on other key physics topics could provide valuable insights into optimizing science teacher education.

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Declaration of interest: The author declares no competing interest.

Data availability: Data generated or analyzed during this study are available from the author on request.

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APPENDIX A: DESCRIPTIVE STATISTICS

Table A1. Descriptive statistics

Variables	Range	Minimum	Maximum	Mean		Standard deviation	Skewness	
				Statistic	Standard error		Statistic	Standard error
VCU	66.67	33.33	100.00	75.297	2.419	16.936	–0.138	0.340
VCU 1D	66.67	33.33	100.00	78.232	2.604	18.227	–0.529	0.340
VCU 2D	66.67	33.33	100.00	72.364	2.783	19.482	0.067	0.340
BMS	40.00	50.00	90.00	72.682	1.554	10.881	–0.140	0.340
M1. Concepts of numbers	50.00	50.00	100.00	73.526	2.557	17.896	–0.175	0.340
M2. Proportionality	50.00	50.00	100.00	70.948	2.505	17.531	0.244	0.340
M3. Coordinates	50.00	50.00	100.00	84.751	2.469	17.283	–0.881	0.340
M4. Basic geometry	50.00	50.00	100.00	68.963	2.0151	14.106	0.371	0.340
M5. Equations	50.00	50.00	100.00	65.221	1.999	13.990	0.618	0.340

APPENDIX B: REGRESSION I

Table B1. Model summary

R	R square	Adjusted R square	Standard error of the estimate
0.477[a]	0.227	0.211	15.04420

[a] Predictors: (Constant), Basic Math Skills

Table B2. ANOVA[b]

	Sum of squares	df	Mean square	F	Significance
Regression	3,129.144	1	3,129.144	13.826	0.001[a]
Residual	10,637.418	47	226.328		
Total	13,766.562	48			

[a] Predictors: (Constant), Basic Math Skills

[b] Dependent variable: Vector Understanding

Table B3. Coefficients[a]

	Unstandardized coefficients		Standardized coefficients	t	Significance
	B	Standard error	Beta		
(Constant)	21.364	14.663		1.457	0.152
Basic Math Skills	0.742	0.200	0.477	3.718	0.001

[a] Dependent variable: Vector Understanding

APPENDIX C: REGRESSION II

Table C1. Model summary

R	R square	Adjusted R square	Standard error of the estimate
0.348[a]	0.121	0.102	17.26843

[a] Predictors: (Constant), Basic Math Skills

Table C2. ANOVA[b]

	Sum of squares	df	Mean square	F	Significance
Regression	1,932.176	1	1,932.176	6.479	0.014[a]
Residual	14,015.345	47	298.199		
Total	15,947.521	48			

[a] Predictors: (Constant), Basic Math Skills

[b] Dependent variable: Vector Understanding 1 Dimension

Table C3. Coefficients[a]

	Unstandardized coefficients		Standardized coefficients	t	Significance
	B	Standard error	Beta		
(Constant)	35.851	16.831		2.130	0.038
Basic Math Skills	0.583	0.229	0.348	2.545	0.014

[a] Dependent variable: Vector Understanding 1 Dimension

APPENDIX D: REGRESSION III

Table D1. Model summary

R	R square	Adjusted R square	Standard error of the estimate
0.503[a]	0.253	0.237	17.01268

[a] Predictors: (Constant), Basic Math Skills

Table D2. ANOVA[b]

	Sum of squares	df	Mean square	F	Significance
Regression	4,615.804	1	4,615.804	15.948	0.000[a]
Residual	13,603.266	47	289.431		
Total	18,219.070	48			

[a] Predictors: (Constant), Basic Math Skills

[b] Dependent variable: Vector Understanding 2 Dimensions

Table D3. Coefficients[a]

	Unstandardized coefficients		Standardized coefficients	t	Significance
	B	Standard error	Beta		
(Constant)	6.861	16.582		0.414	0.681
Basic Math Skills	0.901	0.226	0.503	3.993	0.000

[a] Dependent variable: Vector Understanding 2 Dimensions

APPENDIX E: REGRESSION IV

Table E1. Model summary

R	R square	Adjusted R square	Standard error of the estimate
0.547[a]	0.299	0.218	14.97891

[a] Predictors: (Constant); M1. Concepts of numbers; M2. Proportionality; M3. Coordinates; M4. Basic geometry; M5. Equations

Table E2. ANOVA[b]

	Sum of squares	df	Mean square	F	Significance
Regression	4,118.748	5	823.750	3.671	0.007[a]
Residual	9,647.814	43	224.368		
Total	13,766.562	48			

[a] Predictors: (Constant); M1. Concepts of numbers; M2. Proportionality; M3. Coordinates; M4. Basic geometry; M5. Equations

[b] Dependent variable: Vector Understanding

Table E3. Coefficients[a]

	Unstandardized coefficients		Standardized coefficients	t	Significance
	B	Standard error	Beta		
(Constant)	11.531	15.794		0.730	0.469
M1. Concepts of numbers	0.256	0.152	0.270	1.678	0.101
M2. Proportionality	0.023	0.157	0.024	0.147	0.883
M3. Coordinates	0.109	0.135	0.112	0.811	0.422
M4. Basic geometry	0.517	0.181	0.431	2.858	0.007
M5. Equations	–0.025	0.200	–0.020	–0.123	0.902

[a] Dependent variable: Vector Understanding

APPENDIX F: REGRESSION V

Table F1. Model summary

R	R square	Adjusted R square	Standard error of the estimate
0.422[a]	0.178	0.083	17.45607

[a] Predictors: (Constant); M1. Concepts of numbers; M2. Proportionality; M3. Coordinates; M4. Basic geometry; M5. Equations

Table F2. ANOVA[b]

	Sum of squares	df	Mean square	F	Significance
Regression	2,844.802	5	568.960	1.867	0.120[a]
Residual	13,102.719	43	304.714		
Total	15,947.521	48			

[a] Predictors: (Constant); M1. Concepts of numbers; M2. Proportionality; M3. Coordinates; M4. Basic geometry; M5. Equations
[b] Dependent variable: Vector Understanding 1 Dimension

Table F3. Coefficients[a]

	Unstandardized coefficients		Standardized coefficients	t	Significance
	B	Standard error	Beta		
(Constant)	27.363	18.406		1.487	0.144
M1. Concepts of numbers	0.077	0.178	0.076	0.434	0.666
M2. Proportionality	0.103	0.182	0.099	0.562	0.577
M3. Coordinates	0.154	0.157	0.146	0.977	0.334
M4. Basic geometry	0.425	0.211	0.329	2.016	0.050
M5. Equations	–0.068	0.233	–0.052	–0.291	0.773

[a] Dependent variable: Vector Understanding 1 Dimension

APPENDIX G: REGRESSION VI

Table G1. Model summary

R	R square	Adjusted R square	Standard error of the estimate
0.422[a]	0.589[a]	0.347	0.271

[a] Predictors: (Constant); M1. Concepts of numbers; M2. Proportionality; M3. Coordinates; M4. Basic geometry; M5. Equations

Table G2. ANOVA[b]

	Sum of squares	df	Mean square	F	Significance
Regression	6,320.108	5	1,264.022	4.568	0.002[a]
Residual	11,898.962	43	276.720		
Total	18,219.070	48			

[a] Predictors: (Constant); M1. Concepts of numbers; M2. Proportionality; M3. Coordinates; M4. Basic geometry; M5. Equations
[b] Dependent variable: Vector Understanding 2 Dimensions

Table G3. Coefficients[a]

	Unstandardized coefficients		Standardized coefficients	t	Significance
	B	Standard error	Beta		
(Constant)	−4.313	17.540		−0.246	0.807
M1. Concepts of numbers	0.434	0.169	0.399	2.566	0.014
M2. Proportionality	−0.056	0.174	−0.051	−0.323	0.748
M3. Coordinates	0.065	0.150	0.058	0.435	0.666
M4. Basic geometry	0.609	0.201	0.441	3.030	0.004
M5. Equations	0.019	0.222	0.013	0.084	0.933

[a] Dependent variable: Vector Understanding 2 Dimensions

APPENDIX H: SAMPLE TEST QUESTION

M3. Coordinates
Name :
Student ID :
Class :

Plot the following on a coordinate plane:

1. Point A (6, –10)
2. Point B (–5, –6)
3. Point C (0, –14)
4. A triangle with vertices at D (0, 12), E (6, 5), and F (–6, 5)
5. A quadrilateral with vertices at G (–7, 3), H (–7, –3), I (–13, 3), and J (–13, –3)
6. A circle with center at (10, 0) and radius 4