Submission date: August 2025 **Acceptance date:** October 2025 **Publication date:** December 2025

MATHEMATICAL REASONING AND COMPUTATIONAL THINKING IN PROBLEM-SOLVING: SELF-EFFICACY AS A MEDIATOR AMONG SHANDONG HIGH SCHOOL STUDENTS

RAZONAMIENTO MATEMÁTICO Y PENSAMIENTO COMPUTACIONAL EN LA RESOLUCIÓN DE PROBLEMAS: MEDIACIÓN DE LA AUTOEFICACIA EN ESTUDIANTES DE SECUNDARIA DE SHANDONG

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Suggested citation (APA, seventh ed.)

Ni, Y., Abdul Sathar, M. H., & Shafie Mustafa, M. (2025). Mathematical reasoning and computational thinking in problem-solving: self-efficacy as a mediator among shandong high school students. R*evista Conrado, 21*(S1), e5086.

ABSTRACT

This research investigates the associations among mathematical reasoning competence, computational thinking, and problem-solving achievement among high school students, specifically examining the mediating role of mathematics self-efficacy beliefs in Shandong Province, China. The model treats mathematical reasoning competence as a manifest indicator, operationalized as the sum of deductive reasoning, inductive reasoning, and pattern recognition. The strategy adopted is structural equation modeling, applying a mediation model to test the assumptions that mathematical reasoning competence and computational thinking have both direct and indirect effects, simultaneously influencing problem-solving achievement. The results indicate a direct association between mathematical reasoning competence, computational thinking, and problem-solving achievement, highlighting a statistically significant direct influence of mathematical reasoning competence and computational thinking on problem-solving achievement. The CFA item-level results supported a three-task family structure: Deductive, Inductive, Pattern Recognition, aggregated into a family named Family 3, and summed into a single indicator, making mathematical reasoning a latent factor with three indicators. Additionally, mathematics self-efficacy beliefs partially mediated this effect, explaining 18% of the total effect of mathematical reasoning competence, as well as 24% for computational thinking, related to problem-solving competence. The results confirm the significance of cultivating both problem-solving and motivational beliefs alongside mathematical competence.

Keywords:

Mathematical Reasoning, Computational Thinking, Problem-solving Performance, Self-Efficacy, Mediation Analysis, Structural Equation Modelling

RESUMEN

Esta investigación analiza las relaciones entre la competencia en razonamiento matemático, el pensamiento computacional y el desempeño en resolución de problemas en estudiantes de secundaria, examinando específicamente el papel mediador de las creencias de autoeficacia matemática en la provincia de Shandong, China. El modelo considera la competencia en razonamiento matemático como un indicador manifiesto, operacionalizado como la suma del razonamiento deductivo, el razonamiento inductivo y el reconocimiento de patrones. La estrategia adoptada es el modelado de ecuaciones estructurales, aplicando un modelo de mediación para comprobar la hipótesis de que la competencia en razonamiento matemático y el pensamiento computacional tienen efectos tanto directos como indirectos, influyendo simultáneamente en el desempeño en resolución de problemas. Los resultados indican una relación directa entre la competencia en razonamiento matemático, el pensamiento computacional y el desempeño en resolución de problemas, destacando una influencia directa estadísticamente significativa de la competencia en razonamiento matemático y el pensamiento computacional en el desempeño en resolución de problemas. Los resultados del análisis factorial confirmatorio (AFC) a nivel de ítem respaldaron una estructura de tres tareas: deductiva, inductiva y de reconocimiento de patrones, agrupadas en una familia denominada Familia 3 y sumadas en un único indicador, lo que convierte al razonamiento matemático en un factor latente con tres indicadores. Además, las creencias de autoeficacia matemática mediaron parcialmente este efecto, explicando el 18 % del efecto total de la competencia en razonamiento matemático, así como el 24 % del efecto del pensamiento computacional, relacionado con la competencia en resolución de problemas. Los resultados confirman la importancia de cultivar tanto las creencias motivacionales como las de resolución de problemas, junto con la competencia matemática.

Palabras clave:

Razonamiento matemático, pensamiento computacional, desempeño en resolución de problemas, autoeficacia, análisis de mediación, modelado de ecuaciones estructurales

INTRODUCTION

Since the early 21st century, mathematics education in China has seen a marked change towards a new approach, moving away from the traditional “double base” model, which focuses on foundational mathematical knowledge and computational skills, to an approach that nurtures students’ critical thinking skills of a higher order. The trends seen at an international level acknowledge mathematical reasoning and computational thinking as critical skills in a technology-intense world of the 21st century (Li et al., 2021, Tang et al., 2021).

Shandong Province, a province with a population of over 100 million in the eastern part of China, is one of the developed economic areas and has a strong education system. The students in this province have consistently performed well in mathematics competence tests conducted by the national government, and this makes Shandong Province an appropriate case to study the influence exerted by mathematical reasoning and computational skills on mathematical problem-solving performance. Such findings will be useful in China, for example, since it has a similar educational system.

Mathematical problem-solving has been recognized as an important competency in mathematics education around the world (Gao & Wu, 2021; Xu & Qi, 2022). It has been estimated that 80% of Grade 8 students in China are at a medium to high level with regard to mathematical problem-solving competency, proving the successful delivery of mathematics instruction in China (Gao & Wu, 2021). Still, recent studies point out that, although excelling at procedural fluency and computation, Chinese students may require better development of their reasoning skills and abilities related to higher-level thinking areas, as indicated by Cai (2000); and Zhang & Savard (2023).

Although a vast amount of research has been conducted on mathematics achievement in China, several research gaps exist with regard to the ways in which cognitive abilities could influence problem-solving performance. First, mathematical reasoning and computational thinking have been explored individually, but little research has examined their cumulative influence on problem-solving performance. Second, the psychological processes, including motivational beliefs such as self-efficacy, that could mediate the relationship between cognitive abilities and performance have remained relatively unexplored among the Chinese population. Third, the vast majority of the research conducted has examined either elementary or middle school students, while relatively fewer studies have been conducted on high school students due to the differing levels of cognitive demands and academic pressures they face.

Understanding this is even more important, given that China is undergoing curriculum reform, which targets the development of key skills: reasoning, modeling, creativity, and computational thinking skills (MOE, 2017). Further, given the integration and growing role of technology, computational thinking has assumed a prime position as a literacy skill, which goes beyond programming, reaching into problem-solving skills in a number of areas (Li et al., 2021).

The purpose of this study is to examine the direct impacts of mathematical reasoning skills and computational thinking on problem-solving performance among high school students in Shandong Province, to examine the mediating role of mathematics self-efficacy in the relationships between mathematical reasoning, computational thinking, and problem-solving performance, to validate a complete structural model that explains how mathematical skills and self-efficacy influence problem-solving performance, and to offer evidence related to mathematics curriculum development applicable to high schools in China.

The study offers a number of key contributions to mathematics education scholarship. Theoretical contributions relate to an expanded body of knowledge regarding how cognitive and motivational beliefs interact to predict problem solving, via a mediation model developed within social cognitive theory, as proposed by Bandura (1997).

Some of the contributions of this study are related to methodologies, which involve a structural model, focusing on joint rather than predictive findings.

Practically, the results could help guide curriculum development to identify the competencies that are most predictive of problem-solving outcomes. If self-efficacy is a mediator between reasoning, computational thinking, and problem-solving, this supports curriculum development that balances building the skills and building confidence. Also, given the pressures faced by Chinese educators who are being asked to enhance their students' capabilities related to mathematical reasoning while nurturing computational skills, it is important to understand the implications highlighted by this study, given that computational reasoning is being incorporated into mathematics curricula around the world.

Mathematical reasoning involves a number of cognitive skills that relate to the analysis of associations, patterns, inference, proof, and the evaluation of mathematical statements for their validity (Peng et al., 2016). Based on the Chinese context, various studies have proposed a strengths-and-weaknesses profile related to students' potential to perform mathematical reasoning tasks. A recent study examining the mathematical cognitive processes of eighth-grade students in China suggested that students from the mainland are relatively strong in procedural components, such as calculation, measurement, and standard problem-solving, but comparatively weak at higher-order processes, including analysis, evaluation, and generalization, among others.

Cross-national studies comparing the mathematical problem-solving abilities of American and Chinese students have reported additional findings. Cai (2000) assessed sixth-grade students in both countries on process-constrained and process-open mathematical problems. Chinese students significantly outperformed their American counterparts on process-constrained problems involving routine algorithms, whereas American students performed better on process-open problems requiring flexible strategies. The findings indicate that Chinese students' performance depended more on routine algorithms and symbolic forms, while American students' performance relied more on concrete visual forms and flexible strategies.

Susac et al. (2014) investigated the development of abstract reasoning among 13- to 17-year-olds using equation-rearrangement tasks. The results showed that adolescents excelled at solving numerical equations compared with symbolic equations, reflecting characteristics of the concrete operational stage. However, by ages 16–17, the participants performed equally well on both numerical and symbolic equations, representing the development stage of abstract reasoning skills. The development, importance, and applications of abstract reasoning are highlighted in this article. It explains how abstract reasoning is a developed skill that enables an individual to make decisions involving mathematics, making this reasoning vital at all levels, whether academic or professional.

Computational Thinking has been identified as a new skill for the 21st century, described as the thought processes involved in translating problems and their solutions into a form suitable for execution by an information processor and as a body of problem-solving skills, strategies, and methodologies that can be applied independently as well as in combination, encompassing problem decomposition, pattern recognition, abstraction, algorithm design, and systematic evaluation, as well as coding and programming (Li et al., 2021).

The link between computational thinking and mathematics has gained increasing interest in recent years as well. Li et al. (2021) designed a scale to evaluate computational thinking among primary school students in China, resulting in five crucial components: problem identification, or abstraction and decomposition; data handling, including collection, analysis, and detection of patterns; solution generation, or mathematical reasoning and algorithm development; solution implementation, or automation and modeling; solution evaluation, involving testing, debugging, and generalization. The model shows strong interlinks between computational thinking and mathematical activities.

Zhang & Savard (2023) conducted a comparative study to examine computational thinking as presented in mathematics textbooks in Chinese and Canadian contexts, and found that the "look-back" phase was dominated by the use of CT tools, accounting for 38% of the applications of computational thinking in Chinese mathematics textbooks. They also found that the mathematics education paradigm in China engages students by first using simple questions to build interest in new information, followed by more complex questions to foster computational thinking skills.

Currently, there are emerging studies on the complex associations between mathematics learning and computational thinking. A study involving eighth- and ninth-grade students indicated that mathematics learning beliefs and mathematical literacy directly and indirectly relate to competence in computational thinking. The study highlighted that, as a type of cross-disciplinary literacy, computational thinking involves domain-general problem-solving skills that are broader than computer-based problem-solving tasks, encompassing all STEM fields as well as real-world situations.

An investigation involving metacognition and computational thinking among high school students in China indicated that computational thinking acts as a mediator between metacognition and mathematical modeling skills (Li, Wang, & Chen, 2024). It indicated that creativity, algorithmic thinking, cooperation, critical thinking, and problem-solving skills, as components of computational thinking, are vital elements in mathematical modeling activities. Therefore, this confirms that computational thinking skills are directly involved in complex mathematical activities.

Considering the Chinese education system, Grade 8 students showed robust advantages in calculation and measurement, operation and solution, and representation modeling, which are traditional areas encompassing strong procedural fluency skills. However, the curriculum may require a number of inquiry- or exploration-based learning strategies to impart greater skills related to advanced computational thinking and other high-level cognitive skills.

Problem-solving competence in mathematics is a complex process that involves various components of cognition. Junior high school students' mathematical problem-solving competence, as identified by a study conducted by a Chinese researcher, comprises four primary components: comprehension, mathematical modeling, action, and evaluation (Xu & Qi, 2022). As identified, mathematical problem-solving competence involves aspects beyond mere mathematical calculations, including making sense of the problem, which could preferably be done through mathematical modeling.

The results gained by studying the problem-solving competency of middle school students in China are very valuable. Xu & Qi (2022) studied 42,644 ninth-grade students' mathematical problem-solving competency in mainland China, and the results showed that 48 percent achieved high competency (A level), 35 percent medium competency (B level), and 13 percent basic competency (C level). It was found that student background variables "gender" and "being an only child" affected problem-solving performance to a small degree, while school variables "located in urban or rural areas" had a greater effect.

The classification of influencing factors in mathematical problem-solving includes three types: (1) learner internal factors, including intelligence abilities (intuition, imagination, abstraction, generalization, reasoning, analysis, synthesis), metacognition, and others (motivation, interest, will, belief); (2) problem characteristics, including complexity, familiarity, type, and context; and (3) teachers' self-efficacy beliefs regarding mathematical problem-solving and instructional approaches, as proposed by the study authors Xu & Qi (2022). Kaweck and Trgalova are an exception, as they proposed a different classification.

Comparative studies have shed light on the characteristic features of problem-solving among Chinese students. A study by Gao & Wu (2021) tested the problem-solving skills related to mathematical exercises among eighth-grade students in China and found that approximately 80 percent of the students reached medium or higher levels of competency. The authors stated that Chinese students are well-suited to handle medium- and high-level mathematical problems, as their mode of instruction aids in designing mathematical problems and breaking down procedures step by step. The study also observed that while the mathematical programs among Chinese students are successful in imparting basic knowledge, "Chinese mathematics education emphasizes a focus on acquiring skills, which is successful, but may offer relatively less attention to reasoning activities compared to other countries' systems."

Mathematics self-efficacy, defined as students' beliefs or perceptions of their competence to effectively do and accomplish assigned mathematics tasks, has a motivational role recognized as an important factor influencing mathematics learning and achievement. Based on Social Cognitive Theory by Bandura (1997), mathematics self-efficacy is shaped by four primary origins: mastery experiences, vicarious experiences, verbal persuasion, and physiological perceptions, all stemming from past experiences or reactions to a given mathematics task or a series thereof.

It has been found that mathematics self-efficacy is an important predictive factor for mathematics accomplishment. Pajares & Miller (1994) performed a path analysis to show that self-efficacy beliefs are given greater significance than self-concept beliefs in mathematical problem-solving accomplishment. The results disclosed that self-efficacy has a direct influence, as well as an influence on problem-solving strategy selection and persistence when faced with difficulties in problem-solving activities.

Within the Chinese education system, various studies have explored the implications of self-efficacy in mathematics learning. Su et al. (2021) stated that intelligence mindsets influence mathematics achievement among primary school students, and both failure beliefs and mathematics self-efficacy emerged as full mediators between growth mindsets and mathematics achievement. The implications of this evidence are clear: students with a growth mindset, believing their intelligence can be developed, will show greater self-efficacy, leading to greater mathematics performance and establishing a chain mediation process between motivational beliefs and achievement.

Currently, studies have been examining self-efficacy as a mediator. A study conducted by Tan et al. (2024) explored the link between teacher–student relationship proximity and mathematical problem-solving abilities among 9,163 eighth-grade students in China, and the findings confirmed that mathematics self-efficacy exerted a partial mediation effect between relationship proximity and mathematical problem-solving performance. The researchers concluded that a favorable relationship results in optimistic confidence gains among students, resulting in better resilience and performance against difficult mathematical problems.

Presently, research has been focusing on self-efficacy as a mediator. A study by Tan et al. (2024) examined the association between teacher–student relationship closeness and mathematical problem-solving competence among 9,163 eighth-grade students in China, and the results confirmed a partial mediating role of mathematics self-efficacy between relationship closeness and mathematical problem-solving competence. The study concluded that a positive relationship fosters students' confidence, leading to greater resilience and competence when facing difficult mathematical problems.

A study involving junior high school students in Jiangsu Province, China, indicated that academic self-efficacy played a mediating role between teaching styles and mathematics behavioral engagement (Geng et al., 2024).

MATERIALS AND METHODS

The study involved 1,018 high school students (512 boys, 506 girls) in Grades 10 and 11 from eight public high schools across six cities in Shandong Province. Ages ranged from 15 to 17 years (M = 16.2, SD = 0.68), with 54.2% in Grade 10 and 45.8% in Grade 11. Schools included both key and ordinary schools to capture socioeconomic and instructional diversity. All students followed China's national high school mathematics curriculum. Written consent was obtained from administrators, teachers, and parents, and students provided assent. The study received ethical approval from the university's institutional review board.

Mathematical reasoning (MR) was measured using a 20-item adapted version of the Mathematical Reasoning Test (Peng et al., 2016), covering deductive reasoning, inductive reasoning, and pattern recognition. Items were scored 0–2, producing total scores of 0–40. Pilot testing indicated strong reliability (α = 0.86), and CFA confirmed the three-task-family structure (CFI = 0.94, RMSEA = 0.06). For SEM, items were aggregated into three indicators.

Computational thinking (CT) was assessed with the 24-item Computational Thinking Scale for Chinese Students (Li et al., 2021), evaluating five competencies: problem decomposition and abstraction, data representation and analysis, algorithmic thinking and procedure design, pattern recognition and generalization, and evaluation and optimization. Items used 5-point Likert scales, with total scores ranging from 24 to 120. Reliability was high (α = 0.91), and CFA confirmed excellent model fit (CFI = 0.95, TLI = 0.94, RMSEA = 0.05).

Mathematics self-efficacy (MSE) was measured with an 18-item Chinese adaptation of the Mathematics Self-Efficacy Scale (Gao, 2020; Pajares & Miller, 1994), covering easy, medium, and difficult tasks on a 1–7 scale. Scores ranged from 18 to 126, with higher scores indicating stronger self-efficacy. Reliability was excellent (α = 0.94), with good convergent validity.

Problem-solving performance (PSP) was evaluated using a 25-item standardized test from CICA-BEQ, covering algebra, geometry, data/probability, and applied problem solving. The 90-minute test allowed partial credit, with scores ranging from 0 to 100. Reliability was high (r = 0.92), and construct validity aligned with national assessment standards.

The data analysis followed a five-stage procedure using Stata for preliminary analyses and Mplus for confirmatory factor analysis (CFA) and structural equation modeling (SEM).

Stage 1: Data Screening and Preliminary Analyses

Missing data, entry accuracy, and outliers were examined first. Missing values were treated with full information maximum likelihood (FIML), assuming MAR (Enders, 2022). Outliers were identified using Mahalanobis distance and rechecked for accuracy. Descriptive statistics, including skewness and kurtosis, were evaluated to ensure acceptable normality for SEM (|skew| < 2, |kurtosis| < 7). Reliability was confirmed through Cronbach's alpha for each scale.

Stage 2: Measurement Model Assessment

CFA was conducted to validate the measurement structure of all constructs: MR (three indicators), CT (five subscales), MSE (three item parcels), and PSP (four domain scores). Model fit was evaluated using χ^2, CFI, TLI, RMSEA, and SRMR, applying Hu & Bentler's (1999) criteria. All measurement models demonstrated adequate to strong fit, supporting their use in the structural analyses.

Stage 3: Structural Model Testing

The structural model was estimated using maximum likelihood with robust standard errors (MLR). MR and CT were modeled as exogenous predictors of both MSE and PSP, with MSE serving simultaneously as a mediator. Direct effects (H1–H3) were assessed using standardized coefficients (β), interpreted according to Cohen's (2013) effect size guidelines. Overall model fit was evaluated with the same indices used in the CFA stage.

Stage 4: Mediation Analysis

Mediation effects (H4–H5) were tested using 5,000 bias-corrected bootstrap resamples. Indirect effects were calculated as the product of the relevant path coefficients. Significant mediation was determined when 95% confidence intervals excluded zero. The proportion mediated was computed to estimate the extent to which MSE transmitted the effects of MR and CT on PSP.

Stage 5: Model Comparison and Alternative Models

To assess robustness, the proposed partial mediation model was compared to two alternatives: (a) a direct-effects-only model and (b) a full mediation model without direct paths from MR and CT to PSP. Comparisons relied on chi-square difference testing and information criteria (AIC and BIC). Results indicated that the proposed model provided the best overall fit.

RESULTS AND DISCUSSION

Missing data screening indicated a small percentage of missing values (0.8%), with a prevalence of missing values completely at random, as confirmed by Little's Missing Completely at Random test (MCAR test; $\chi^2 = 142.67$, df = 156, $p = 0.75$). No univariate or multivariate outliers were identified by Mahalanobis distance at a significance level of .001. The final sample included 1,018 students, all of whom were retained for analysis.

Table 1. Descriptive Statistics and Correlations Among Study Variables.

Variable	M	SD	1	2	3	4
1. Mathematical Reasoning	28.45	6.72	(0.86)			
2. Computational Thinking	89.32	14.26	0.58***	(0.91)		
3. Mathematics Self-Efficacy	81.47	18.92	0.52***	0.54***	(0.94)	
Problem-Solving Performance	67.83	16.34	0.50***	0.47***	0.59***	(0.92)

Note. N = 1,018. Values in parentheses on the diagonal are Cronbach's alpha reliability coefficients. ***p < 0.001.

Source: Authors' own elaboration

Table 1 shows the results of the descriptives and bivariate correlations among the study variables. The internal consistency reliability coefficients ranged from 0.86 to 0.94, indicating that all scales were acceptable to excellent in reliability tests. The values for skewness ranged between −0.45 and 0.62, while the values for kurtosis ranged between −0.38 and 0.85, indicating normal distributions suitable for structural equation modeling analysis.

All were positively correlated and statistically significant at the 0.001 level, proof that the proposed notions were valid. A strong relationship existed between mathematical problem-solving achievement and mathematical reasoning (0.50), as well as computational thinking (0.47) and mathematics self-efficacy beliefs (0.59). The relationship between mathematical reasoning and computational thinking was moderately strong at 0.58, implying a convergence and a difference between the two concepts.

Measurement Model

The confirmatory factor analysis was conducted to evaluate the measurement model that included all four latent constructs. For computational thinking, the five subscale scores were specified as indicators. For mathematics self-efficacy, three parcels were specified: easy, moderate, and hard task self-efficacy. For problem-solving performance, four indicators captured the four domain scores: algebraic, geometric, data analysis, and applied problems. For mathematical reasoning, three indicators related to deductive reasoning, inductive reasoning, and pattern recognition were specified.

The fit of the measurement model was excellent: $\chi^2(84) = 186.24$, $p < 0.001$, CFI = 0.97, TLI = 0.96, RMSEA = 0.04 (90% CI [0.03, 0.05]), SRMR = 0.03. As seen in Table 2, all factor loadings were statistically significant ($p < 0.001$) and large, ranging between 0.78 and 0.91. For mathematical reasoning, strong loadings existed between the three types of tasks (deductive, inductive, and pattern recognition) and the latent construct ($\lambda = 0.82$ to 0.88), validating the approach to treat the construct as unitary with various components. The computational thinking parcels loaded strongly onto their respective latent construct ($\lambda = 0.80$ to 0.89), with the highest loading for algorithmic thinking. The mathematics self-efficacy parcels loaded strongly onto their respective latent construct ($\lambda = 0.87$ to 0.91), implying strong internal consistency between confidence components. Problem-solving performance domain scores loaded strongly onto their respective latent construct ($\lambda = 0.78$ to 0.88), with the highest loading for applied problem-solving performance. The results show that all the manifest indicators adequately captured their respective latent structure, validating the measurement model's construct interpretation.

Table 2. Standardized Factor Loadings for the Measurement Model

Latent Variable / Indicator	λ
Deductive Reasoning Tasks	0.84*** (0.03)
Inductive Reasoning Tasks	0.88*** (0.02)
Pattern Recognition Tasks	0.82*** (0.03)
Problem Decomposition & Abstraction	0.86*** (0.02)
Data Representation & Analysis	0.83*** (0.03)
Algorithmic Thinking & Procedure Design	0.89*** (0.02)
Pattern Recognition & Generalization	0.85*** (0.02)
Evaluation & Optimization	0.80*** (0.03)
Easy Tasks Confidence (Parcel 1)	0.91*** (0.02)
Moderate Tasks Confidence (Parcel 2)	0.89*** (0.02)
Challenging Tasks Confidence (Parcel 3)	0.87*** (0.02)
Algebraic Reasoning	0.85*** (0.02)
Geometric Reasoning	0.82*** (0.03)
Data Analysis & Probability	0.78*** (0.03)
Applied Problem-Solving	0.88*** (0.02)

Note. N = 1,018. λ = standardized factor loading; SE = standard error. All factor loadings are significant at $p < 0.001$.

Source: Authors' own elaboration

Structural Model Testing

The hypothesized structural model was tested, specifying direct paths from mathematical reasoning and computational thinking to both mathematics self-efficacy and problem-solving performance, and a direct path from self-efficacy to performance. The model demonstrated excellent fit: $\chi^2(85) = 192.48$, $p < 0.001$, CFI = 0.96, TLI = 0.95, RMSEA = 0.04 (90% CI [0.03, 0.05]), SRMR = 0.03.

Table 3. Standardized Path Coefficients in the Structural Model

Path	β (SE)	95% CI
MR → MSE	0.31*** (0.04)	[0.23, 0.39]
CT → MSE	0.34*** (0.04)	[0.26, 0.42]
MR → PSP	0.36*** (0.04)	[0.28, 0.44]
CT → PSP	0.29*** (0.04)	[0.21, 0.37]
MSE → PSP	0.27*** (0.04)	[0.19, 0.35]

Note. MR = Mathematical Reasoning; CT = Computational Thinking; MSE = Mathematics Self-Efficacy; PSP = Problem-Solving Performance. All paths significant at $p < 0.001$.

Source: Authors' own elaboration

As shown in Table 3, all hypothesized paths were statistically significant, supporting H1, H2, and H3. Mathematical reasoning had a significant direct effect on problem-solving performance ($\beta = 0.36$, $p < 0.001$), explaining H1. Computational thinking also had a significant direct effect on problem-solving performance (β = 0.29, $p < 0.001$), supporting H2. Mathematics self-efficacy significantly predicted problem-solving performance (β = 0.27, $p < 0.001$), confirming H3.

Additionally, both mathematical reasoning (β = 0.31, $p < 0.001$) and computational thinking (β = 0.34, $p < 0.001$) significantly predicted mathematics self-efficacy. These paths are necessary for the proposed mediation effects.

The model explained substantial variance in both endogenous variables: 34% of the variance in mathematics self-efficacy ($R^2 = 0.34$) and 61% of the variance in problem-solving performance ($R^2 = 0.61$).

Mediation Analysis

Indirect effects were tested using bias-corrected bootstrap procedures with 5,000 resamples. Results are presented in Table 4.

Table 4. Direct, Indirect, and Total Effects

Effect	β	95% CI
Mathematical Reasoning → Problem-Solving Performance		
Direct effect	0.36*** (0.04)	[0.28, 0.44]
Indirect effect (via MSE)	0.08*** (0.02)	[0.05, 0.12]
Total effect	0.44*** (0.04)	[0.36, 0.52]
Proportion mediated	18%	
Computational Thinking → Problem-Solving Performance		
Direct effect	0.29*** (0.04)	[0.21, 0.37]
Indirect effect (via MSE)	0.09*** (0.02)	[0.06, 0.13]
Total effect	0.38*** (0.04)	[0.30, 0.46]
Proportion mediated	24%	

Source: Authors' own elaboration

The indirect effect between mathematical reasoning and problem-solving performance via mathematics self-efficacy was statistically significant (β = 0.08, 95% CI [0.05, 0.12], $p < 0.001$), proving H4. The percentage of the total effect represented by this indirect effect was 18%, signifying partial mediation. Students' better mathematical reasoning skills are positively related to their mathematics self-efficacy, which enhances problem-solving performance.

Likewise, the indirect relationship between computational thinking and problem-solving performance via mathematics self-efficacy remained significant (β = 0.09, 95% CI [0.06, 0.13], $p < 0.001$), which supported H5. The proportion of the total effect explained by this indirect relationship was 24%, which shows partial mediation as well. Enhanced computational thinking skills help boost students' mathematics self-efficacy, which, in turn, affects their problem-solving performance positively.

The strong indirect effects, coupled with strong direct effects, confirmed the partial mediation models for both predictors. It indicates that mathematical reasoning and computational skills both contribute toward problem-solving performance through two channels: (1) direct utilization of cognitive skills to solve problems and (2) via an indirect channel, through boosted self-confidence, which augments efficient problem-solving behavior.

Alternative Model Comparisons

Three other models were explored and compared to the proposed model of partial mediation:

Model A: Direct Effects Only

The model included only direct effects, with no paths via self-efficacy beliefs between mathematical reasoning and computational thinking skills and problem-solving performance. The model had acceptable but inferior fit indexes compared to the proposed model: CFI = 0.93, TLI = 0.92, and RMSEA = 0.06. The chi-square difference test showed significantly poorer fit, $\Delta\chi^2(3) = 67.32$, $p < 0.001$, and the information criteria were greater: AIC = 28945.67 as opposed to 28882.15, and BIC = 29087.23 as opposed to 29031.48; thus, the model is inferior.

Model B: Partial Mediation

In this model, both the direct paths and the indirect paths involving mathematics self-efficacy were estimated as described previously.

This model fit the data well, with a CFI, TLI, and RMSEA of 0.96, 0.95, and 0.04, respectively, and the lowest values of the information criteria.

Model C: Full Mediation

The direct paths between mathematical reasoning and computational thinking and problem-solving performance were fixed to zero, meaning that only indirect effects via self-efficacy were allowed. The fit results indicated a significantly poorer fit relative to Model B: $\chi^2(87) = 335.15$, $p < 0.001$, CFI = 0.91, TLI = 0.89, RMSEA = 0.07, 90% CI [0.06, 0.08], SRMR = 0.06. The chi-square difference test confirmed a significantly poorer fit, $\Delta\chi^2(2) = 134.84$, $p < 0.001$, and the information criteria were considerably higher: AIC = 29018.84; BIC = 29147.92.

The results of these tests confirm that Model B, with partial mediation, represents the best fit, establishing that the proposed theoretical model, whereby cognitive abilities directly and indirectly influence problem-solving performance via self-efficacy, is the correct model.

Grade and Gender Differences

Multi-group analysis was conducted to determine whether the structural model differed by grade level (Grade 11 versus Grade 10) and gender (male versus female). Sequential tests of configural, metric, scalar, and structural equality were conducted as described by Cheung & Rensvold (2002). Table 5 presents the results of invariance testing for both grouping variables.

Results in Table 5 indicate configural invariance ($\chi^2(170) = 312.48$, CFI = 0.96, RMSEA = 0.04), suggesting the same model structure fits both grade groups. Metric invariance was supported ($\Delta\chi^2(11) = 18.34$, $p = 0.073$, ΔCFI = -0.008, ΔRMSEA = +0.011), indicating equivalent factor loadings across grades. Scalar invariance was also supported ($\Delta\chi^2(5) = 9.67$, $p = 0.085$, ΔCFI = -0.007, ΔRMSEA = +0.009), suggesting equivalent item intercepts. Finally, structural path equality testing showed no significant differences ($\Delta\chi^2(5) = 7.66$, $p = 0.176$, ΔCFI = -0.003), indicating the relationships among variables are equivalent for Grade 10 and Grade 11 students. As shown in Table 6, path coefficients were remarkably consistent across grade levels, with all differences non-significant (all z-tests $p > 0.05$). The explained variance in both self-efficacy and problem-solving performance was similar across grades (R^2 differences < 0.02).

Table 5 shows that tests of invariance across gender similarly supported configural invariance ($\chi^2(170) = 318.92$, CFI = 0.96, RMSEA = 0.04), metric invariance ($\Delta\chi^2(11) = 16.78$, $p = 0.116$, ΔCFI = -0.009, ΔRMSEA = +0.012), scalar invariance ($\Delta\chi^2(5) = 8.45$, $p = 0.133$, ΔCFI = -0.006, ΔRMSEA = +0.008), and structural path equality ($\Delta\chi^2(5) = 7.33$, $p = 0.197$, ΔCFI = -0.002). While mean levels of self-efficacy differed slightly between males and females (males: M = 83.12, SD = 17.84; females: M = 79.78, SD = 19.88; $t(1016) = 2.84$, $p = 0.005$, $d = 0.18$, representing a small effect), Table 6 demonstrates that the pattern of structural relationships (path coefficients) was statistically equivalent across gender. Given scalar invariance, the small difference reflects a latent mean difference ($d = 0.18$) rather than differences in structural relations.

The results of the overall invariance tests imply robustness and generalizability of the relationships among mathematical reasoning, computational thinking, and self-efficacy as a moderating factor influencing problem-solving performance, as they generalize well across grade levels and gender, adding robustness to the findings. The constancy of the structural paths supports the construct validity of the proposed model, as it encapsulates a general principle rather than a group-specific regularity.

Table 5. Multi-Group Invariance Testing Across Grade Level and Gender

Group/Model	χ^2	df	CFI	RMSEA	$\Delta\chi^2(\Delta df)$	ΔCFI	ΔRMSEA	Decision
Grade Level (Grade 10 vs. Grade 11)								
Configural Invariance	312.48	170	0.96	0.04				Accept
Metric Invariance	330.82	181	0.952	0.051	18.34 (11)	-0.008	+0.011	Accept
Scalar Invariance	340.49	186	0.945	0.060	9.67 (5)	-0.007	+0.009	Accept
Structural Path Equality	348.15	191	0.942	0.063	7.66 (5)	-0.003	+0.003	Accept
Gender (Male vs. Female)								
Configural Invariance	318.92	170	0.96	0.04				Accept
Metric Invariance	335.70	181	0.951	0.052	16.78 (11)	-0.009	+0.012	Accept
Scalar Invariance	344.15	186	0.945	0.060	8.45 (5)	-0.006	+0.008	Accept
Structural Path Equality	351.48	191	0.943	0.062	7.33 (5)	-0.002	+0.002	Accept

Source: Authors' own elaboration

Table 6. Structural Path Coefficients by Grade Level and Gender.

Path	Grade 10 β (SE)	Grade 11 β (SE)	Male β (SE)	Female β (SE)
MR → MSE	0.32 (0.05)	0.30 (0.06)	0.33 (0.05)	0.29 (0.05)
CT → MSE	0.35 (0.05)	0.33 (0.06)	0.32 (0.05)	0.36 (0.05)
MR → PSP	0.37 (0.05)	0.35 (0.06)	0.35 (0.05)	0.37 (0.06)
CT → PSP	0.28 (0.05)	0.30 (0.06)	0.31 (0.05)	0.27 (0.05)
MSE → PSP	0.26 (0.05)	0.28 (0.06)	0.28 (0.05)	0.26 (0.05)
R^2 for MSE	0.35	0.33	0.34	0.34
R^2 for PSP	0.62	0.60	0.61	0.61

Source: Authors' own elaboration

The purpose of this research was to examine the correlations between mathematical reasoning, computational thinking, mathematics self-efficacy, and problem-solving performance among high school students, focusing on the population in Shandong Province, China. A structural equation model was proposed, tested, and confirmed among a sample of 1,018 students, hypothesizing a mediation model whereby mathematical abilities positively influence problem-solving performance as both a direct effect and a self-efficacy mediation. All research hypotheses were confirmed, and the model fit the data very well.

The results show several patterns. First, mathematical reasoning and computational thinking are established as having strong, positive predictive influences on problem-solving performance, with mathematical reasoning having a slightly stronger direct influence than computational thinking. Second, mathematics self-efficacy is confirmed as a partial mediator, explaining 18% to 24% of the total influence exerted by cognitive abilities. Finally, a vast amount of variance, 61%, is accounted for by the model, which shows that all the proposed variables fully account for individual variations in mathematical problem-solving performance.

Direct Effects of Cognitive Abilities on Problem-Solving Performance

The strong direct impacts of mathematical reasoning ($\beta = 0.36$) and computational thinking ($\beta = 0.29$) on mathematical problem-solving performance confirm H1 and H2, as hypothesized. The results are consistent with the theoretical assumptions and related findings showing that reasoning skill positively predicts mathematical performance at various developmental levels (Peng et al., 2016). Computational thinking skills are crucial for mathematical problem-solving, as identified by Li et al. (2021).

The slightly greater effect size for mathematical reasoning than for computational thinking could be attributed to several reasons. First, mathematical reasoning engages directly with the cognitive processes involved in mathematical problem-solving, such as analyzing, making inferences, and building logical arguments. Second, the mathematical curriculum and instruction in China have often stressed mathematical reasoning and the development of logical thinking, which could affect the level of development or the link between mathematical reasoning and mathematical problem-solving performance in this group of participants.

Computational thinking, although important as well, may operate through a slightly different mechanism. Applications of computational thinking skills, including problem decomposition, pattern recognition, and algorithm development, are general strategies that can be reused and applied to a variety of problems, including mathematical ones, possibly through an additional step of translating a solution strategy into a mathematical problem, which could result in a slightly smaller but still strong direct effect.

The strong impacts of both abilities imply that mathematics learning should cultivate various cognitive abilities rather than only traditional mathematical abilities. This supports the mathematics curriculum reform in China, which focuses on cultivating various thinking abilities (Tang et al., 2021).

The Mediating Role of Mathematics Self-Efficacy

One of the implications or contributions emerging from this study is the evidence that mathematics self-efficacy partially mediates the relationship between cognitive abilities and performance related to the solution of mathematical problems, as suggested by H4 and H5.

Theoretically, the results of mediation tests are consistent with social cognitive theory, which contends that cognitive skills are not directly translated into performance but that motivational beliefs, specifically self-efficacy beliefs, play a vital role in the process (Bandura, 1997).

The partial, rather than total, mediation suggests that both direct and indirect associations are present. The direct associations imply that cognitive abilities have a direct influence on problem-solving, as students with strong cognitive abilities are able to better evaluate a problem, think out a strategy, and correctly implement a solution. The indirect associations between cognitive abilities and problem-solving via self-efficacy imply that cognitive abilities are related to personal confidence, which positively impacts related behavioral traits, including selecting difficult problems, persisting when encountering difficulties, effectively handling anxiety, and approaching a problem with optimistic expectations.

The proportion of mediation provides useful information regarding the relative weight given to motivational as opposed to cognitive components. Cognitive abilities are seen to be the primary direct predictive forces underpinning performance, whereas self-efficacy explains a substantive part of this influence. The implication is that any performance improvement strategy relating to problem-solving should enhance both skill and self-efficacy levels.

The results are consistent with recent studies by Chinese scholars that have confirmed the mediating role of self-efficacy in diverse classroom environments. Tan et al. (2024) indicated that self-efficacy played a mediating role between teacher–student relationships and mathematical problem-solving among eighth-grade students in China. Another study, by Su et al. (2021), confirmed that self-efficacy played a part in the mediation effect between growth mindsets and mathematics achievement among primary school students in China. The present study confirms this by establishing that self-efficacy mediates the relationships of growth mindsets and of cognitive skills related to reasoning and computational thinking with problem-solving abilities.

Relative Contributions of Mathematical Reasoning and Computational Thinking

One intriguing result concerns the relative strength of the effect sizes between mathematical reasoning and computational thinking. Although mathematical reasoning exerted a mildly stronger direct effect (0.36 vs. 0.29), the effect sizes were relatively similar when including the indirect effect via self-efficacy (0.09 vs. 0.08), so that both total effects were 0.44 and 0.38, respectively. Taking into account the standard errors of these values (SE = 0.02), both indirect effects are essentially equivalent and should not be treated as differing significantly.

Such an outcome could be related to the type of competencies involved and their associations with self-efficacy beliefs. Reasoning, a competence strongly related to traditional mathematical problem-solving, may have a more direct link to mathematical problem-solving activities. Students are in a position to directly apply their reasoning skills to examine a problem structure, identify principles, and build a solution logically.

Computational thinking, involving approaches such as decomposition, pattern recognition, and algorithmic thinking, may even appear as newer or innovative skills to the students. Being successful with the strategies involved in CT could be a strong confidence-builder, as it involves proficiency with twenty-first-century approaches to problem-solving. Second, the systematic nature of problem-solving as a hallmark of CT could bring the students' attention to their problem-solving approaches, leading to a metacognitive development that aids self-efficacy development.

The result supports the integration of computational thinking into mathematics education, as both skills are major contributors to problem-solving performance. Recent research comparing mathematics textbooks in China and Canada indicated that the integration of computational thinking is still an emerging process among the former group (Zhang & Savard, 2023). The results from this study imply that development in computational thinking skills, when incorporated with mathematical reasoning, could better prepare problem-solving skills among Chinese students.

Explained Variance and Model Comprehensiveness

The structural model accounted for 61% of the variance in problem-solving performance, which suggests a strong predictive fit. Such a high proportion of explained variance is exceptional in educational research, implying that mathematical reasoning, computational thinking, and self-efficacy tap into the dominant elements influencing problem-solving competence.

The remaining 39% unaccounted variance reflects a number of other influences that are not specified by this model: other cognitive skills (working memory, processing speed, spatial skills), other motivational parameters (interest, goal orientations, academic emotions), other teaching parameters (classroom instruction, curriculum, peers as a learning environment), and contextual parameters (support at home, socioeconomic parameters, values).

Interestingly, the model accounted for 34% of the variance in mathematics self-efficacy, signifying that reasoning and computational thinking are crucial markers related to confidence beliefs, but they are not the only indicators related to self-efficacy development. Based on the theory proposed by Bandura (1997), self-efficacy is developed through four sources: Mastery Experiences, Vicarious

Experiences, Verbal Persuasion, and Physiological States. The present model deals mostly with cognitive capabilities related to the development of Mastery Experiences. Other areas that could increase the variance explained in self-efficacy include observing successful peers, teacher and parent support, and mathematics anxiety, among others.

Implications for Mathematics Education in China

The results have a number of implications for mathematics education in China:

The findings are consistent with a reform curriculum approach adopted by China, focusing on the development of a variety of mathematical competencies. Instead of exclusively stressing computational fluency, mathematical reasoning and computational thinking should be developed as components of mathematics instruction. This could occur by integrating open mathematical problems, directly instructing decomposition or algorithmic strategies, or allowing applications related to the mathematical concept, among other approaches.

Teachers should be aware that building cognitive abilities is only part of the job, and they should concern themselves with building students' confidence as well, or even communicate this concern to students as their teachers. This could be achieved in a number of ways: by providing appropriate levels of challenges and exercises that will extend their abilities but will still be reachable; by providing feedback stressing improvement and effort rather than a fixed, concrete ability; by organizing class settings centered around success rather than mere accomplishment; by teaching students self-management strategies that will allow them to deal with difficulties; and by establishing a classroom atmosphere that makes failures a natural part of learning.

Presently, the evaluations conducted are viewed as stressing fluency and accuracy by many schools in China. Based on the findings, the evaluations should consider examining an individual's reasoning skills, computational competence, and self-regulated problem-solving skills to signal their significance by showing their importance to students and teachers.

Diagnosis-based tests could indicate whether mathematics difficulties are due to a lack of skills, low self-efficacy, or both. Based on this, strategies could be developed to address the issue effectively. Students with strong skills but low confidence could receive attribution retraining, anxiety management, or goal-setting approaches. Students with low skills could receive training in reasoning strategies and approaches, as well as confidence-building activities.

One implication that emerges from the results is the importance of training teachers to enhance both cognitive skills and motivational beliefs. It could be beneficial if teachers are trained to: (1) enhance students' reasoning skills directly rather than expecting them to acquire those skills implicitly, as they appear to do now; (2) attend to self-efficacy concerns; (3) enhance competence as well as confidence; and (4) enhance self-efficacy while maintaining high demands.

Comparison with Western Educational Contexts

The pattern of results shows both convergence and divergence when compared with Western-based studies. The meaningful significance of the effect of reasoning on problem-solving performance is consistent with Western findings, as stated by Jing, Wan, & Holvoet (2016). The strength of significance may differ across cultural environments due to instructional emphases.

A past study comparing US and Chinese students found that Chinese students outperformed their US counterparts on process-constrained problems involving algorithmic reasoning but fared less well on process-open problems demanding flexible reasoning (Cai, 2000). The results of this study show that reasoning, when present, was a strong predictor of problem-solving among Chinese participants, implying that Chinese students with the potential to solve problems by flexible reasoning can do so effectively, but this potential may not be fostered by education equally among all students.

The mediating role of self-efficacy appears strong across cultures, although the relative weight may differ. In Western cultures that value individualism and agency, self-efficacy could mediate a greater percentage of the variation in performance. From the Chinese cultural perspective, which emphasizes improvement, the relative weights on cognitive versus motivational beliefs may differ, as proposed by Su et al. (2021). The present study's mediation percentage of 18–24% suggests that self-efficacy plays a role, although perhaps not a crucial one, among this population in China.

CONCLUSIONS

The present study provides empirical evidence that mathematical reasoning (MR) and computational thinking (CT) are strong predictors of problem-solving performance (PSP) among high school students, with mathematics self-efficacy (MSE) acting as a partial mediator. Together, MR, CT, and MSE account for 61% of the shared variance in problem-solving performance. Mediation analysis indicated that self-efficacy explains 18–24% of the total effects, highlighting its role in translating cognitive abilities into performance. Both MR and CT exert significant direct and indirect effects, emphasizing the importance of enhancing cognitive and motivational competencies simultaneously in mathematics education.

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The findings were consistent across grades and genders, suggesting that these relationships reflect general educational processes rather than group-specific patterns. This has implications for mathematics curriculum development and reform, encouraging educators and policymakers to emphasize both cognitive skills and students' confidence beliefs to foster higher-order problem-solving abilities. Integrating CT alongside traditional mathematics skills may support more holistic and 21st-century–oriented mathematics education.

This study contributes to the global research literature by validating these relationships in a Chinese context, facilitating cross-cultural comparisons and informing theory on the interplay between cognitive and motivational factors in mathematics learning.

Limitations include the cross-sectional design, which prevents causal inference and raises the possibility of reversed effects (e.g., better problem-solving enhancing self-efficacy). The reliance on self-reported CT and MSE measures may introduce response biases, and participants were drawn from a relatively wealthy region (Shandong Province), limiting generalizability.

Future research directions include longitudinal studies to examine the developmental pathways of MR, CT, and MSE, experimental interventions to enhance these competencies, and cross-cultural studies comparing Eastern and Western contexts. Additional studies should incorporate objective performance measures, broader regional sampling, and process-tracing methods to better understand how self-efficacy interacts with cognitive skills, choice, persistence, and mathematical creativity over time.

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