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Path Analysis of Teachers' Cognitive Activation and Students' Mathematics Achievement in PISA 2022 Indonesia

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ABSTRACT

Data PISA 2022 menunjukkan skor capaian matematika Indonesia sangat rendah, sebesar 366, dan peringkat 70 dari 81 negara, sehingga perlu dilakukan identifikasi faktor-faktor yang memengaruhi capaian matematika siswa. Berdasarkan kerangka teaching quality, aktivasi kognitif merupakan dimensi yang paling berpengaruh dalam meningkatkan capaian matematika karena mendorong siswa untuk berpikir mendalam, menalar konsep, dan menyelesaikan masalah yang kompleks, dibandingkan dengan peran guru ataupun manajemen kelas.Penelitian sebelumnya umumnya menguji hubungan langsung antarvariabel, sedangkan penelitian ini menambahkan jalur mediasi iklim disiplin, dukungan guru, dan perilaku proaktif matematika sebagai bentuk adaptasi kontekstual. Penelitian ini merupakan penelitian kuantitatif dengan data PISA 2022 Indonesia yang diikuti oleh 13.439 siswa dari 410 sekolah, tetapi hanya menggunakan sampel jawaban lengkap sebanyak 12.209 siswa dari 410 sekolah. Data dianalisis menggunakan model mediasi analisis jalur berbasis structural equation model (SEM) dengan metode estimasi parameter maksimum likelihood, dan standard error bagi penduga parameter diperoleh dari 1.000 sampel bootstrap. Validasi model dilakukan melalui analisis faktor konfirmatori dengan indeks kecocokan CFI < 0,90 dan RMSEA < 0,08, yang menunjukkan kesesuaian model yang baik. Hasil penelitian menunjukkan bahwa aktivasi kognitif dan jenis kelamin berpengaruh langsung dan tidak langsung terhadap capaian matematika melalui iklim disiplin dan perilaku proaktif. Status sosial ekonomi dan budaya juga berpengaruh melalui perilaku proaktif matematika. Siswa laki-laki memiliki skor lebih rendah dalam iklim disiplin, perilaku proaktif matematika, dan capaian matematika dibandingkan dengan siswa perempuan. Temuan ini menegaskan pentingnya pembelajaran berbasis aktivasi kognitif serta kebijakan peningkatan kapasitas guru dalam menciptakan iklim belajar yang disiplin, suportif, dan menumbuhkan penalaran matematis siswa.

PISA 2022 data show that Indonesian students' mathematics performance remains low, with an average score of 366 and ranking 70th out of 81 participating countries. This highlights the need to identify factors influencing students' mathematics achievement. Based on the teaching quality framework, cognitive activation is considered the most influential dimension in improving mathematics performance because it encourages students to think deeply, reason conceptually, and solve complex problems, beyond the effects of teacher support or classroom management. Previous studies mainly examined direct relationships among variables, while this study adds the mediating roles of disciplinary climate, teacher support, and proactive mathematics behavior as a form of contextual adaptation. This quantitative study used data from PISA 2022 Indonesia involving 13,439 students from 410 schools, with 12,209 students providing complete responses. Data were analyzed using a path mediation model based on structural equation modeling (SEM) with maximum likelihood estimation, and standard errors were obtained from 1,000 bootstrap samples. Model validation was conducted through confirmatory factor analysis, showing good model fit with CFI > 0.90 and RMSEA < 0.08. The *results indicate that cognitive activation and gender have both direct and indirect effects on mathematics achievement through disciplinary climate and proactive behavior. Socioeconomic and cultural status also influence achievement through proactive mathematics behavior. Male students scored lower in disciplinary climate, proactive behavior, and mathematics performance compared to female students. These findings emphasize the importance of cognitively activating instruction and teacher capacity-building policies to foster disciplined, supportive learning environments that enhance students' mathematical reasoning.*

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INTRODUCTION

Education plays a role in improving the quality of human resources, which is the main key to a nation's progress. In Indonesia, education serves as a foundation for national development (Safitri et al., 2022). However, the quality of education in Indonesia still lags behind other countries. According to the 2022 Programme for International Student Assessment (PISA) survey, Indonesia's education quality is ranked low, which is reflected in the achievement scores for reading, mathematics, and science at ranks 71, 70, and 67, respectively (OECD, 2023).

PISA, organized by the Organization for Economic Co-operation and Development (OECD), evaluates the abilities of 15-year-old students worldwide in reading, mathematics, and science (OECD, 2024b). Over the years, Indonesia's mathematics performance has shown limited improvement, with persistent challenges in mathematical reasoning and problem solving. In 2012, Indonesia scored 375 compared to the OECD average of 494; in 2015, 386 compared to 490; and in 2018, 379 compared to 489 (OECD, 2019). The 2022 results reveal a further decline to 366, far below the OECD average of 472, placing Indonesia 70th among 81 countries (OECD, 2023). These outcomes underline the need for a deeper understanding of the factors that influence students' mathematics achievement.

Mathematics plays an essential role in developing scientific literacy and supporting technological progress (Siagan, 2016). It provides a framework for logical reasoning and quantitative decision-making that is crucial for addressing complex problems in various disciplines (Celestine et al., 2024).

Students' mathematics achievement measured in PISA can be influenced by a variety of factors (Pakpahan, 2017). Research conducted by Umar & Miftahuddin (2012) identified three groups of variables that affect student learning outcomes, affective development, and behavior, namely personal variables, instructional variables, and environmental variables. Among these, instructional quality—particularly teacher effectiveness—plays a central role in shaping student learning outcomes. In mathematics learning, the quality of teacher instruction has a significant impact on students' interest and learning achievement (Ambussaidi & Yang, 2019).

Based on the theoretical model developed by Klieme et al. (2009)), there are three fundamental dimensions of teaching quality identified: cognitive activation, classroom management, and supportive classroom climate. Cognitive activation refers to teaching practices that challenge students to engage in deep thinking, reasoning, and problem solving. Studies have shown that cognitively stimulating tasks promote conceptual understanding and higher-order reasoning (Klieme et al., 2009). Research by Zhang et al. (2021) was conducted to analyze the mediating role of mathematical interest and perseverance on the effects of cognitive activation on mathematical achievement using 25,969 students from 86 schools in central China. The results of this study reported that cognitive activation was positively related to students' mathematical achievement.

OECD (2024a) further emphasizes that cognitive activation strategies, such as encouraging connections between new and prior knowledge or exploring multiple solution pathways substantially enhance students' mathematical learning. However, the effectiveness of such instruction also depends on students' proactive engagement. Low-achieving students, in particular, tend to demonstrate less proactive learning behavior, which may weaken the impact of cognitively demanding instruction

In addition to instructional factors, demographic and contextual variables such as gender and socioeconomic background also influence mathematics performance. OECD (2024a) reported that female students in Indonesia scored six points higher than males in mathematics. Similar findings were obtained by Karn et al. (2023) in Pakistan, suggesting that gender differences may reflect social and motivational factors rather than cognitive ability. Furthermore, OECD (2024a) found that Indonesian students from higher socioeconomic backgrounds scored 34 points higher in mathematics than their less advantaged peers, consistent with findings from Oyelami et al. (2024) in Nigeria, who highlighted the role of parental socioeconomic status in shaping students' academic success.

School-level environmental factors, such as disciplinary climate and teacher support, also contribute to learning effectiveness. Ning (2020) analyzed the relationship between school disciplinary climate and mathematics achievement using PISA 2012 data in Shanghai and found that a positive disciplinary climate significantly improved students' mathematics outcome. OECD (2024a) further found that teacher support strongly correlates with improved learning outcomes, particularly among students who face academic difficulties.

The use of mediation variables to connect independent variables and dependent variables has been explored in prior studies. Koğar (2015) examined the mediating roles of disciplinary climate and teacher support in the relationship between gender, socioeconomic status, and academic achievement using Turkey's PISA 2012 data, finding significant mediation effects. Zhang et al. (2021) applied a path analysis mediation model to examine how cognitive activation in mathematics teaching affects mathematics achievement through the mediating roles of interest and perseverance, showing both direct and indirect effects.

While previous studies have examined these factors separately, limited research has integrated them into a comprehensive mediation framework, particularly within the Indonesian context. Therefore, this study aims to analyze the relationship between gender, economic social and cultural status (ESCS), and cognitive activation in mathematics teaching on students' mathematics achievement through the mediation of disciplinary climate, teacher support, and proactive behavior in mathematics, using PISA 2022 data from Indonesia.

METHOD

This study used a quantitative approach since the PISA 2022 survey yielded quantitative data that can be analyzed through statistics. The sample for PISA 2022 Indonesia consists of 13,439 students and 410 schools.

Data Source

This research used secondary data from PISA 2022 results which is available on the OECD website (https://www.oecd.org/en/data/datasets/pisa-2022-database.html). PISA data contains individual responses from students, teachers, school principals, and parents. The variable used in this study is the mathematic achievement score as the dependent variable, which is calculated as the average (mean) value of ten available Plausible Values in mathematics. In addition, the predictor in this study consists of gender, socio-cultural status (ESCS), and cognitive activation in mathematics teaching, while the mediating variable was disciplinary climate, teacher support, and proactive behavior in mathematics. The definition and measurement of each independent and mediating variable are presented in Table 1.

Table 1. Variables used in this study

Role	Variable name	Explanation	Code
Dependent	Mathematics achievement	The arithmetic mean of the ten plausible values in mathematics (OECD, 2024b)	PV1MATH-PV10MATH
Role	Variable name	Explanation	Code
Independent	Gender	A (re-coded) dummy for student's gender: 0 = male; 1 = female	ST004D01T

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Independent	Economic, Social, and Cultural Status (ESCS)	A standardized index representing students' background that consists of parents' higher education (HISEI), parents' occupation (PARED), and house possession (HOMEPOS) (OECD, 2024b)	ESCS
Independent	Cognitive Activation in Mathematics Teaching	An index created by students' responses to several statements about how often mathematics teachers apply methods that encourage the development of mathematical reasoning and thinking (OECD, 2024b).	COGACRCO and COGACMCO
Mediation	Disciplinary climate	An index created by students' responses to several statements about how often a situation occurs in mathematics learning (OECD, 2024b).	DISCLIM
Mediation	Teacher support	An index represents how students perceive their teacher to support them in learning (OECD, 2024b).	TEACHSUP
Mediation	Proactive behavior in mathematics	An index was created from students' responses to several statements about how often they engage in behaviors that indicate effort and persistence in mathematics (OECD, 2024b).	MATHPERS

Data analysis

The data analysis technique in the research uses path analysis to determine the direct and indirect effects of gender, socioeconomic and cultural status, and cognitive activation in mathematics teaching on students' mathematics achievement scores in Indonesia with disciplinary climate, teacher support, and proactive behavior in mathematics, as a mediating variable. The data analysis process in this research uses the help of the R program (R Core Team, 2022) with the R Studio interface (Posit Team, 2024). This research employed several R packages including "haven" (Wickham et al., 2023). "dplyr" (Wickham et al., 2023), "plyr" (Wickham, 2011), "ggplot2" (Wickham, 2016), "psych" (Revelle, 2024), "MASS" (Venables & Ripley, 2002), "car" (Fox & Weisberg, 2019), dan "lavaan" (Rosseel, 2012). Following Hayes (2022), the data analysis steps in this research are as follows:

1. Conducting data analysis using descriptive statistics which include minimum values, maximum values, averages, and standard deviations. This analysis uses the min(), max(), mean(), and sd() functions in R.
2. Formulating an initial model that included a total influence model and a mediation model using a path chart for path analysis. The preparation of the initial model is carried out using the lm() function and the summary() function to see the results of the model analysis.
3. Conducting an initial identification of the path analysis mediation model.
4. Conducting preliminary data screening including checks of linearity, normality, homogeneity, and multicollinearity to ensure the adequacy of the model data. These steps are informative and not strictly required in SEM, as the model relies on overall distributional assumptions.
5. Performing parameter estimation, mediation model, path analysis with maximum likelihood (ML), and standard error for estimated parameters using the Bootstrap method with a sample size of 1000. This stage is performed using the sem() function of the "lavaan" package. The results of the standard error estimate are used to construct a confidence interval for the parameter estimator.
6. Making inference for the parameters based on the path analysis mediation model using confidence intervals.
7. Determining the magnitude of direct effect, indirect effect, and total effect.
8. Evaluating the estimated path analysis mediation model using values of the determination coefficient (R^2) with formulas $R_m^2 = 1 - (1 - R_1^2)(1 - R_2^2) \ldots . . (1 - R_p^2)$ (Yang et al., 2021), Comparative Fit Index (CFI) with formula $CFI = d_{null} - d_{specified}/d_{null}$ with $d = (X^2 - df)$,

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Tucker Lewis Index (TLI) with the formula $\text{TLI} = \left[\left(\frac{\chi^2_{\text{null}}}{\text{df}_{\text{null}}}\right) - \left(\frac{\chi^2_{\text{specified}}}{\text{df}_{\text{specified}}}\right) \Big/ \left(\frac{\chi^2_{\text{null}}}{\text{df}_{\text{null}}}\right)\right] - 1$, Root Mean Square Error of Approximation (RMSEA) with formula $\text{RMSEA} = \sqrt{(\chi^2_s - \text{df}_s)/\text{N})/\text{df}_s} = \sqrt{(\chi^2_s/\text{df}_s) - 1/\text{N}}$, Standardized Root Means Square Residual (SRMR) with formula $\text{SRMR} = \left(\left(\sum\sum r^2_{jk}\right)/e\right)^{1/2}$ (Wang & Wang, 2020). These values are obtained using the summary() function of the "lavaan" package.

RESULTS AND DISCUSSION

Descriptive Statistics

In this study, the sample size was 12,208 students from 410 schools that provided complete responses for the selected variables. The sample consists of 6,223 (50.98%) female students and 5,985 (49.02%) male students. Descriptive statistics are used to understand the characteristics of each variable used in this study. The results of descriptive statistics analysis can be seen in Table 2.

Table 2. Descriptive statistics of the data

Variable	Minimum	Maximum	Mean	SD
ESCS	−6.350	3.470	−1.430	1.050
Cognitive activation in mathematics teaching	−5.020	6.340	0.430	1.940
Disciplinary climate	−2.490	1.850	0.060	0.960
Teacher support	−2.910	1.560	0.090	1.020
Proactive mathematics behavior	−3.130	2.850	0.030	1.130
Mathematics achievement	200.400	644.760	381.960	60890

Table 2 shows that cognitive activation in mathematics teaching shows a slightly positive average (0.430) but with a high standard deviation (1.940), indicating that there is a variation in cognitive activation practices in mathematics teaching that is perceived by the student. The average ESCS of Indonesian students is still below the international average. The value of -1.430 indicates that most Indonesian students have a low ESCS status. Disciplinary climate, teacher support, and proactive behavior in mathematics are still below the OECD average. The average mathematics achievement score of Indonesian students (381.960) is still far below the OECD average of 472.

Formulation of Mediation Model

In this study, the path diagram of the mediation effect model specifically uses variables denoted by Greek notation and presented in Figure 1. η_1, η_2, and η_3 represent the mediation variables (disciplinary climate, teacher support, and proactive behavior in mathematics,) and η_4 represent the dependent variable (students' mathematics achievement). In addition, ξ_1, ξ_2, and ξ_3 denote the independent variable (gender, ESCS, and cognitive activation in mathematics teaching. ζ_1, ζ_2, ζ_3, and ζ_4 denote the error of the model.

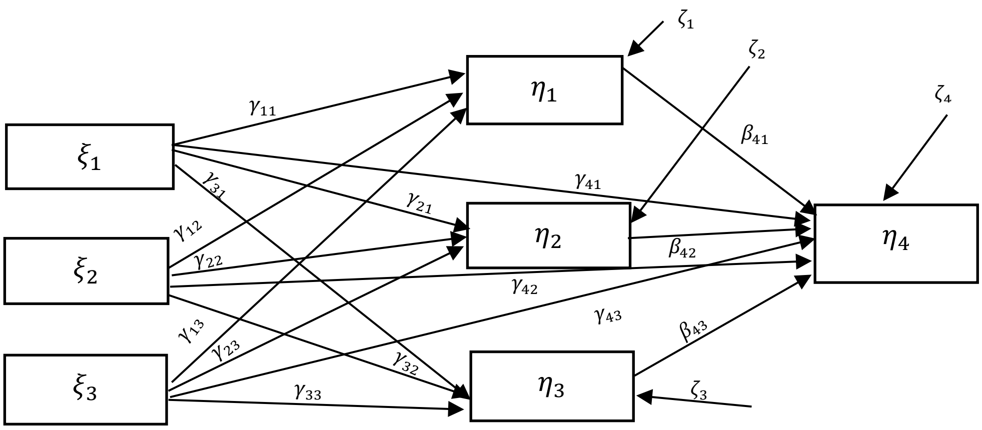

Figure 1. Path diagram of a mediation model in Greek Notation

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Following Figure 1, the mediation model can be stated in four equations as follows

$$\eta_1 = \gamma_{11}\xi_1 + \gamma_{12}\xi_2 + \gamma_{13}\xi_3 + \zeta_1 \quad (1)$$

$$\eta_2 = \gamma_{21}\xi_1 + \gamma_{22}\xi_2 + \gamma_{23}\xi_3 + \zeta_2 \quad (2)$$

$$\eta_3 = \gamma_{31}\xi_1 + \gamma_{32}\xi_2 + \gamma_{33}\xi_3 + \zeta_3 \quad (3)$$

$$\eta_4 = \beta_{41}\eta_1 + \beta_{42}\eta_2 + \beta_{43}\eta_3 + \gamma_{41}\xi_1 + \gamma_{42}\xi_2 + \gamma_{43}\xi_3 + \zeta_4 \quad (4)$$

or, in matrix notation

$$\begin{bmatrix}\eta_1\\ \eta_2\\ \eta_3\\ \eta_4\end{bmatrix} = \begin{bmatrix}0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0\\ \beta_{41} & \beta_{42} & \beta_{43} & 0\end{bmatrix}\begin{bmatrix}\eta_1\\ \eta_2\\ \eta_3\\ \eta_4\end{bmatrix} + \begin{bmatrix}\gamma_{11} & \gamma_{12} & \gamma_{13}\\ \gamma_{21} & \gamma_{22} & \gamma_{23}\\ \gamma_{31} & \gamma_{32} & \gamma_{33}\\ \gamma_{41} & \gamma_{42} & \gamma_{43}\end{bmatrix}\begin{bmatrix}\xi_1\\ \xi_2\\ \xi_3\end{bmatrix} + \begin{bmatrix}\zeta_1\\ \zeta_2\\ \zeta_3\\ \zeta_4\end{bmatrix} \quad (5)$$

The mediation influence model consists of 4 multiple linear regression models with model 1 for disciplinary climate stated in equation (1), model 2 for teacher support stated in equation (2), model 3 for proactive behavior in mathematics stated in equations (3) and model 4 for mathematics achievement score stated in equations (4).

Model Identification and Estimation

Model identification is carried out by comparing the number of parameters estimated in the model with the variance-covariance of the measured variables. The number of parameters to be estimated is determined by knowing the elements of the variance-covariance matrix and the model coefficient matrix. The number of estimated parameters and the number of unique elements is stated in Table 3.

Table 3. Elements of parameters in the model

Matrix	Elements	Number of parameters
Ψ	$\psi_{11}, \psi_{21}, \psi_{31}, \psi_{31}, \psi_{32}, \psi_{33}, \psi_{44}$	7
Φ	$\phi_{11}, \phi_{12}. \phi_{13}. \phi_{22}. \phi_{23}. \phi_{33}$	6
Γ	$\gamma_{11}, \gamma_{12}, \gamma_{13}, \gamma_{21}, \gamma_{22}, \gamma_{23},$ $\gamma_{31}. \gamma_{32}, \gamma_{33}, \gamma_{41}, \gamma_{42}, \gamma_{43}$	12
B	$\beta_{41}, \beta_{42}, \beta_{43}$	3
	Total	28

This study involves eight observed variables $p = 8$, resulting in $\frac{p(p+1)}{2} = \frac{8(8+1)}{2} = 28$ unique elements in the observed variance-covariance matrix. As shown in Table 3, the model is identified as a just-identified model because the number of estimated parameters, and the number of unique elements are the same (28). Therefore, the model has zero degrees of freedom and can be still estimated. The linearity assumption was satisfied, as demonstrated through scatterplot matrix analysis confirming linear relationships between independent and dependent variables. Homoscedasticity was verified for all models, evidenced by constant error variance in plots of fitted values versus standardized residuals. Multicollinearity assumptions were met, with all variance inflation factor $VIF_S < 10$. However, normality assumptions assessed via normal q-q plots were violated across all models. Consequently, the study employed bootstrapping with 1,000 samples to estimate robust standard errors for parameter estimates, which were subsequently used for confidence interval construction. This approach maintains validity despite non-normality in the data distribution.

In this study, parameter estimation was performed using the Maximum Likelihood (ML) method with 1,000 bootstrap replications to estimate standard errors. The analysis was implemented in R using the *lavaan* package, and the results are presented in Table 4. The four models, corresponding to Equation (1)-(4) were evaluated under this framework.

For the first model, the confidence interval for gender ($\hat{\gamma}_{11} = -0.137\, ; -0.171 \le \gamma_{11} \le -0.102$ and cognitive activation in mathematics teaching ($\hat{\gamma}_{13} = 0.062\, ; 0.050 \le \gamma_{13} \le 0.072$) did not contain zero, meaning that these two variables significantly affect disciplinary climate. However, ESCS ($\hat{\gamma}_{12} = 0.007\, ; -0.008 \le \gamma_{12} \le 0.023$) showed a non-significant effect, as the confidence interval included zero. The increase of index cognitive activation in mathematics teaching is related to the increase of disciplinary climate for 0.062, while substantively gender is associated with a 0.137 decrease in

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disciplinary climate scores. The negative coefficient of -0.137 on the gender variable indicates that male students have an average disciplinary climate score of 0.137 lower than female students.

For the second model, the confidence interval for ESCS ($\hat{\gamma}_{22} = -0.038\,; -0.055 \leq \gamma_{22} \leq -0.020$) and cognitive activation in mathematics teaching ($\hat{\gamma}_{23} = 0.092\,; 0.081 \leq \gamma_{23} \leq 0.104$) did not contain zero, meaning that these two variables significantly affect teacher support. However, gender ($\hat{\gamma}_{21} = 0.002\,; -0.033 \leq \gamma_{21} \leq 0.038$) showed a non-significant effect, as the confidence interval included zero. The positive coefficient on the gender variable shows that male students have an average teacher support score of 0.002 higher than female students, but this difference is not statistically significant. The increase in index cognitive activation in mathematics teaching is related to the increase of teacher support for 0.092, while ESCS is associated with a 0.038 decrease in teacher support scores.

For the third model, the confidence interval for gender ($\hat{\gamma}_{31} = -0.210; -0.248 \leq \gamma_{31} \leq -0.170$), ESCS ($\hat{\gamma}_{32} = 0.024\,; 0.006 \leq \gamma_{32} \leq 0.043$), and cognitive activation in mathematics teaching ($\hat{\gamma}_{33} = 0.181\,; 0.169 \leq \gamma_{33} \leq 0.193$) did not contain zero, meaning that these three variables significantly affect proactive behavior in mathematics. An increase of ESCS and cognitive activation in mathematics teaching related to the increase of proactive behavior in mathematics, for 0.024 and 0.181, respectively, while gender is substantively associated with a 0.223 decrease in proactive behavior in mathematics scores. The negative coefficient of -0.210 on the gender variable indicates that male students have an average proactive behavior in mathematics score of 0.210 lower than female students.

Table 4 presents the estimation results for Model 4, in which students' mathematics achievement becomes the dependent variable. The confidence interval for disciplinary climate ($\hat{\beta}_{41} = 5.837\,; 4.812 \leq \beta_{41} \leq 6.965$), proactive behavior in mathematics ($\hat{\beta}_{43} = 2.777\,; 1.908 \leq \beta_{43} \leq 3.639$), gender ($\hat{\gamma}_{41} = -8.478\,; -10.535 \leq \gamma_{41} \leq -6.505$), ESCS ($\hat{\gamma}_{42} = 19.605\,; 18.599 \leq \gamma_{42} \leq 20.599$) and cognitive activation in mathematics teaching ($\hat{\gamma}_{43} = 0.953\,; 0.394 \leq \gamma_{43} \leq 1.478$) did not contain zero, meaning that these five variables significantly affect mathematics achievement. However, teacher support ($\hat{\beta}_{42} = -0.994\,; -2.005 \leq \beta_{42} \leq 0.078$) showed a non-significant effect, as the confidence interval included zero. Substantively, gender is associated with 8.478 decreases in mathematics achievement scores. The negative coefficient of -8.478 on the gender variable indicates that male students have an average mathematics achievement score of 8.478 lower than female students. Disciplinary climate, proactive behavior in mathematics, ESCS, and cognitive activation in mathematics teaching are related to the increase of mathematics achievement scores, for 5.837, 2.777, 19.605, and 0.953, respectively.

Table 4. Results of parameters estimation

Regression	Coefficient Estimation	Standard Error	95% Confidence Interval Lower	Upper
Model 1				
Intercept	0,111	0.016	0.081	0.146
Gender → Disciplinary climate (γ_{11})	−0137	0.017	−0.171	−0.102
ESCS → Disciplinary climate (γ_{12})	0.007	0.008	−0.008	0.023
Cognitive activation in mathematics teaching→ Disciplinary climate (γ_{13})	0.062	0.006	0.050	0.072
Model 2				
Intercept	0.000	0.018	−0.036	0.036
Gender → Teacher support (γ_{21})	0.002	0.018	−0.033	0.038
ESCS → Teacher support (γ_{22})	−0.038	0.009	−0.055	−0.020
Cognitive activation in mathematics teaching → Teacher support (γ_{23})	0.092	0.006	0.081	0.104
Model 3				
Intercept	0.083	0.016	0.048	0.119
Gender → Proactive behavior in mathematics (γ_{31})	−0.210	0.019	−0.248	−0.170

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Regression	Coefficient Estimation	Standard Error	95% Confidence Interval	
			Lower	Upper
ESCS → proactive behavior in mathematics (γ_{32})	0.024	0.009	0.006	0.043
Cognitive activation in mathematics teaching → Proactive behavior in mathematics (γ_{33})	0.181	0.006	0.169	0.193
Model 4				
Intercept	413.399	1.112	411.161	415.564
Disciplinary climate → Mathematics achievement (β_{41})	5.837	0.527	4.812	6.965
Teacher support → Mathematics achievement (β_{42})	−0.994	0.518	−2.005	0.078
Proactive behavior in mathematics → Mathematics achievement (β_{43})	2.777	0.453	1.908	3.639
Gender → Mathematics achievement (γ_{41})	−8.478	1.040	−10.535	−6.505
ESCS → Mathematics achievement (γ_{42})	19.605	0.503	18.599	20.599
Cognitive activation in mathematics teaching → Mathematics achievement (γ_{43})	0.953	0.278	0.394	1.470

Direct, Indirect, and Total Effect

The direct, indirect (mediated), and total effects are presented in Table 5, Table 6, and Table 7. Following Table 5, the direct effect of student gender on mathematics achievement (c'_1) equal to -8.478 with a confidence interval of $-10.535 \leq \gamma_{41} \leq -6.505$. Direct effect of ESCS on mathematics achievement (c'_2) equal to 19.605 with a confidence interval of $18.599 \leq \gamma_{42} \leq 20.599$ and the direct effect of cognitive activation in mathematics teaching on mathematics achievement (c'_3) equal to 0.953 with a confidence interval of $0.394 \leq \gamma_{43} \leq 1.470$. These results show that both ESCS and cognitive activation in mathematics teaching to mathematics achievement have a significant positive direct effect on students' mathematics achievement.

Table 6 shows that the relationship between gender and mathematics achievement is only significantly mediated by disciplinary climate and proactive behavior in mathematics. The mediation effect of the teacher is not significant, as its confidence intervals contain zero. Similarly, from the confidence intervals, we know that the relationship between ESCS and mathematics achievement is mediated by proactive behavior in mathematics, but not by disciplinary climate and teacher support. The relationship between cognitive activation in mathematics teaching and mathematics achievement is only significantly mediated by disciplinary climate and proactive behavior in mathematics.

Table 7 presents the total effect of three independent variables on students' mathematics achievement. The estimated effect sizes of gender, ESCS, and cognitive activation in mathematics teaching are −9.861, 19.749, and 1.724, respectively. The confidence intervals for all three estimations did not contain zero, indicating statistically significant effects. Specifically, the negative coefficient for gender is -9.948, implying that male students have significantly lower mathematics achievement when compared to female students. Meanwhile, ESCS shows a strong positive relationship with mathematic achievement (19.749), suggesting students with higher economic, social, and cultural status tend to perform better in mathematics. Although smaller in magnitude, cognitive activation in mathematics teaching also has a significant positive effect (1.724) on mathematics achievement.

Table 5. The direct effect of the independent variable

Regression	Parameter	Estimation	95% Confidence Interval	
			Lower	Upper
Gender → Mathematics achievement	$c'_1(\gamma_{41})$	−8.478	−10.535	−6.505
ESCS → Mathematics achievement	$c'_2(\gamma_{42})$	19.605	18.599	20.599
Cognitive activation in mathematics teaching → Mathematics achievement	$c'_3(\gamma_{43})$	0.953	0.394	1.470

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Table 6. Indirect (mediated) effect of independent variable

Regression	Parameter	Estimation	95% Confidence Interval	
			Lower	Upper
Gender → Disclim → Mathematics achievement	$a_{11}b_1$ $(\gamma_{11}\beta_{41})$	−0.799	−1.072	−0.567
Gender → Teacher support → Mathematics achievement	$a_{21}b_2$ $(\gamma_{21}\beta_{42})$	−0.002	−0.043	0.038
Gender → Proactive behavior in mathematics → Mathematics achievement	$a_{31}b_3$ $(\gamma_{31}\beta_{43})$	−0.582	−0.820	−0.387
ESCS→ Disclim → Mathematics achievement	$a_{12}b_1$ $(\gamma_{12}\beta_{41})$	0.041	−0.048	0.129
ESCS→ Teacher support → Mathematics achievement	$a_{22}b_2$ $(\gamma_{22}\beta_{42})$	0.037	−0.003	0.081
ESCS→ Proactive behavior in mathematics → Mathematics achievement	$a_{32}b_3$ $(\gamma_{32}\beta_{43})$	0.066	0.017	0.128
Cognitive activation in mathematics teaching → Disclim → Mathematics achievement	$a_{13}b_1$ $(\gamma_{13}\beta_{41})$	0.360	0.264	0.457
Cognitive activation in mathematics teaching → Teacher support → Mathematics achievement	$a_{23}b_2$ $(\gamma_{23}\beta_{42})$	−0.091	−0.187	0.006
Cognitive activation in mathematics teaching → Proactive behavior in mathematics → Mathematics achievement	$a_{33}b_3$ $(\gamma_{33}\beta_{43})$	0.503	0.339	0.668

Table 7.Total Effect

Regression	Parameter	Estimation	95% Confidence Interval	
			Lower	Upper
Gender → Mathematics achievement	c_1	−9.861	−10.410	−6.360
ESCS → Mathematics achievement	c_2	19.749	18.670	20.828
Cognitive activation in mathematics teaching → Mathematics achievement	c_3	1.724	0.405	1.499

Model evaluation

This study employed multiple criteria to assess model fit, including the coefficient of determination (R^2), CFI, TLI, RMSEA, and SRMR. Model evaluation indicates that the model has strong explanatory power, with a total coefficient determination R^2 of 0.270, indicating that approximately 27.0% of the variance in students' mathematics achievement can be attributed to the specified mediation pathways, while the remaining 73.0% is accounted for by external factors not included in the model. According to Cohen et al. (2003), this coefficient of determinations belongs to medium effect, since it closes to 0.26. The CFI and TLI of this study are $1 > 0.9$, the RMSEA is $0 < 0.06$, and the SRMR is $0 < 0.08$, which means that this path mediation model is in good fit.

Discussion

This analysis shows that gender has a significant effect on disciplinary climate and proactive behavior in mathematics, but no effect on teacher support. Vekiri (2010) study revealed no significant gender differences in students' perceptions of teacher support. Similarly, Wit et al. (2010) found that male and female students reported comparable levels of teacher support. Research by Koğar (2015) found that gender has a significant influence on disciplinary climate in mathematics learning and influence on proactive behavior in mathematics, especially student persistence in learning mathematics. Research by Sortkær & Reimer (2018) also found a significant relationship between gender and disciplinary climate.

This analysis shows that ESCS has a significant effect on proactive behavior in mathematics, but no effect on disciplinary climate and teacher support. Research on ESCS with disciplinary climate is still very limited, but there are previous studies that show the same results as this research. Nugraheni et al. (2022) research in two Purbalingga schools demonstrated that the relationship between parental socioeconomic and cultural status and discipline levels was negative, indicating that other factors exert greater influence than socioeconomic and cultural status. Research by Bloem et al. (2024) revealed that teachers tend to provide less support to students from low socioeconomic backgrounds. However, in this study, ESCS did not significantly affect teacher support. This may occur because teachers' support is more strongly shaped by students gender, classroom behavior, and perceived academic ability than by their socioeconomic background. Research by Radišić & Pettersen (2024) similarly indicates that students from higher socioeconomic backgrounds tend to exhibit more proactive learning behaviors in mathematics compared to their peers from disadvantaged backgrounds. Students with higher ESCS indices were found to meticulously review their work, actively engage in questioning, and consistently connect new concepts with prior knowledge. Thus, while ESCS contributes to students' internal motivation and learning engagement, it does not necessarily alter teachers' interaction patterns or the shared behavioral norms within classrooms.

This analysis shows that cognitive activation in mathematics teaching has a significant effect on disciplinary climate and proactive behavior in mathematics, but no effect on teacher support. Teacher support can be manifested in various forms, including providing assistance in comprehending subject matter, fostering a positive and safe learning environment, and establishing emotionally supportive relationships (Kitsantas et al., 2021). Research on cognitive activation in mathematics learning with disciplinary climate is still very limited, but there are previous studies that show the same results as this research. Research by Mukuka et al. (2023), found that teachers who consistently encourage students to explain their reasoning when solving mathematical problems foster more active student participation in learning, a collaborative classroom environment, and ultimately the development of a positive disciplinary climate. Research by Wang (2023), revealed that cognitive activation strategies enhance students' engagement in mathematical problem-solving processes. This pedagogical approach indirectly fosters increased student perseverance and effort in mathematics, which manifests as observant proactive learning behavior in mathematics.

How do three mediation variables affect students' mathematics achievement? In this study, we find that disciplinary climate and proactive behavior in mathematics affected students' mathematics achievement scores, but teacher support did not. Research by Purnomo, (2016) at SMP Negeri 2 Tamansari Bogor revealed a significant correlation between students' mathematical attitudes and achievement scores. Positive attitudes were associated with three key behavioral indicators, smoother learning progression, active classroom participation, and sustained knowledge-seeking behavior, all of which ultimately lead to superior mathematics performance. Research by Ning (2020) revealed that a positive school disciplinary climate significantly enhances students' academic achievement in mathematics. These findings indicate that a positive disciplinary climate and proactive behavior in mathematics enhance students' achievement because both reflect students' ability to regulate their learning and stay actively engaged in academic activities. Previous research stated that student achievement in mathematics is influenced by various factors, including discipline and engagement in learning, where consistent school rules, teacher professionalism, and motivational strategies such as rewards and punishments help maintain students' focus, motivation, and participation during lessons (Salma & Alsa, 2023). Research by Kitsantas et al. (2021) found that teacher support does not directly influence mathematics performance scores.

This study shows that gender directly influences students' mathematics achievement scores. Even though, gender only has an indirect effect through the mediation of disciplinary climate and proactive behavior in mathematics. Research by Koğar (2015) revealed that gender indirectly influences mathematics achievement through disciplinary climate and proactive behavior in mathematics, particularly students' perseverance in mathematics learning. Research by Utami & Yonanda (2020) revealed that female students typically achieve higher academic performance than their male counterparts. Research by Ortega-Rodríguez (2024) also stated that gender affects mathematics achievement scores.

This study shows that ESCS directly influences students' mathematics achievement scores. Even though, ESCS only has an indirect effect through the mediation of proactive behavior in mathematics. Research by Koğar (2015) revealed that ESCS indirectly influences mathematics achievement through proactive behavior in mathematics, particularly students' perseverance in mathematics learning. Research by Ortega-Rodríguez (2024) revealed that students' socioeconomic factors significantly affect

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mathematics achievement scores. Students from lower socioeconomic backgrounds often face limitations in accessing learning resources, academic guidance, and supportive educational environments, all of which adversely impact their educational attainment (Liu et al., 2024).

This study shows that cognitive activation in mathematics teaching directly influences students' mathematics achievement scores. Even though, cognitive activation in mathematics teaching only has an indirect effect through the mediation of disciplinary climate and proactive behavior in mathematics. Research indicates that students who perceive their mathematics teachers are employing cognitive activation strategies tend to achieve better learning outcomes (Kitsantas et al., 2021). Alomiear (2024) also stated that teacher cognitive activation has a positive influence on mathematics literacy. Research by Bellibaş et al. (2025) stated that there is a positive relationship between teacher cognitive in mathematics teaching and mathematics achievement. Teachers who use student-centered methods by developing cognitive processes tend to produce students with higher test scores (Bellibaş et al., 2025).

CONCLUSION

Based on the results of the analysis, it can be concluded that gender, socioeconomic background (ESCS), and cognitive activation in mathematics teaching play essential roles in shaping students learning environments and mathematics achievement. Gender and cognitive activation significantly contribute to the development of a positive disciplinary climate and proactive learning behavior, both of which are strong predictors of higher mathematics performance. Meanwhile, students socioeconomic status primarily influences proactive behavior, reflecting how economic and cultural capital affect motivation and engagement in learning.

Theoretically, these findings reinforce the view that students achievement in mathematics is not solely determined by cognitive ability, but also by the interaction between individual characteristics, instructional quality, and classroom behavioral dynamics. Practically, the results suggest that teachers should employ cognitively activating instructional strategies that foster reasoning, autonomy, and active engagement especially for male and socioeconomically disadvantaged students who tend to exhibit lower persistence and discipline in mathematics learning.

For educational policy, promoting teacher training programs that emphasize cognitive activation and equitable support practices can strengthen students engagement and disciplinary climate across diverse classrooms. Future research could expand this model by incorporating additional mediators such as mathematics self-efficacy, perception of classroom management, or learning motivation to provide a more comprehensive understanding of the pathways that enhance mathematics achievement.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author Contribution

S.C.E: Conceptualization, Methodology, Formal Analysis, Writing, Original Draft.

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K: Review & Editing.

Conflict of Interest

The authors declare that there is no conflict of interest.

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