International Journal of Mathematics and Mathematics Education
https://journals.eduped.org/index.php/ijmme
Volume 04, No. 1, 2026

e-ISSN 2986-4534
p-ISSN 2988-0734

Metacognitive Knowledge and Mathematics Engagement Among Senior High School Students: Mediating Role of Cognitive Flexibility

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Received: 6/12/2025 Revised: 15/1/2026 Accepted: 18/1/2026

ABSTRACT

Purpose – The study aimed to investigate the impact of metacognitive knowledge on senior high school students' engagement in mathematics and to explore cognitive flexibility as a mediating variable. The study addresses the ongoing disengagement in mathematics and the need to understand the cognitive processes that facilitate active learning.

Methodology – The study used a quantitative cross-sectional survey of 341 students from three senior high schools in Ghana. Participants were selected using both stratified and simple random sampling.

Findings – Metacognitive knowledge did not directly influence engagement in mathematics, but it did positively influence cognitive flexibility. Furthermore, cognitive flexibility positively affected engagement. Cognitive flexibility fully mediated the effect of metacognitive knowledge on mathematics engagement ($\beta = 0.393$, $p < 0.001$).

Novelty – This study provides a novel empirical contribution by demonstrating the full mediating role of cognitive flexibility in the relationship between metacognitive knowledge and mathematics learning engagement.

Significance – This study is helpful for teachers, curriculum developers, and educational researchers in designing mathematics learning strategies that emphasize the development of students' cognitive flexibility.

Significance – This study also contributes to the evidence from Ghana by demonstrating that engagement in mathematics depends on cognitive flexibility to supplement metacognitive knowledge, thereby providing valuable insight into the psychological mechanisms underlying mathematics learning.

Keywords: Adaptability; Cognitive flexibility; Mathematics engagement; Metacognitive knowledge; Self-regulated learning.

How to cite: Gyimah, I. O., Ackon, J., & Frimpong, K. O. (2026). Metacognitive Knowledge and Mathematics Engagement Among Senior High School Students: Mediating Role of Cognitive Flexibility. *International Journal of Mathematics and Mathematics Education*, 04(1), pp, 40-54, doi: https://doi.org/10.56855/ijmme.v4i1.1866

1. Introduction

Mathematics requires key qualities such as engagement, motivation, and perseverance, which are essential for students to succeed and sustain their involvement in STEM-related professions (Dogaru et al., 2025). However, international evidence (Caspi & Gorsky, 2024; OECD, 2023) shows growing disengagement. A duration of commitment ends with a conceptual grasp of mathematics, as well as the opportunity to apply mathematics to solving problems in the real world (Asare & Boateng, 2025). Many students abandon their interest in a task upon discovering methods that are too inflexible or do not work for them, even though several more flexible options are available.

A significant barrier to learning flexibility is a lack of adaptability, as modern learning environments require it to facilitate effective learning. Recent studies have started exploring cognitive factors that encourage adaptability with a focus on metacognitive knowledge of one's thinking processes and cognitive flexibility (the ability to shift thinking to a new context (İdawati et al., 2020). Metacognitive knowledge refers to how people understand their abilities to control their own thinking processes. It includes not only knowing how to do things but also being able to assess one's own performance and the extent of one's learning. Metacognitive knowledge is particularly relevant in mathematics education, especially in Ghanaian senior high schools, where disengagement is prevalent, as it involves approach monitoring and adaptation, and demands focused investigation.

A student's awareness of their metacognitive abilities enables them to monitor, assess, and revise their learning styles when faced with challenges, which in turn increases both motivation and achievement (Asare & Larbi, 2025). Instruction that supports metacognitive awareness has been linked to improvements in problem-solving skills and increased flexibility. Several studies have examined the effect of metacognitive knowledge on students' mathematics engagement and cognitive flexibility. For example, Gaylo and Dales (2017) In their study of 60 grade 9 students, they found that metacognitive strategies together with mathematics engagement positively influenced students' academic achievement. Moreover, Idawati et al. (2020) investigated the effect of problem-solving method and cognitive flexibility on improving 144 pre-service students' metacognitive skills. Their results found that metacognitive knowledge positively impacted pre-service students' cognitive flexibility. Furthermore, Caliskan and Altun (2025) examined the impact of cognitive flexibility and 341 high school students' mathematics engagement, and they found that the effect of cognitive flexibility positively impacted high school students' mathematics engagement. However, little is known about the specific mechanism through which metacognitive knowledge promotes sustained engagement in mathematics, especially in Ghana, where student disengagement is a recurring issue. Based on this, we decided to add to the literature by examining the mediating cognitive flexibility in the nexus between metacognitive knowledge and students' mathematics engagement.

The purpose of this study is to clarify the relationship between metacognitive knowledge and cognitive flexibility in promoting sustained engagement in mathematics, with a particular focus on whether cognitive flexibility can help bridge the current gap. Cognitive flexibility refers to one's ability to adjust thinking and behavior in response to new learning or an environment (Katekhaye & Magda, 2024) and may serve as the mechanism that links metacognitive knowledge to learning engagement among students. As a result of this relationship, instructional approaches will be designed to foster active, resilient, and motivated secondary school mathematics learners.

Flexible students cognitively view problems from multiple perspectives to reorganize their prior knowledge and gain a deeper understanding of concepts (Kalyuga et al., 2010). In mathematics, cognitive flexibility enables students to avoid rigid, recurrent patterns of behavior and to consider alternative forms of inquiry. Ghanaian studies show that cognition is positively related to creative thinking and problem-solving, thereby reducing students' struggle with the rich and complex mathematics involved (Asare et al., 2025). On the contrary, many students exhibit tendencies toward cognitive rigidity, relying on routines and traditional approaches. Additionally, students adopt these cognitive strategies out of a fear of inconsistency (Cotič & Zuljan, 2009). Research supports the notion that the development of cognitive flexibility not only enhances the quality of thinking related to problem-solving but also increases emotional resilience and well-being, all of which contribute to academic engagement (Çetinkaya & Haskan Avcı, 2025).

El Galad et al. (2024) claimed that flexibility and resilience enable students to address academic challenges with greater success, which is consistent with Bandura's (1999) Social Cognitive Theory posits that self-efficacy is a precursor to adaptive cognition and resilience. Consequently, cognitive flexibility may underpin the process by which metacognitive knowledge enables students to persist in their engagement with mathematics.

1.1 Literature Review and Hypothesis Development

The Metacognitive Theory posits that learners who are aware of their cognitive actions (task demands, strategy use, and self-regulation of thinking) achieve a deeper level of learning among Ghanaian mathematics learners when they can regulate their awareness of problem-solving processes and persist in the face of problem-solving difficulty. Learners will, through metacognitive regulation, continue to check and adjust to permit greater flexibility and perseverance (Asare & Mitchell, 2020).

Zimmerman's (1989) Self-Regulated Learning (SRL) Theory complements the metacognitive perspective by describing the processes of goal setting, action planning, progress monitoring, and outcome reflection, allowing learners to guide their learning experience. Self-regulated learning enables learners to take charge of their learning, interests, and perseverance, which are essential requirements for academic success. Goal setting, in addition to strategic modifications, enhances motivation and cognitive flexibility (Asare et al., 2024).

Combining these two perspectives offers a comprehensive account of the influence of metacognitive awareness on adaptive learning behavior. Metacognitive Theory provides insight into how students become aware of their own thinking, and Self-Regulated Learning Theory offers an understanding of how individuals apply that knowledge to regulate their own learning (Negretti, 2012). These two frameworks reveal that metacognitive reasoning and self-regulation lead to less rigidity, greater tenacity, and a higher willingness to engage in mathematics.

Wolters (2003) claim that having some degree of understanding about their cognitive processes contributes to persistence, motivation, and a sense of control over their learning. Kumassah et al. (2024) found that when students were taught metacognitive strategies, their academic performance and engagement increased. Students with a weak understanding of their own metacognition, including those who are anxious about mathematics, may exhibit rigid strategies that hinder their engagement. Aladini et al. (2025) claim that engaging students in opportunities for reflective thinking as part of their problem-solving can increase engagement in the learning task by enhancing cognitive flexibility.

Wang and Jou (2023) highlighted the strong relationship between metacognition and learning conditions that enhance flexibility. When students acquire metacognitive knowledge of cognitive strategies, they can use them flexibly and creatively. Interventions that involve metacognitive knowledge can lead to improvement in adaptation and resilience (Brinkhof et al., 2023). Furthermore, Merkebu et al. (2023) demonstrated that the implicit metacognitive elements of emotional regulation and critical thinking are predictive of cognitive flexibility.

Students who demonstrate cognitive flexibility are more inclined to transition between strategies, exhibit creative thinking, and stay engaged in an activity (Önen & Koçak, 2015). Cognition correlates with lower anxiety when performing mathematics (Passolunghi et al., 2016), and students who are flexible in their cognitive approach may be more willing to consider distinct paths to solutions. Emotional bandwidth is also a component of cognitive flexibility, contributing to students' ability to engage in mathematics (Wang & Jou, 2023).

Metacognitive knowledge is the basis for adaptive learning; however, it does not necessarily mean that students will be able to apply what they have learned flexibly while they are learning (Vovides et al., 2007). Cognitive flexibility enables students to transform their metacognitive knowledge into adaptable, context-specific problem-solving strategies (Leclercq et al., 2022). Cognitive flexibility helps students stay interested by serving as a bridge between metacognitive knowledge and engagement in mathematics. This is especially true when they have to solve difficult or unfamiliar mathematics problems.

Based on the integration of Metacognitive Theory and Self-Regulated Learning, we propose testable hypotheses linking mathematics engagement to metacognitive knowledge, with cognitive flexibility as a mediating mechanism. Recognizing that Self-Regulated Learning concentrates on goal setting and strategy adaptation, which rely on metacognitive awareness, we will suggest:

H1: Metacognitive knowledge has a positive and significant direct effect on students' mathematics engagement.

H2: Metacognitive knowledge has a positive and significant direct effect on cognitive flexibility.

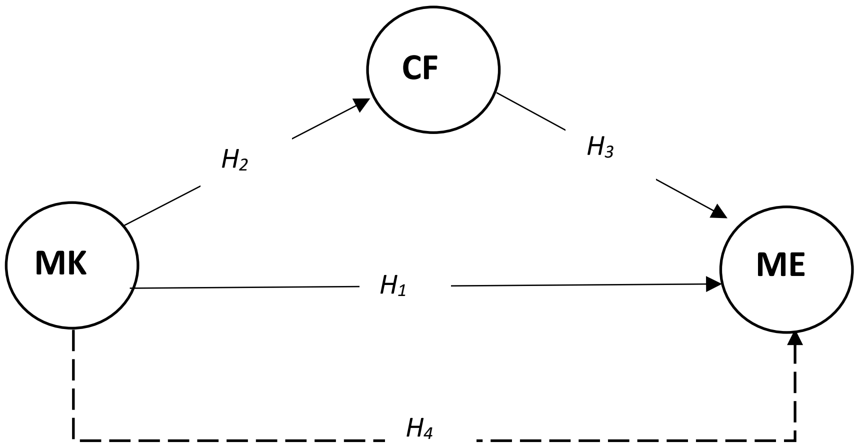
H3: Cognitive flexibility has a positive and significant direct effect on students' mathematics engagement.

H4: Cognitive flexibility mediates the relationship between metacognitive knowledge and students' mathematics engagement.

2. Methods

2.1. Research Design

The study employed a quantitative cross-sectional survey design, which provided a structured approach to gathering and analyzing numerical data, enabling the identification of patterns and relationships between selected variables. Consistent with Creswell (2014) In cross-sectional surveys, which measure the relationship between constructs at a single point in time, the researchers were able to examine the factors of interest without time-changing influences. The study examined how cognitive flexibility mediates the relationship between metacognitive knowledge and mathematics engagement among Senior High School students in the Kumasi Metropolis of Ghana, using a single assessment and collecting all data from participants at one time. Figure 1 illustrates the study's conceptual framework.



Source: Authors' Creation (2025)

Figure 1. Conceptual Framework

The conceptual framework for the current study illustrates the relationships between Metacognitive Knowledge (MK), Cognitive Flexibility (CF), and Mathematics Engagement (ME). The framework describes relationships in which MK is interpreted as a predictor of whether students' engagement in mathematics occurs directly or indirectly. Students who are aware of and regulate their thinking become more flexible and adaptable in their use of strategies to solve mathematical problems. That flexibility and adaptability, which represent CF support, are ongoing interests, motivations, and/or persistences in learning. As a result, CF acts as a mediator between MK and ME. Anchored in Metacognitive Theory and Self-Regulated Learning Theory, the conceptual framework illustrates the relationships among awareness, regulation, and flexibility in supporting Ghanaian students' ongoing engagement in mathematics.

2.2. Population

The participants in the study comprised all first- and second-year learners selected from three senior high schools within the Kumasi Metropolis of Ghana's Ashanti Region. This group consisted of diverse adolescents who are currently pursuing secondary education in the area. Since mathematics is a compulsory subject for all learners in senior high school, it can be expected that each participant attended mathematics instruction at some point during the school day. This critical aspect validates the learners' exposure to mathematics lessons in their respective schools and is a necessary criterion for this sample to align with the study's aims.

2.3. Sampling and Sample size.

It was not feasible to include all students from the three selected senior high schools. Therefore, the authors considered a representative sample. We calculated the minimum sample size needed for the study using Daniel Soper's A-priori Sample Size Calculator for Structural Equation Modeling (Soper, 2025) using three latent constructs, fifteen measured variables, an effect size of 0.20, a power of 0.86, and a significance level set at 0.05. The calculator recommended a minimum of 341 students for the study. Once this was determined, the study used a multi-stage sampling technique. Stratified random sampling was used to group students by their academic programs, and simple random sampling was used to select participants from each group.

Table 1 - Demographics of Respondents

Demographic Characteristics	N	Percentage (%)
Gender		
Male	160	46.92
Female	181	53.08
Age		
Under 15 years	72	21.11
15 – 17 years	89	26.10
18 – 20 years	80	23.46
Above 20 years	100	29.33
Level of Study		
SHS 1	148	43.40
SHS 2	193	56.60
Programme of Study		
General Arts	93	27.27
General Science	85	24.93
Business	82	24.05
Home Economics	81	23.75
Total	341	100

2.4. Questionnaire and Measures

A 5-point Likert scale (1 = strongly disagree to 5 = strongly agree) was used to collect quantitative data on the items from the study's scale. The questionnaire was divided into four sections: Section A contained respondents' demographic information, and Sections B, C, and D addressed the study's constructs (Metacognitive Knowledge, Cognitive Flexibility, and Mathematics Engagement). To assess students' metacognitive knowledge, the researchers developed five items based on the study by Tian et al. (2018), which explored the impact of metacognitive knowledge on mathematics performance.

For measuring cognitive flexibility, this study borrowed from the well-established Cognitive Flexibility Inventory developed by Dennis and Vander Wal (2010) and adapted five items from this inventory. An additional five items were adapted from the study of Luttrell et al. (2010) to address students' engagement in mathematics. The use of a pre-validated questionnaire significantly contributed to the methodological rigor of the study, as it assisted in ensuring, for example, the reliability and validity of the findings, as recommended by Haji-Othman and Yusuff (2022). The original items from previous research were appropriately modified to ensure cultural appropriateness, contextual relevance for the Ghanaian educational setting, and clarity.

2.5. Validity and Reliability

The validity of the research instrument was evaluated for content validity by experts who reviewed each item for clarity, its relevance to the study's aims, and its relation to the research objectives. The construct validity of the research instrument was additionally supported by the factor loadings and Average Variance Extracted (AVE). Following Haji-Othman & Yusuff (2022), Sürücü & Maslakçi (2020), and Taherdoost (2018), an AVE greater than 0.50 and a minimum of Cronbach's alpha of 0.70 indicated sufficient convergent validity and reliability. All three constructs measured, metacognitive knowledge, cognitive flexibility, and mathematics engagement, passed the suggestive thresholds for sufficient convergent validity. Additionally, the scales' reliability was assessed using Cronbach's alpha in SPSS (v.27), and the scales demonstrated internal consistency, exceeding the minimum threshold. These are represented in Table 2.

Table 2 - Convergent Validity and Reliability

Variables	Number of items	AVE	Cronbach's Alpha
MK	5	0.631	0.895
CF	5	0.628	0.893
ME	5	0.648	0.902

2.6. Exploratory Factor Analysis, KMO, and Bartlett's Test

We conducted an exploratory factor analysis (EFA) to determine the latent structure of items measuring the constructs of interest in the study. Component analysis with varimax rotation was used to verify whether our observed variables grouped correctly under their intended constructs, as this method maximizes the variance accounted for by each factor. Consistent with existing guidance (Akendita et al., 2025; Boateng et al., 2024; Davor et al., 2024; Edo et al.,, 2024; Lotey et al., 2025), only items with factor loadings greater than 0.50 are considered meaningful in the amount of variance that they are helping to explain.

The Kaiser-Meyer-Olkin (KMO) measure, with a value of 0.935, indicated sufficient sample adequacy and assessed the suitability of our data for factor analysis. The Bartlett's Test of Sphericity also yielded $\chi^2(105) = 3156.340$, $p < .001$, suggesting adequate correlations for factor extraction. We evaluated multicollinearity and found it acceptable based on the determinant of the correlation matrix (7.905E-5). Overall, the factors extracted for the three constructs explained 71.11% of the total variance, which exceeds the 50% threshold indicated by Marsh et al. (2020).Table 3 presents the EFA results in detail.

Table 3 - Exploratory Factor Analysis, KMO, and Bartlett's

Rotated Component Matrix			
Measurement Items	**Component**		
	1	**2**	**3**
MK1		.820	
MK3		.790	
MK4		.784	
MK5		.788	
MK6		.795	
CF2			.753
CF3			.788
CF4			.727
CF5			.807
CF6			.749
ME1	.794		
ME2	.828		
ME3	.808		
ME4	.810		
ME5	.791		

Rotated Component Matrix			
Measurement Items	Component		
	1	2	3

KMO and Bartlett's Test

Total Variance Explained		71.11%
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.935
Bartlett's Test of Sphericity	Approx. Chi-Square	3156.340
	df	105
	Sig.	.000
Determinant		7.905E-5

2.7. Confirmatory Factor Analysis

Confirmatory factor analysis (CFA) is a multivariate statistical method that examines whether observed variables serve as indicators of a designated number of latent constructs, thereby assessing their theoretical validity. Regarding model fitness, previous studies (Hair et al., 2010; Ong et al., 2020) have suggested the following standards: CMIN/DF less than 3, CFI and TLI greater than 0.90, RMR and RMSEA less than 0.08, and GFI equal to or greater than 0.80.

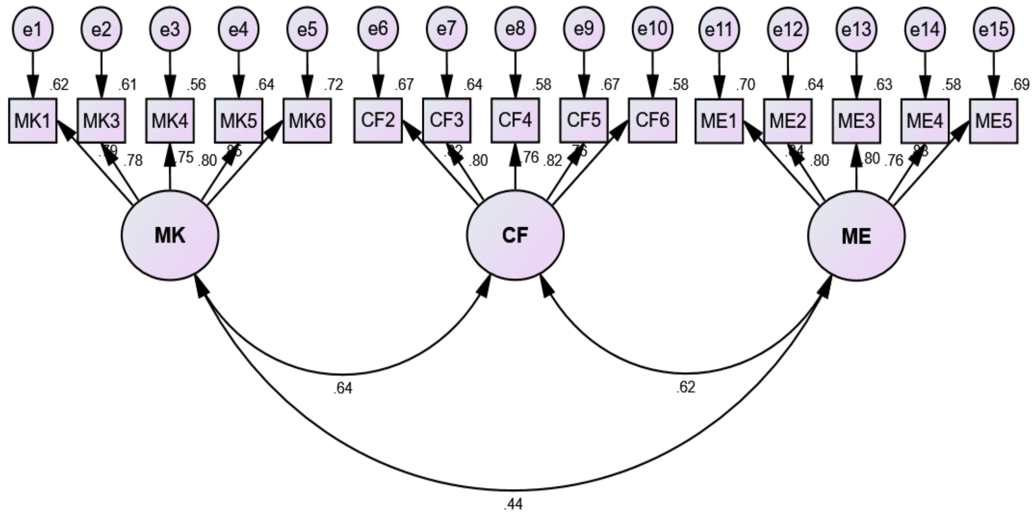
All indices met these criteria in the CFA results, indicating the model demonstrated an adequate fit. All observed variables also yielded standardized factor loadings (SFLs) greater than 0.50, indicating construct validity. Additionally, both composite reliability (CR) and the average variance extracted (AVE) exceeded the common standards of 0.70 and 0.50, respectively, indicating convergent validity (Fornell & Larcker, 2014). These results provide support for the validity and strength of the measurement model.

Table 4 - Confirmatory Factor Analysis

Model Fitness: *CMIN = 99.244; DF = 87; CMIN/DF = 1.141; TLI = 0.995; CFI = 0.996; GFI = 0.963; RMSEA = 0.020; RMR = 0.063; PClose = 0.998*		***SFL***
MK: CA= 0.895; CR = 0.895; AVE = 0.631		
MK1	I understand what I am good at and what I need to improve when working in mathematics.	.789
MK3	I think about how I will solve the mathematics task before I start it.	.778
MK4	I reflect on how I solved mathematical problems and consider whether I could have done so better.	.752
MK5	I am aware of the conditions under which I learn mathematics best	.799
MK6	I am aware of how well I am progressing while working on a mathematics activity	.849
CF: CA= 0.893; CR = 0.894; AVE = 0.628		
CF2	When a mathematics task becomes difficult, I can think of several ways to approach it	.819
CF3	I find it easy to switch between different problem-solving strategies in mathematics.	.799
CF4	I can see things from multiple perspectives in mathematics class.	.761
CF5	If I don't understand a mathematical topic, I search for alternative explanations.	.817
CF6	I am flexible in how I organise my work when doing mathematics.	.764
ME: CA= 0.902; CR = 0.902; AVE = 0.648		

ME1	I participate actively in mathematics class discussions.	.836
ME2	I ask questions in mathematics when I am unsure.	.802
ME3	I collaborate with classmates in mathematics to better understand concepts.	.796
ME4	I reflect on my mathematics learning and consider ways to improve.	.759
ME5	I always strive to excel in my mathematics lessons.	.829

NB: SFL = Standard Factor Loading(s)



Source: Authors' Creation (2025)

Figure 2. Confirmatory Factor Analysis (CFA)

2.8. Discriminant Validity

Discriminant validity was assessed by comparing the square root of the Average Variance Extracted (√AVE) for each construct with the correlations among the constructs. Several studies (e.g., Arthur et al., 2024; Asare, 2026; Asare et al., 2025; Roemer et al., 2021) assert that discriminant validity is established when the minimum √AVE value of the constructs surpasses the maximum correlation between constructs. As presented in Table 5, the minimum √AVE obtained was 0.792, whereas the maximum inter-construct correlation was 0.644. This indicates that the constructs demonstrate adequate discriminant validity, as the smallest √AVE is larger than the highest correlation coefficient.

Table 5 - Discriminant Validity

Variables	CR	AVE	MK	CF	ME
MK	0.895	0.631	0.794		
CF	0.894	0.628	0.644*	0.792	
ME	0.902	0.648	0.437*	0.618*	0.805

*Note: √AVEs are in italic and bolded; * represents a p-value less than 0.01 significant level.*

3. Results and Discussion

3.1 Results

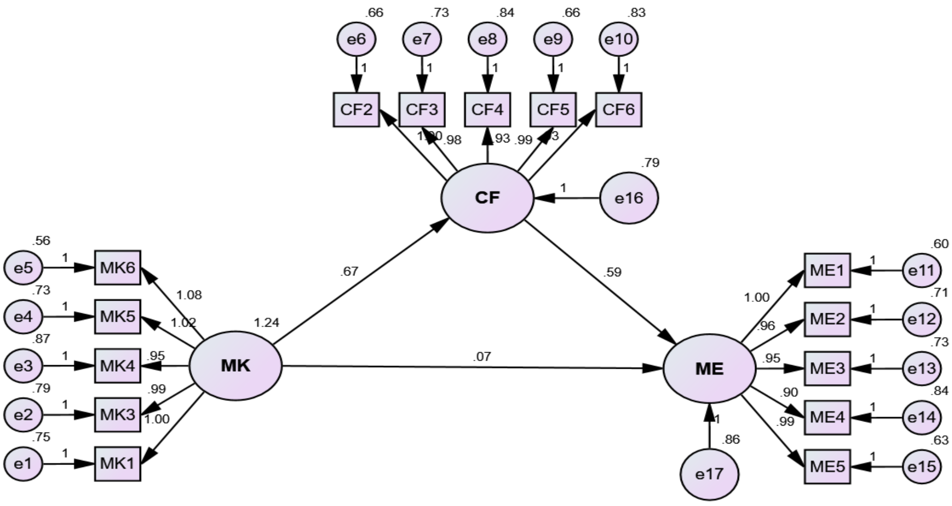
The structural relationships highlighted in the study's conceptual framework were analyzed using AMOS version 23. To minimize estimation bias, we employed a bias-corrected bootstrap method at the 95% confidence level, with 5,000 resamples. The model hardware was evaluated according to the widely used fit thresholds recommended by Hu and Bentler (1999) to ensure the model was sufficient. A summary of the hypothesis testing is shown in Table 6.

Table 6 - Path Summary

Direct Effects	**Std. Estimate**	**S.E.**	**C.R.**	**p-value**
MK → ME	0.071	0.074	0.960	0.339
MK → CF	0.670	0.063	10.635	***
CF → ME	0.587	0.077	7.623	***
Indirect Effect	**Std. Estimate**	**Lower BC**	**Upper BC**	**p-value**
MK → CF→ ME	0.393	0.286	0.523	0.000

*Note: *** represents p-value less than 0.01(1%) level of significance*

According to Table 6, the direct path from metacognitive knowledge to mathematics engagement was not statistically significant ($\beta = 0.071$, $p = 0.339$), suggesting that metacognitive knowledge does not directly influence students' engagement. Metacognitive knowledge had a strong, statistically significant direct effect on cognitive flexibility ($\beta = 0.670$, $p < .001$), indicating that students who are more metacognitively aware are better able to adjust their thinking strategies when approaching mathematical activities. This result supports the second hypothesis, as it maintains the conclusion that students who reflect on their own learning processes will be better equipped to effectively switch and shift cognitive processes. Moreover, cognitive flexibility also had a statistically significant positive effect on mathematics engagement ($\beta = 0.587$, $p < .001$). Students who adapt their ideas and approach to problems are more likely to maintain engagement while learning mathematics. The third hypothesis is thereby supported, suggesting that flexible thinking can be an important part of sustained engagement in mathematics.



(Source: Authors' Creation, 2025)

Figure 3. Path Analysis

The mediation analysis indicated that cognitive flexibility (CF) significantly mediates the relationship between metacognitive knowledge (MK) and mathematics engagement (ME), $\beta = 0.393$, $p < .001$. This is consistent with the mediation hypothesis and suggests that when students are more aware of their metacognitive processes, cognitive flexibility, which is the mechanism responsible for greater engagement and involvement with what they are learning about mathematics, is positively mediated.

3.2 Discussion

This research investigated the direct effect and mediating role of cognitive flexibility on the nexus between senior high school students' metacognitive knowledge and mathematics engagement. The study found that metacognitive knowledge had a positive effect on students' mathematics engagement. The result is in line with several studies. For instance, Wolters (2003) found that students' metacognitive knowledge had a significant positive effect on their mathematics engagement. Similarly, Aladini et al. (2025) revealed that engaging students in opportunities for reflective thinking as part of their problem-solving can increase engagement in the learning task by enhancing cognitive flexibility.

We noticed that metacognitive knowledge had a positive effect on cognitive flexibility. Wang and Jou (2023) found that there is a strong relationship between metacognition and learning conditions that enhance flexibility. Similarly, Brinkhof et al. (2023) found that interventions that involve metacognitive knowledge can lead to improvement in adaptation, resilience, and students' mathematics engagement. Furthermore, Merkebu et al. (2023) demonstrated that the implicit metacognitive elements of emotional regulation influence critical thinking and also impact cognitive flexibility.

Cognitive flexibility was found to impact students' mathematics engagement. Students who demonstrate cognitive flexibility are more inclined to transition between strategies, exhibit creative thinking, and stay engaged in an activity (Önen & Koçak, 2015). Cognition correlates with lower anxiety when performing mathematics (Passolunghi et al., 2016), and students who are flexible in their cognitive approach may be more willing to consider distinct paths to solutions. Emotional bandwidth is also a component of cognitive flexibility, contributing to students' ability to engage in mathematics (Wang & Jou, 2023).

Finally, the study suggests that cognitive flexibility fully mediates the nexus between metacognitive knowledge and students' mathematics engagement. Based on the results, metacognitive knowledge had a positive effect but was statistically insignificant on students' mathematics engagement, while metacognitive knowledge had a significant positive effect on cognitive flexibility, and cognitive flexibility also had a significant effect on students' mathematics engagement. Since the direct effect of metacognitive knowledge on students' mathematics engagement was not significant, cognitive flexibility fully mediates this nexus.

4. Conclusions

This research highlights the crucial role of cognitive adaptability in applying metacognitive knowledge to engage students meaningfully in mathematics. It is essential to note that metacognitive knowledge, on its own, may not directly foster engagement. However, the influence of metacognitive knowledge is evident in students' ability to be flexible and adjust their cognitive thinking when responding to challenging mathematics problems. This study supports theoretical perspectives that observe the interaction between metacognition, adaptive cognition, and self-regulation in learning. Therefore, with the possibility of improving student engagement and tenacity in mathematics, it is essential to further develop instructional strategies that promote metacognitive reflection and cognitive adaptability. Developing these skills in learners is crucial for growing their resilience in mathematics and also preparing them for success in academia, as well as in future STEM opportunities.

Educators should employ pedagogies that encourage reflection and flexible thinking, such as purposeful metacognitive prompts, open-ended tasks, and real-world investigative practices. Additionally, professional learning experience should prepare teachers to be modelers of cognitive-thinking strategies. Moreover, the curriculum and assessment programs should value process-oriented problem-solving in order to build resilient, confident, and engaged learners who are prepared to pursue complex STEM work. Moreover, the research highlighted that metacognitive knowledge fosters engagement in mathematics through cognitive flexibility, thereby illustrating the interdependencies between knowledge of one's thinking and the ability to adjust and adapt one's thinking. That is, the theoretical value of incorporating metacognition and flexibility within learning models is presented, with the emphasis that engagement is a function not just of knowledge. It is a function of strategizing, application, and adjustment within a problem context.

For further studied recommendation, future studies should employ longitudinal methodologies to more accurately demonstrate the causal relationships between metacognitive knowledge, cognitive flexibility, and engagement in mathematics. Another area to explore is the emotional and motivational components to expand the model. Comparative studies across different school contexts and intervention-based studies examining students' training in metacognitive and cognitive flexibility skills would be informative.

Acknowledgement
The authors express their sincere appreciation to all participants whose cooperation made this study possible. We are also grateful to the heads and teachers at the selected schools who provided support during the data collection process.

Conflict of Interest
The author declares that there were no conflicts of interest related to the study.

Author's Contribution
Author 1: Led the study design, methods, and original manuscript; gave input on how to review and helped in editing the manuscript.
Author 2: Collected and analyzed data, made visual outputs, and helped with revisions to the manuscript.
Author 3: Organized field activities and resources, helped with project management, reviewing and editing the manuscript.

Data Availability
Data supporting the findings of this study are available from the corresponding author upon request.

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