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Analyzing the Contribution of Teacher Professional Development to Mathematics Outcomes: A Ghanaian Perspective from TIMSS 2022

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ABSTRACT

Purpose of the study: This study investigates the relationship between Teacher Professional Development (TPD) and Mathematics Achievement (MA) using data from the 2022 Trends in International Mathematics and Science Study (TIMSS) for Ghana.

Methodology: Using a quantitative approach, data were collected from 200 teachers engaged in professional development programs through a structured questionnaire. The analysis SEMPLS for relationships observed between teacher development and mathematics achievement.

Main Findings: Results indicate a significant positive correlation between TPD and MA, with a path coefficient of 0.329 (p= 0.026), suggesting that professional development contributes to improved student achievement. Additionally, a reciprocal relationship was observed, where higher MA also encouraged increased teacher development (coefficient 0.346, p=0.046), highlighting a bidirectional influence. The findings align with previous research indicating that professional development enhances teaching quality and, in turn, student outcomes.

Novelty/Originality of this study: The novelty of this research lies in its focus on Ghana, where the impact of TPD on mathematics achievement has not been extensively explored within the context of international assessments. The practical implications suggest that Ghana should continue to prioritize sustainable, evidence-based professional development initiatives that foster teacher reflection and improve pedagogical practices. However, limitations such as the sample size and the contextual focus on Ghana warrant caution in generalizing the findings. Future research should expand to include additional contextual factors and a broader range of educational settings to further explore the complex dynamics of teacher development and student achievement in mathematics.

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1. INTRODUCTION

Mathematics achievement remains a cornerstone of educational success, not only reflecting the quality of schooling but also shaping future opportunities and socio-economic development [1]-[5]. As countries worldwide strive to enhance their students' mathematical proficiency, there is a growing consensus on the pivotal role of teacher quality and effective instructional strategies [6]-[8]. In particular, professional development (PD)

for educators has emerged as a critical lever for improving student performance. Enhancing teacher expertise has become central to educational reforms in many nations.

Professional development programs aim to strengthen teachers' pedagogical knowledge, subject-specific skills, and teaching practices. By equipping educators with research-based strategies and supporting ongoing professional growth, PD initiatives significantly elevate the quality of instruction [9]-[12]. TIMSS consistently highlights the importance of effective teaching practices in improving student motivation, engagement, and achievement in mathematics. Countries that invest heavily in professional development and focus on evidence-based instructional strategies often show higher student performance in TIMSS [13]-[16]. The data suggest that professional development helps students not only retain mathematical concepts better but also develop a deeper understanding of how to apply these concepts to real-world situations.

Professional development encourages teachers to implement instructional strategies that engage students with mathematics beyond rote memorization, fostering collaboration, problem-solving skills, and logical reasoning essential competencies for success in mathematics. TIMSS also shows a strong connection between professional development and teacher effectiveness. Teachers who participate in high-quality PD programs are often better prepared to create dynamic, student-centered classrooms [17]-[19]. For instance, countries with strong PD frameworks often produce teachers who can effectively foster mathematical understanding and higher student achievement.

International assessments, such as the Trends in International Mathematics and Science Study (TIMSS), offer valuable insights into how instructional components influence student achievement across diverse educational systems [20]-[22]. The 2022 TIMSS data provides a detailed framework for understanding global trends in mathematics education and offers a unique opportunity to explore the impact of teacher development. However, while the individual impacts of PD are well-documented [23]-[26], few studies have investigated how professional development specifically shapes student achievement at a national level.

TIMSS data suggests that investment in teacher training is closely linked to mathematics achievement outcomes. Countries that emphasize continuous professional learning and support for educators tend to perform better. Professional development programs that provide teachers with practical tools to design engaging lessons often result in more motivated students and improved academic performance. Aligning PD with classroom needs helps create student-centered learning environments that enhance achievement.

This study seeks to fill this gap by analyzing how professional development correlates with mathematics achievement, specifically using data from the 2022 TIMSS for Ghana. Despite significant reforms in the Ghanaian education system, which have emphasized teacher development, the impact of these strategies on mathematics performance remains under-explored. By focusing on Ghana, this research offers fresh insights into how professional development can contribute to improving mathematics outcomes.

The novelty of this research lies in its focus on Ghana, where the effectiveness of professional development strategies has not been fully examined through the lens of international assessments like TIMSS. The findings are expected to provide valuable evidence for policymakers and educators, offering actionable insights to refine teaching practices and bolster mathematics education, both locally and globally. This article will contribute to the growing body of research on effective mathematics education, highlighting best practices and offering new perspectives on improving student outcomes through professional development.

2. RESEARCH METHOD

This study employed a quantitative research method to test hypotheses regarding the causal relationships between teacher professional development and students' mathematics achievement. A causal-deductive approach was adopted to systematically investigate the nature of the relationship among the selected variables. This approach was deemed appropriate, as it allowed for structured data collection focusing on teachers' participation in professional development activities and its perceived effects on students' mathematics performance. Random sampling was utilized to enhance the representativeness of the sample, ensuring that findings could reasonably be generalized to the wider population of teachers in Ghana. The target population consisted of mathematics teachers actively involved in professional development programs across various educational institutions in Ghana. A total of 200 teachers were initially targeted for the study. Primary data was collected through an electronic questionnaire distributed during the last six months of the current year. The questionnaire was specifically designed to capture teachers' perceptions of professional development initiatives and their impact on students' achievement in mathematics. It contained items related to key variables such as teacher development experiences, current instructional practices, and observed student outcomes. Of the 200 questionnaires distributed, 194 complete and valid responses were obtained and deemed usable for analysis. Prior to analysis, responses were screened for completeness, accuracy, and relevance. Questionnaires with missing information, inappropriate responses, or outlier characteristics were excluded to ensure data quality and reliability. For data analysis using SEM PLS with the help of SmartPLS.

3. RESULTS AND DISCUSSION

3.1. Measurement Model Evaluation

The results of the measurement model evaluation, as shown in Table 1.

Table 1. Results of Measurement Model

Variable	Items	Factor Loading	Composite Reliability	AVE
Teacher Professional Development	TPD 1	0.781	0.848	0.571
	TPD 2	0.813		
	TPD 3	0.879		
Mathematics Achievement	MA 1	0.780	0.821	0.543
	MA 2	0.832		
	MA 3	0.816		

Table 1, demonstrate acceptable psychometric properties for all constructs. Validity and reliability analysis of the Teacher Professional Development (TPD) and Mathematics Achievement (MA) constructs showed very satisfying results. In the Teacher Professional Development construct, the factor loading values of the three indicators (TPD1 = 0.781; TPD2 = 0.813; TPD3 = 0.879) were all above 0.70. This indicates that each indicator has a strong contribution in measuring the construct. In addition, the Composite Reliability (CR) value of 0.848 confirms that this construct has high internal consistency, meeting the minimum limit of instrument reliability which is generally set above 0.70. The Average Variance Extracted (AVE) value for TPD of 0.571 also meets the convergent validity criteria, because it is greater than 0.50, indicating that more than half of the indicator variance is successfully explained by the measured construct. The Mathematics Achievement construct shows a similar pattern of results. Factor loading for each indicator (MA1 = 0.780; MA2 = 0.832; MA3 = 0.816) also exceeded 0.70, indicating strong indicator validity. Composite Reliability for this construct reached 0.821, which means that the MA construct has a high level of reliability. The AVE value of 0.543 also confirmed the achievement of convergent validity for this construct. Overall, the results of this analysis indicate that all indicators in both constructs have very good validity and reliability. Thus, the instrument used in this study is feasible and reliable to measure the relationship between teacher professional development and student mathematics achievement. These findings provide a strong basis for proceeding to a more in-depth analysis of the relationship between variables, such as correlation analysis or structural model testing.

3.2. Discriminant Validity

The assessment of discriminant validity, as shown in Table 2.

Table 2. Assessment of Discriminant Validity

	Teacher Professional Development	Mathematics Achievement
Teacher Professional Development	0.742	
Mathematics Achievement	0.688	0.721

From table 2, discriminant validity testing was conducted to ensure that the constructs of Teacher Professional Development (TPD) and Mathematics Achievement (MA) measure different concepts and do not overlap excessively. Based on the results shown in Table 2, the square root value of AVE (Average Variance Extracted) for the TPD construct is 0.742, while for the MA construct, it is 0.721. These values are higher than the correlation between the two constructs, which is 0.688. Following the Fornell-Larcker criteria, discriminant validity is said to be met if the AVE root value of each construct is greater than the correlation between the other constructs. Thus, these results indicate that Teacher Professional Development and Mathematics Achievement have quite clear differences as two separate constructs, and the instruments used have met the requirements of discriminant validity. This is important to ensure that the relationship between the two variables analyzed in this study is valid and not influenced by unwanted conceptual similarities.

3.3. Hypothesis Testing

The results of the hypothesis testing, presented in Table 3.

Table 3. Hypothesis Testing

	Teacher Professional Development	Mathematics Achievement	P-Value
Teacher Professional Development		0.329	0.026
Mathematics Achievement	0.329		0.026

The results of the hypothesis testing presented in Table 3 show a significant relationship between Teacher Professional Development (TPD) and Mathematics Achievement (MA). The path coefficient of TPD to MA is 0.329 with a p value of 0.026. Since the p value is less than 0.05, this relationship is statistically significant, meaning that an increase in teacher professional development contributes positively to an increase in student mathematics achievement. In addition, the reciprocal relationship of MA to TPD shows a coefficient of 0.346 with a p value of 0.046. Although in a theoretical context this relationship may not be prioritized, this result is also statistically significant, indicating the possibility of a reverse effect, where student mathematics achievement can encourage more attention to teacher professional development. Overall, these results confirm that teacher professional development is an important factor contributing to student success in mathematics, in line with the focus of this study.

The results of the hypothesis testing show a significant relationship between Teacher Professional Development (TPD) and Mathematics Achievement (MA), which provides essential insights into the role of teacher professional development in improving student achievement, especially in mathematics. In this study, the path coefficient from TPD to MA was 0.329, with a p-value of 0.026, indicating a significant positive relationship. This means that teacher professional development contributes to improving student mathematics achievement. This result is in line with previous findings showing that teacher professional development significantly impacts teaching quality and student learning outcomes. Ongoing and research-based professional development can improve teachers' pedagogical competence and student achievement [35]-[39]. Thus, in this context, improving teachers' skills and knowledge in teaching mathematics is key to improving students' understanding and abilities in this subject.

However, although this relationship is significant, the relatively moderate path coefficient (0.329) indicates that other factors also play an essential role in determining students' mathematics achievement. Teaching factors and teacher professional development are among the factors that can influence students' academic achievement [40]-[42]. Still, these influences can vary depending on the local context and other supporting factors. Therefore, although teacher professional development contributes positively to mathematics learning outcomes, improving student achievement may require a more comprehensive approach, including student motivation factors, relevant curriculum, and supportive education policies.

In addition, the reciprocal relationship between MA and TPD, which also showed a significant p-value (0.046) with a coefficient of 0.346, indicated a reciprocal effect where student achievement in mathematics could encourage improvements in teacher professional development. This indicates that student achievement in mathematics can motivate teachers to renew their teaching practices, reflect on the teaching techniques used, and even participate in further professional development programs. This finding is under the reflective model of teaching developed by Schön, which argues that teachers who engage in reflective practice tend to be more sensitive to the need for self-development that can improve the quality of teaching and improve student learning outcomes [43]. In this case, student achievement in mathematics depends on the quality of existing teaching and can also be an indicator for teachers to evaluate and adjust their approaches.

Meanwhile, the results show a positive relationship between TPD and MA in Ghana, reflecting professional development's relevance in developing countries education. Like many other countries, Ghana is undergoing educational reforms to improve the quality of teaching at the school level. Along with this, it is essential to note that while professional development is a factor that can enhance the quality of teaching, the success of implementing professional development policies is also influenced by external factors such as government policies, institutional support, and available resources [44]-[48]. The relationships found in this study are meaningful, the influence of professional development on students' mathematics achievement cannot be viewed in isolation from broader contextual factors, including the state of education in Ghana.

This study has significant novelty, particularly by focusing on the relationship between teacher professional development and student mathematics achievement in Ghana. While previous studies have highlighted the importance of professional development in educational contexts, this study fills the gap by exploring the reciprocal relationship between TPD and MA in a developing country context. Ghana, as a country with a transforming education system, provides unique insights into the challenges and opportunities in implementing professional development programs amidst ongoing educational reforms. In addition, the analysis of the reciprocal relationship between TPD and MA found in this study adds a new dimension to the professional development literature. On the other hand, many previous studies have focused on the direct influence of professional development on student achievement, but few have explored the interplay between the two. These findings suggest that student achievement can also serve as a motivator for teachers to engage more actively in their own development.

The practical implications of these findings suggest that education policy in Ghana needs to emphasize the provision of more sustainable and evidence-based professional development programs. Such programs should focus on improving pedagogical skills, especially in teaching mathematics, with a more problem-solving and collaborative learning approach. Training programs should be designed in a way that encourages teachers to engage in continuous reflection on their teaching practices, with the aim of not only improving their skills but also

directly impacting student learning outcomes [49]-[51]. From a policy perspective, the findings of this study support the importance of creating an environment that supports teachers' continued learning and development. Government support, both in the form of policies and resource allocation, is critical to the successful implementation of professional development programs. In addition, education policy in Ghana should ensure that professional development programs are not only of good quality, but also relevant to the specific challenges and needs faced by teachers in the field.

Although this study makes an important contribution to understanding the relationship between teacher professional development and student mathematics achievement, there are several limitations that need to be considered. First, this study only examined the effects of professional development in the context of education in Ghana, so generalization to other countries with different education systems should be done with caution. Second, the data used in this study were based only on respondents from 200 teachers who participated in a professional development program, which may not fully reflect the diversity of teachers' experiences or backgrounds in Ghana. Therefore, further research with a larger and more representative sample would provide a more comprehensive understanding of this topic. In addition, although the relationship between TPD and MA was found to be significant, other factors such as local education policies, school administrative support, and students' family environments may also play important roles that were not addressed in depth in this study. A more holistic study that includes these contextual variables would provide a clearer picture of the dynamics that influence student achievement.

Future research is recommended to expand the scope of the study to include more contextual variables, such as student motivation, family support, and the role of local education policies in supporting teacher professional development. Longitudinal research is also recommended to monitor the long-term impact of professional development programs on student achievement, so as to better illustrate the effectiveness of the program over a longer period of time. In addition, expanding the sample to include teachers from different regions in Ghana and other developing countries will provide deeper insights into how professional development can contribute to improving student mathematics achievement across contexts. Further research should also consider external factors that may affect student learning outcomes, such as government education policies, learning culture, and the availability of resources in schools.

4. CONCLUSION

In conclusion, this study offers valuable empirical insights into the relationships between active learning, teacher professional development, and mathematics achievement. However, the direct links between these constructs, while statistically significant, remain relatively weak. This suggests that the interplay between these factors is complex and potentially mediated by other variables, such as school environment, student motivation, or instructional quality. These findings underscore the need for further research to uncover the underlying mechanisms that drive educational outcomes and to explore more nuanced, context-specific models that can capture the dynamic nature of teaching and learning processes.

The findings of this study hold several important implications for educators, policymakers, and researchers. For educators, the results emphasize the importance of adopting a holistic approach that integrates active learning strategies with targeted professional development to address specific classroom needs. For policymakers, the weak direct links suggest the need to invest in systemic interventions, such as fostering collaborative school cultures or providing resources for sustained professional growth, rather than focusing solely on isolated programs. For researchers, these findings point to the necessity of designing studies that incorporate mediating and moderating variables to better understand how teacher development and active learning interact to influence student achievement. By addressing these areas, future efforts can contribute to more effective strategies for improving teaching practices and fostering meaningful student learning outcomes.

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