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Mathematical Self-Efficacy Mediating the Relationship Between Motivation, Anxiety, and Achievement

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Earlier studies on mathematical self-efficacy, motivation, anxiety, and mathematics achievement have shown significant controversies; however, mathematics achievement is highly important. This study adopts a quantitative research method, with a sample of 5,464 15-year-old secondary school students from 175 schools in Hong Kong. The aim is to explore the mediating role of mathematical self-efficacy in the relationship between motivation, anxiety, and mathematical achievement, and to analyze the moderating effects of gender and grade on this relationship.This study found that mathematics self-efficacy played a negative role between mathematics anxiety and mathematics performance, and played a completely positive role between mathematics motivation and mathematics performance. For Hong Kong secondary school students around 15 years old, there were significant differences in mathematics motivation and self-efficacy among students of different grades. As the grade increased, students' mathematics motivation and self-efficacy gradually increased. However, gender did not show a significant moderating effect on this. This study provides a new perspective for understanding the complex relationships among these variables, offers a theoretical basis for personalized education and tiered intervention strategies, and contributes to promoting adolescents' mental health and improving mathematics instruction.

Keywords: anxiety, learning motivation, mathematical achievement, mathematical self-efficacy, learning

INTRODUCTION

Anxiety is one of the most common mental health issues globally, and math anxiety is among the most prominent and widespread problems in educational settings across all age groups (Luttenberger et al,, 2018). Previous studies have found that self-efficacy and motivation significantly predict math achievement (Kriegbaum & Spinath, 2015). Different levels of math academic achievement shape students' motivation through distinct experiences (Prast et al., 2018).

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However, the literature on achievement and motivation remains limited. Although many studies have examined the relationships among self-efficacy, motivation, math anxiety, and academic achievement, the results have been inconsistent (Prast et al., 2018; Süren & Kandemir, 2020). While numerous studies attempt to explain math achievement, few delve deeply into the relationships between variables and how they collectively explain math achievement (Rodríguez et al., 2017; Zou & Mustakim, 2024). Therefore, investigating the relationships between math anxiety, self-efficacy, motivation, and academic performance is necessary.

Self-efficacy is a construct focusing on an individual' s assessment of their ability to successfully perform a task in a given situation (Waddington, 2023). Research has shown a significant positive correlation between students' self-efficacy and academic performance (Shores & Shannon, 2007; Rodríguez et al., 2017; Zou & Mustakim, 2024). Math anxiety has been found to be highly negatively correlated with math self-efficacy, and lower math self-efficacy, along with female gender, predicts higher math anxiety (Rozgonjuk et al., 2020).

Earlier studies have indicated relationships among motivation, anxiety, and academic performance (Shores & Shannon, 2007). Motivation shows a moderate positive correlation with math academic achievement (Süren & Kandemir, 2020). There is a small-to-moderate significant negative correlation between math anxiety and math achievement, with grade level moderating this relationship (Barroso et al., 2021). A moderate negative correlation exists between students' math motivation and math anxiety (Li et al., 2021). Middle school students exhibit high levels of both math anxiety and motivation (Süren & Kandemir, 2020). Academic performance significantly differs by gender and grade level, and students' self-efficacy also shows significant differences based on grade level (Zou & Mustakim, 2024).

Previous research has explored factors influencing students' math performance, but these studies remain controversial and insufficient. Therefore, this study further investigates the mediating effect of math self-efficacy in the relationships among motivation, anxiety, and math achievement among Hong Kong secondary school students around the age of 15. Additionally, it examines differences in math anxiety, self-efficacy, and math motivation among students of different genders and grade levels to identify strategies to promote psychological well-being and improve math performance among Hong Kong students.

METHOD

Sample

This study uses secondary data from PISA 2022, which aimed to assess the mathematical, scientific, and reading literacy of 613,744 15-year-old students from 81 countries and economies during the 2021-2022 period. The researchers employed a two-stage stratified random sampling method. In the first stage, 175 schools were selected where 15-year-old students were enrolled. In the second stage, 42 eligible 15-year-old students were randomly selected from each chosen school (if the number of eligible students was fewer than 42, all eligible students were selected). According to data from

the Hong Kong Education Bureau (2021), the target population of this study is 49144 15-year-old students from Hong Kong. The target sample consisted of 5,907 samples, and after data cleaning and screening, a total of 5,464 valid samples from grades 7 to 12 were included in this study, with 2,674 males (51.1%) and 2,790 females (48.9%), distributed across grades as follows: 7th grade (3.5%), 8th grade (30.5%), 9th grade (65.4%), and 10th grade (0.7%).

Data Analysis

This study adopted a quantitative research method. In this study, the researchers used Mplus 8.3 to conduct structural equation modeling (SEM) and analyzed gender-based differences in anxiety, motivation, and self-efficacy using R. They also created a Multilevel Structural Equation Modeling path diagram. SPSS 27.0 was used to analyze the differences in anxiety, motivation, and self-efficacy based on different grade levels. This study aims to explore the effects of mathematical learning motivation, anxiety, and self-efficacy on the mathematics achievement of secondary school students and to analyze the moderating effects of gender and grade level. Specifically, the study aims to explore: (1) the impact of mathematical learning motivation and mathematical anxiety on the mathematics achievement of Hong Kong secondary school students; (2) the effects of mathematical learning motivation and mathematical anxiety on mathematics achievement through mathematical self-efficacy; and (3) the differences in mathematical motivation, anxiety, and self-efficacy based on gender and grade level.

Ethical Considerations

The original data were approved by the relevant ethics committees, and consent was obtained from the students' parents before participation, upholding the principles of privacy and confidentiality in the collection and analysis.

FINDINGS

The direct and indirect effects between anxiety, learning motivation, self-efficacy, and mathematical achievement

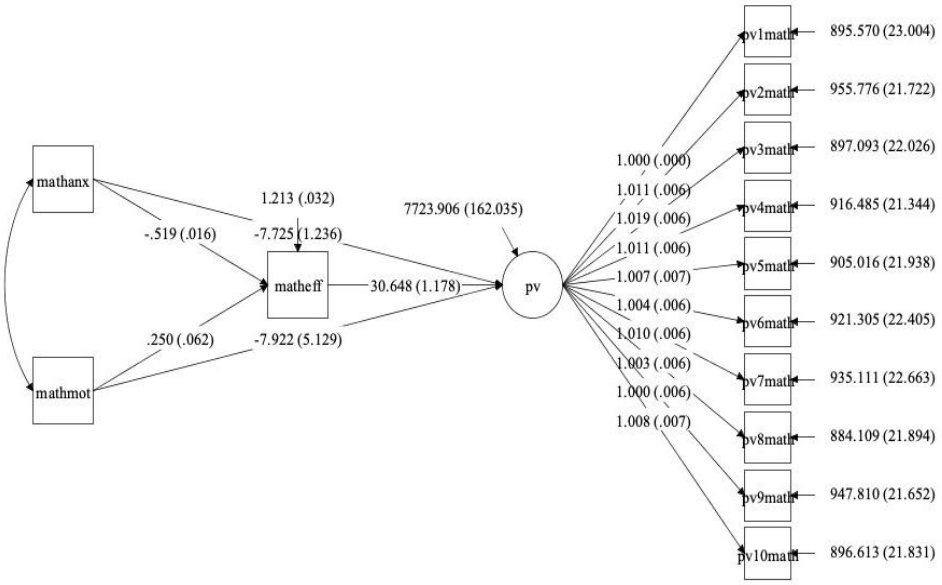

Figure 1
The direct and indirect effects SEM model diagram between anxiety, motivation, self-efficacy, and mathematical achievement.

Table 1
Results of direct effects test

Path	Estimate	S.E.	95%IC		Results
			LL	UL	
MATHANX→MATHEFF	-0.519***	0.016	-0.510	-0.453	support
MATHMOT→MATHEFF	0.250***	0.062	0.015	0.068	support
MATHEFF→PV	30.648***	1.178	0.355	0.416	support
MATHANX→PV	-7.725***	1.236	-0.128	-0.067	support
MATHMOT→PV	-7.922	5.129	-0.052	0.002	not support

Path represents the relationship path between different variables, while Estimate represents the magnitude of the interaction between variables. S.E. (Standard Error) represents the accuracy of the estimate, and the smaller the S.E., the more accurate the estimate. 95% IC (95% Confidence Interval) represents the range of Estimate, LL (Lower Limit) is the lower limit of Confidence Interval, and UL (Upper Limit) is the upper limit of Confidence Interval. Results represents the result of hypothesis testing, support indicates the significance of the relationship between variables, and not support indicates no significant relationship between variables. Based on the results in the table, the coefficient values of the influences of MATHANX and MATHMOT on MATHEFF are -0.519 and 0.250, respectively, both significant at the 1% level. This indicates that MATHANX has a significant negative effect on MATHEFF, while MATHMOT has a significant positive effect on MATHEFF. The coefficient values of MATHEFF and

MATHANX on PV are 30.648 and -7.725, respectively, both significant at the 1% level. This shows that MATHEFF has a significant positive effect on PV, while MATHANX has a significant negative effect on PV. The coefficient value of MATHMOT on PV is -7.922, which is not significant at the 5% level.

Table 2
Results of indirect effect test (Bootstrap)

Path	Effect	Estimate	S.E.	95%IC		Results
				LL	UL	
MATHANX→MA	Direct	-0.079	0.013	-10.756	-5.644	Some
THEFF→PV	Indirect	-0.162	0.007	-17.676	-14.613	intermediaries
MATHMOT→MA	Direct	-0.081	0.052	-21.582	0.668	Fully
THEFF→PV	Indirect	-0.078	0.020	2.353	10.771	Intermediate

Based on the Bootstrap test results, in the path MATHANX → MATHEFF → PV, the 95% confidence interval for the Direct effect is [-10.756, -5.644], and for the Indirect effect, it is [-17.676, -14.613]. Since neither confidence interval includes 0, it indicates that MATHEFF plays a mediating role in the effect of MATHANX on PV, and this is a partial mediation. In the path MATHMOT → MATHEFF → PV, the 95% confidence interval for the Direct effect is [-21.582, 0.668], and for the Indirect effect, it is [2.353, 10.771]. The confidence interval for the Indirect effect does not contain 0, but the confidence interval for the Direct effect does include 0, indicating that MATHEFF plays a mediating role in the effect of MATHMOT on PV, and this is a full mediation.

The Moderating Effect of Gender on Math Anxiety, Motivation, and Self-Efficacy

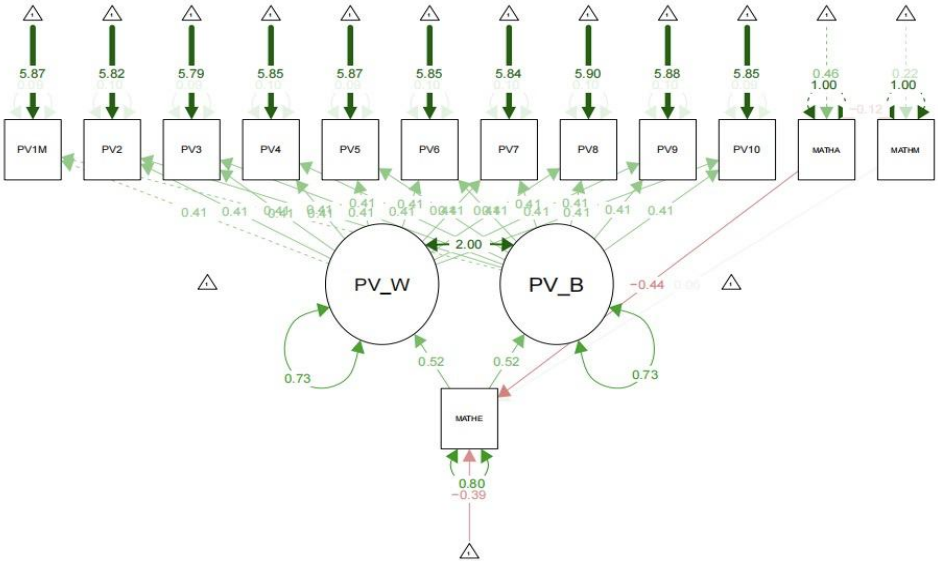

Figure 4
Multilevel Structural Equation Model of Anxiety, Motivation, and Self-Efficacy Differences Based on Male Students

Figure 4 shows the characteristics of anxiety, motivation, and self-efficacy in the male group.

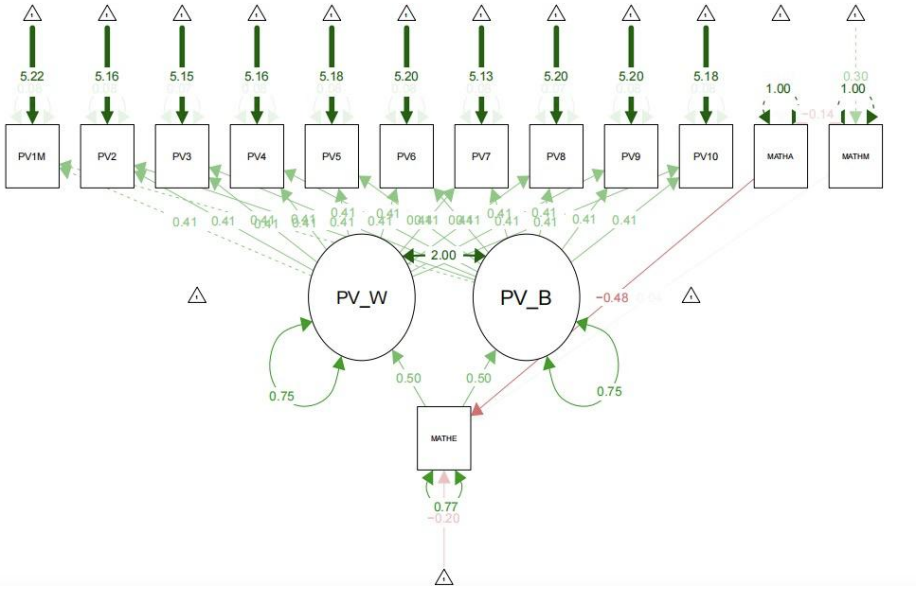

Figure 5
Multilevel Structural Equation Model of Anxiety, Motivation, and Self-Efficacy Differences Based on Female Students.

Figure 5 illustrates the characteristics of anxiety, motivation, and self-efficacy in the female group.

Table 3
Differences in anxiety, learning motivation, and self-efficacy based on gender

Gender	Path	Estimate	Relationship Type	Result
Female	MATHANX→MATHEFF	-0.48	Direct Effect	support
	MATHMOT→MATHEFF	0.04	Direct Effect	invalid
	MATHEFF→PV_W、PV_B	0.50	Direct Effect	support
	MATHANX → MATHEFF → PV_W、PV_B	-0.24	Indirect Effects	negative
	MATHMOT → MATHEFF → PV_W、PV_B	0.02	Indirect Effects	invalid
	PV_W→PV_B	2.0	Cross-correlation	strong
	MATHEFF→MATHEFF	0.77	Autocorrelation	strong
	PV_W→PV_W	0.75	Autocorrelation	stability
	PV_B→PV_B	0.75	Autocorrelation	stability
Male	MATHANX→MATHEFF	-0.44	Direct Effect	support
	MATHMOT→MATHEFF	0.06	Direct Effect	invalid
	MATHEFF→PV_W、PV_B	0.52	Direct Effect	support
	MATHANX → MATHEFF → PV_W、PV_B	-0.229	Indirect Effects	negative
	MATHMOT → MATHEFF → PV_W、PV_B	0.03	Indirect Effects	invalid
	PV_W→PV_B	2.0	Cross-correlation	Strong
	MATHEFF→MATHEFF	0.80	Autocorrelation	Strong
	PV_W→PV_W	0.73	Autocorrelation	stability
	PV_B→PV_B	0.73	Autocorrelation	stability

Table 3 reveals the path relationships between variables based on gender and grade level. As shown in the figure, for the female group, there is a significant negative correlation between MATHANX and MATHEFF (-0.48), indicating that as MATHANX increases, MATHEFF significantly decreases. The effect of MATHMOT on MATHEFF is small and not significant (0.04).

The direct effects of MATHEFF on PV_W and PV_B are significantly positively correlated (0.50), suggesting that higher self-efficacy in students results in better mathematical achievement both within grades and across different grades. The indirect effect of MATHANX → MATHEFF → PV_W and PV_B is -0.24, indicating that MATHANX can negatively influence students' academic performance through MATHEFF. The indirect effect of MATHMOT on academic performance through MATHEFF is almost negligible (0.02). There is a strong correlation (2.0) between academic performance, indicating that academic performance within and between grades (PV_W and PV_B) is highly correlated. MATHEFF and PV_W and PV_B exhibit strong self-reinforcing effects, indicating a high level of self-maintenance of students' MATHEFF.

For males, the effect of MATHANX on MATHEFF is a significant negative correlation (-0.44), indicating that anxiety has a significant negative impact on male students' self-efficacy. The effect of MATHMOT on MATHEFF is very small and nearly ineffective (0.06). The direct effects of MATHEFF on PV_W and PV_B are significantly positively correlated (0.52), similar to the female results, indicating that self-efficacy also has a positive effect on male students' academic performance. The indirect effect of MATHANX through MATHEFF on academic performance is negatively correlated (-0.229), showing that higher anxiety leads to lower self-efficacy, thus affecting students' academic performance both within and across grades. The indirect effect of MATHMOT through MATHEFF on academic performance is almost negligible (0.03). PV_W and PV_B also exhibit a strong positive correlation (2.0). MATHEFF → MATHEFF is 0.80, and PV → PV_W is 0.73, showing strong self-reinforcement effects of MATHEFF and academic performance, indicating a high level of self-stability.

PV_W within grades shows strong stability and consistency (PV_W → PV_W is 0.75), suggesting that academic performance within grades is relatively stable. Between grades, the differences in PV_B show a significant positive correlation (2.0) for both males and females between PV_W and PV_B.

The Moderating Role of Grade Level on Math Anxiety, Motivation, and Self-Efficacy

Table 4
Differences in anxiety, motivation, and self-efficacy across grades

Methods	Comparison	Grade	N	Mean Rank/Test statistic	S.E./df	Standardized statistics	Sign.(p)	Results
Wilcoxon Signed-Rank Test	Differences in anxiety and self-efficacy among students in the same grade	Same grade	5464	4448821.000	116609.792	Z=-25.867	0.000	support
Kruskal-Wallis H Test	Anxiety between different grades (MATHANX)	7	189	Mean Rank=2709.93	df=3	H=5.963	0.113	not support
		8	1665	Mean Rank=2809.66				
		9	3572	Mean Rank=2699.37				
		10	38	Mean Rank=2578.22				
	Motivation among different grades (MATHMOT)	7	189	Mean Rank=2642.23	df=3	H=19.466	0.00	support
		8	1665	Mean Rank=2681.84				
		9	3572	Mean Rank=2761.24				
		10	38	Mean Rank=2699.29				
	Self-efficacy among different grades (MATHEFF)	7	189	Mean Rank=2420.63	df=3	H=24.266	0.00	support
		8	1665	Mean Rank=2630.06				
		9	3572	Mean Rank=2790.67				
		10	38	Mean Rank=3304.71				

Table 4 presents the test results for the differences in MATHANX, MATHMOT, and MATHEFF within the same grade and between different grade levels.

As shown in the table, within the same grade, the Wilcoxon Signed-Rank test yielded a Z value of -25.867 and a p-value of 0.000 ($P < 0.05$), indicating a significant difference between MATHANX and MATHEFF among students within the same grade. Therefore, this result supports the hypothesis that there are differences between anxiety and self-efficacy within the same grade.

Between different grade levels, the Kruskal-Wallis H test found that for anxiety, the mean ranks of MATHANX were: 7th grade 2709.93, 8th grade 2809.66, 9th grade 2699.37, and 10th grade 2578.22. The H value was 5.963 with 3 degrees of freedom, and the p-value was 0.113, which did not reach the significance level ($p > 0.05$). Thus, there is no significant difference in MATHANX between different grade levels, which does not support the hypothesis of anxiety differences between grades.

For motivation (MATHMOT), the mean ranks were: 7th grade 2642.23, 8th grade 2681.84, 9th grade 2761.24, and 10th grade 2699.29. The H value was 19.466 with 3 degrees of freedom, and the p-value was 0.00 ($p < 0.05$), indicating a significant difference in MATHMOT between grade levels, supporting the hypothesis of differences in learning motivation across grades.

For self-efficacy, the mean ranks of MATHEFF were: 7th grade 2420.63. The data for 8th, 9th, and 10th grades were not fully listed. The H value was 24.266 with 3 degrees of freedom, and the p-value was 0.00, which is less than 0.05, indicating a significant difference in MATHEFF between different grade levels, supporting the hypothesis of differences in self-efficacy across grades.

Therefore, within the same grade, there is a significant difference between anxiety and self-efficacy; while there is no significant difference in mathematical anxiety between grades, there are significant differences in learning motivation and self-efficacy across different grade levels.

DISCUSSION

In summary, the study found a significant positive correlation between mathematics learning motivation and self-efficacy among Hong Kong secondary school students, as well as a positive correlation between self-efficacy and math achievement (Shores & Shannon, 2007; Rodríguez et al., 2017; Zou & Mustakim, 2024). However, learning motivation was not found to have a significant direct impact on math achievement. This finding supports the theory of Shores and Shannon (2007) but contradicts Rozgonjuk et al. (2020), who suggested a moderate positive correlation between motivation and math academic achievement, possibly due to differences in the study population. Therefore, this study concludes that higher self-efficacy leads to better math performance. Although learning motivation does not directly influence academic achievement, students with stronger math motivation often exhibit higher math self-efficacy, which in turn affects academic performance.

The study also revealed a significant negative correlation between math anxiety and math achievement (Barroso et al., 2021) and a positive correlation between self-efficacy and academic performance (Kriegbaum & Spinath, 2015). Anxiety directly or indirectly negatively impacts students' math performance through self-efficacy. Thus, anxiety has both direct and indirect significant effects on the math performance of Hong Kong secondary school students. Higher levels of anxiety are associated with lower self-efficacy and poorer math performance (Rozgonjuk et al., 2020).

No significant gender differences were found in anxiety, motivation, or self-efficacy. Math anxiety showed no significant differences across grade levels and remained relatively stable. However, significant differences in anxiety levels were observed within the same grade. Math motivation significantly differed across grade levels, with motivation and self-efficacy gradually increasing as grade level advanced. Significant differences in math self-efficacy were observed both within the same grade and across different grade levels. These findings contradict the conclusions of many researchers (Rozgonjuk et al., 2020; Barroso et al., 2021; Zou & Mustakim, 2024). Therefore, the

differences in anxiety, motivation, and self-efficacy based on gender and grade level remain complex. Given the intricate mechanisms affecting math achievement, this study provides both theoretical and practical insights by demonstrating that self-efficacy serves as a crucial mediator between motivation, anxiety, and achievement. The findings highlight that although motivation alone does not directly predict achievement, its influence operates through self-efficacy, emphasizing the importance of fostering students' confidence in their mathematical abilities. Furthermore, the significant negative impact of anxiety on self-efficacy and achievement suggests that interventions aimed at reducing anxiety may indirectly enhance academic performance. These insights extend previous research by clarifying the indirect pathways through which psychological factors shape math achievement and offer practical implications for educational strategies that focus on building self-efficacy while mitigating anxiety.

This study focused on secondary school students around the age of 15 in Hong Kong, which may pose limitations in terms of regional and age group applicability. The findings may not be generalizable to students from other regions or age groups. Moreover, the study did not delve deeply into external factors such as family relationships and school resources, which may interact with anxiety, motivation, and self-efficacy to collectively influence mathematics achievement. Due to the complexity of individual differences and family backgrounds, this study may not fully explain the specific effects of these variables on mathematics achievement. Therefore, the findings should be interpreted with caution, and further exploration is warranted.

Future research is encouraged to expand the sample scope to include students from different regions, countries, and broader age groups to validate the generalizability of the results. Additionally, employing multidimensional analysis methods to examine a wider range of potential factors influencing mathematics achievement is recommended. Interventional studies could also be designed to evaluate the effectiveness of strategies aimed at reducing mathematics anxiety and enhancing self-efficacy and motivation. Such efforts would provide a more comprehensive explanation of the complex relationships among the study variables and offer more actionable guidance for educational practice.

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