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Delving into the Critical Thinking Skills of Pre-Service Mathematics Teachers with Their Metacognitive Awareness

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Metacognitive awareness (MA) and critical thinking (CT) are crucial higher-order thinking skills in mathematics education. MA and CT skills of pre-service teachers are considered important predictors of their future teaching practices in the teaching and learning of mathematics. In this context, the study examines the potential effects of socio-demographic (e.g., gender) and academic variables (e.g., academic year and academic achievement) on MA and CT skills of pre-service mathematics teachers (PSTs). Additionally, the aim of this study is to explore the relationship between the MA and CT skills of PSTs. Employing a quantitative research methodology, the study was structured around a correlational model. It involved 218 PSTs, using the "MA Inventory" and "CT Standards Scale" for data collection. The data were analyzed through independent sample t-test, one-way analysis of variance, correlation analysis, and simple linear regression analysis. The findings indicate that PSTs possess a high level of MA and CT skills. Significant differences in MAs of PSTs were observed with respect to academic year and academic achievement, while the CT skills of PSTs showed significant differences concerning gender and academic achievement. A strong, positive, and significant correlation was found between MA and CT skills of PSTs. Furthermore, the MAs of PSTs were identified as a significant predictor of their CT skills, explaining 38% of the variance in CT skills.

Introduction

Higher-order thinking skills encompass a complex set of abilities that students must master throughout their educational journey to become competent adults in the 21st century (Zohar & Ben-Ari, 2022). An often overlooked yet critical aspect of 21st-century education is metacognition. Metacognition, the process of reflecting on one's own thinking, is essential for enhancing learning and empowers students to take a more active role in managing their learning processes (Wilson & Conyers, 2016). Critical thinking (CT) is a quintessential for the 21st century skill, vital for individuals' daily lives and a competency that everyone should develop (P21, 2019). As a higher-order thinking skill, CT involves the capacity to draw valid inferences, discern relationships, evaluate possibilities, predict outcomes, make logical

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decisions, and effectively solve complex problems (Ennis, 2018; Halpern, 2014).

Thinking skills are closely correlated with mathematical abilities (Schoenfeld, 2016). Within this framework, metacognitive awareness (MA) (Kuzle, 2018; Wilson & Conyers, 2016) and CT (Peter, 2012; Su et al., 2016) play a crucial role in mathematical problem-solving. Therefore, cultivating students' MA and CT skills in mathematics education is imperative. Besides, teachers play a significant role in nurturing students' MA (Karlen et al., 2023) and CT abilities (Romero-Ariza et al., 2024). In fostering 21st-century competencies, educators are pivotal agents of change, and teacher education represents a crucial phase for addressing this transformation (Romero-Ariza et al., 2024).

Researchers studying the conceptualization of MA and CT have noted that these constructs intersect in areas such as questioning, monitoring, and regulation (Ellerton, 2015; Halpern, 1998, 2014; Wilson & Conyers, 2016). Furthermore, it has been suggested that developing CT is challenging without a solid foundation in MA (Brown, 2004) and that CT depends on the effective functioning of MA mechanisms and awareness of processes, actions, and emotions (Rivas et al., 2022). Consequently, the primary objective of this study is to explore the relationship between MA and CT skills among pre-service mathematics teachers (PSTs).

Literature review

MA in mathematics education

Metacognition refers to an individual's awareness and control over their cognitive processes and strategies, as delineated by Flavell (1979). Kramarski and Kohen (2017) conceptualize metacognition as the knowledge of cognitive processes essential for comprehending a task and formulating a solution strategy. Also, MA pertains to the recognition of one's position within the learning or problem-solving trajectory, their domain-specific knowledge, and their individual learning or problem-solving strategies (Wilson & Conyers, 2016).

Research commonly conceptualizes metacognition around two interconnected components: metacognitive knowledge and metacognitive control (Desoete & De Craene, 2019; Veenman & van Cleef, 2019). Metacognitive knowledge encompasses an individual's awareness of their cognitions concerning knowledge, typically categorized into three dimensions: declarative, procedural, and conditional knowledge (Desoete & De Craene, 2019; Kuzle, 2018). Declarative knowledge pertains to what individuals understand about themselves, others, and the external environment. Procedural knowledge involves insights on effective problem-solving methods. Conditional knowledge concerns the discernment of appropriate moments for strategy application (Veenman & van Cleef, 2019). Metacognitive control relates to the application of metacognitive skills throughout the learning process or when addressing a task, with literature emphasizing four core skills: prediction, planning, monitoring, and evaluation (Kuzle, 2018).

MA is instrumental in both mathematical problem-solving and learning (Kuzle, 2018) and becomes particularly crucial when engaging with novel and challenging mathematical tasks (Urban & Urban, 2024). MA facilitates the monitoring and organization of cognitive processes within the problem-solving framework (Schoenfeld, 2016). Students lacking MA may struggle to recognize errors, monitor their actions, employ effective strategies, or articulate their solutions, which can impede successful performance (Veenman & van Cleef, 2019). Consequently, MA has a significant impact on students' mathematical achievement and performance (Muncer et al., 2022) and learning process (Schoenfeld, 2016; Veenman & van Cleef, 2019).

Given that MA is both teachable and developable, the educator's role is emphasized (Deseote & De Craene, 2019). Moreover, teachers must demonstrate cognitive and metacognitive skills to their students (Wafubwa et al., 2022), with those exhibiting high MA more likely to implement strategies that foster student MA (Dignath & Büttner, 2018). The updated General Qualifications for the Teaching Profession in Türkiye highlight the importance of self-evaluation within the "personal and professional development" competency (Ministry of National Education [MoNE], 2017), with MA encompassing the metacognitive monitoring and evaluation inherent in self-assessment (Desoete & De Craene, 2019). Therefore, uncovering and enhancing the MA of both current and pre-service teachers is of paramount importance.

CT in mathematics education

A widely accepted classical definition posits that CT is a logical and meticulous higher-order thinking skill essential for deciding what to believe or do (Ennis, 2018). As a higher-order cognitive skill, CT necessitates self-awareness of the thought process, verification of information sources, development of desired outcomes, and judicious decision-making (Facione, 1990). It encompasses problem-solving, inference, and decision-making abilities, rendering it indispensable for addressing the complex problems of daily life (Halpern, 2014).

CT is a pivotal higher-order thinking skill within mathematics education (Ennis, 2018). Throughout their lives, individuals face numerous uncertain situations, many of which require mathematical resolutions (Rott, 2021). Generally, mathematics instruction focuses on knowledge acquisition and problem-solving using this knowledge. However, the profound understanding necessary for problem-solving is contingent upon the cultivation of CT skills (Peter, 2012). Students can develop their CT skills while learning mathematics (Su et al., 2016). At the heart of CT lies the cognitive dimension of reasoning, which also forms the foundation of mathematics instruction (Ennis, 2018; Halpern, 2014). Teachers must recognize the significance of mathematical reasoning and, consequently, CT skills. They should embody and exercise CT skills in their teaching, thereby fostering the development of students' CT abilities through effective cognitive strategies (Su et al., 2016).

Considering the pivotal role of educators in cultivating CT skills, the proficiency of pre-service teachers in CT is a matter warranting attention. Teacher education programs should prioritize CT to advance societal development, as future educators have the potential to shape the CT abilities of society, beginning with K-12 education (Ellerton, 2015). The updated General Qualifications for the Teaching Profession in Türkiye underscore the necessity for teachers to be committed to ongoing professional growth (MoNE, 2017). "Continuous professional development" is listed among the domains where these General Qualifications are applicable. CT skills serve as a means to facilitate teachers' professional advancement (Romero-Ariza et al., 2024). Consequently, the CT competencies of pre-service teachers are a significant indicator of future CT pedagogical practices in mathematics classrooms (Soliemanifar et al., 2022).

Intersections between MA and CT skills

MA and CT are cognitive processes that intersect at key points (Magno, 2010). Schoen (1983, cited in Halpern, 1998), was the first to propose the connection between MA and CT, viewing the development of knowledge as CT and its organization as metacognition. Halpern (1998) later integrated metacognition and CT into his four-stage model, highlighting that metacognitive monitoring is crucial for the evolution of CT skills, with MA guiding the deployment of thinking skills through self-awareness and planning functions.

CT is commonly defined as a metacognitive process comprising sub-skills such as analysis, evaluation, and inference, which collectively augment the probability of producing a logical conclusion to an argument or a solution to a problem (Ellerton, 2015). Indeed, definitions of CT in the literature frequently include terms like reasoning, logic, judgment, metacognition, reflection, inquiry, and mental processes (Halpern, 2014). MA, often associated with various epistemological processes, can be interpreted as critical analysis of thought (Flavell, 1979; Kuzle, 2018).

There are three skill groups that can be distinguished in most approaches, and the goals and objectives of these skill groups can be characterized in terms of interpretive, evaluative and MA (Halpern, 2014). Therefore, interpretive and evaluative skills, as well as MA, are within the scope of CT skills. In the process of CT, which is becoming increasingly important as an educational goal today, individuals can use MA in the process of monitoring learning outcomes (Halpern, 1998). Thus, developing CT skills appears challenging without robust MA (Brown, 2004; Magno, 2010). The organizational structure inherent in MA is vital for the development of CT skills (Magno, 2010), and the maturation of CT skills relies on the effective functioning of an individual's mechanisms and awareness of processes, actions, and emotions (Rivas et al., 2022).

The present study

The purpose of this study is twofold. The first aim of the study was to examine the potential effects of gender, academic year, and academic achievement on MA and CT skills of PSTs. Gender variable has been examined in many studies as a factor affecting both MA (e.g., Baş, 2016; Gutierrez & Montoya, 2023; Hashmi et al., 2019; Lemieux et al., 2019; Özturan-Sağırlı et al., 2020; Stewart et al., 2007) and CT skills (Deringöl, 2017; Kandemir, 2017; Liu & Pásztor, 2022, 2023; Yorgancı, 2016; Zhao et al., 2024). However, most of these studies have focused on undergraduate students as their sample. Furthermore, the findings regarding the impact of the gender variable on both MA and CT skills are contradictory.

The results concerning the effect of the academic year, an academic variable, on both MA (e.g., Ekici et al., 2019; Gutierrez & Montoya, 2023) and CT skills among PSTs are inconsistent (e.g., Kandemir, 2017; Liu & Pásztor, 2022). Additionally, some studies have focused on the effect of academic achievement variable on MAs of PSTs (e.g., Ekici et al., 2019; Özturan-Sağırlı et al., 2020) or CT skills (Le & Chong, 2024). Evidence on the effects of academic achievement variable on MA and CT skills of PSTs reveals contradictory findings.

While studies have examined the potential impact of gender, academic year, and academic achievement variables on MA and CT skills, few have focused on PSTs within a domain-specific context in mathematics. Consequently, there is a dearth of knowledge regarding how these background factors influence MA and CT skills among this demographic. The literature has established that MA and CT skills significantly affect students' learning in mathematics, and that teachers are instrumental in developing these skills in their students. It is therefore important to investigate whether and how gender, academic year, and academic achievement influence the MA and CT skills of PSTs. Understanding their MA and CT skills profiles will offer valuable insights for the design and execution of teacher education programs.

The second one is to determine the relationship between MA and CT skills of PSTs. Researchers have been examining the links between 21st century skills such as MA and CT, but the studies were mostly conducted with undergraduate students (e.g., Magno, 2010; Ossa et al., 2023; Soliemanifar et al., 2022). In mathematics teaching processes, MA and CT emerge as crucial higher-order thinking abilities. Given the pivotal role of teachers in fostering both MA (Karlen et al., 2023) and CT skills (Magno, 2010; Romero-Ariza et al., 2024), evaluating pre-service teachers' competencies in these areas is instrumental for predicting their future instructional efficacy. However, limited research exists on this topic involving pre-service teachers across various majors including mathematics (e.g., Akcaoğlu et al., 2023; Karaoğlan-Yılmaz et al., 2019; Kozikoğlu, 2019). Henceforth, analyzing the evidence on the relationship between MA and CT skills from the perspective of PSTs is important in terms of expanding the mathematics education literature. Furthermore, cultural norms and expectations have been found to impact MA and CT abilities (Gutierrez & Montoya, 2023). This study, which was conducted in a different culture in the context of Türkiye, will provide outputs on the generalizability of the results of previous studies. In this context, this study aims to address this gap by exploring the following sub-questions:

(1) What are the levels of MA and CT skills of PSTs?
(2) Do the MA and CT skills of PSTs differ significantly according to the gender, academic year and academic achievement variables?
(3) Is there a relationship between MA and CT skills of PSTs?
(4) Do MA predict CT skills?

Method

Research model

In this study correlational research model was utilized. Correlational research determines the degree of association between two or more quantitative variables, employing a correlation coefficient for this purpose (Fraenkel et al., 2012). The rationale for employing the relational survey model in this study is to examine the relationship between MA and CT skills of PSTs.

Sample

The study's sample comprised 218 PSTs from the Elementary Mathematics Teacher Education Programme at the Faculty of Education of a state university in the Eastern Anatolia Region of Türkiye. The PSTs were selected using a convenience sampling method, which allows researchers to choose a readily accessible group for study, offering the clear benefit of ease (Fraenkel et al., 2012). Additionally, G*Power software, as recommended by Faul et al. (2009), was utilized to determine the sample size. Based on a 5% type I error and an absolute power of .99, the required number of participants was established as 101. Out of the 218 PSTs sampled, 162 (74.3%) were female, and 56 (25.7%) were male. The distribution across the academic years was as follows: 59 (27.1%) in the first year, 52 (23.9%) in the second, 56 (25.7%) in the third, and 51 (23.4%) in the fourth. Academic achievement was gauged by the

PSTs' grade point average (GPA, with a maximum of 4) from the previous semester. GPAs were categorized as low (2.99 and below), moderate (3.00-3.49), and high (3.5 and above). Accordingly, 51 PSTs (23.4%) demonstrated low, 82 (37.6%) moderate, and 85 (40.0%) high levels of academic achievement. Participation of PSTs in the study was voluntary.

Instruments

Demographic information form

This form includes questions about the gender, academic year, and academic achievement levels of PSTs.

MA Inventory

The MA Inventory (MAI), developed by Schraw and Dennison (1994) to assess the MA of adolescents and adults, was translated into Turkish by Akın et al. (2007), who also confirmed its validity and reliability. The MAI does not contain any negatively phrased items. It encompasses eight sub-dimensions: declarative, procedural, and conditional knowledge, planning, monitoring, evaluating, debugging, and information management. The inventory is structured as a five-point Likert scale, ranging from "never" to "always" and comprises 52 items. Scores on the MAI can range from a minimum of 52 to a maximum of 260, with lower scores indicating a lower level of MA and higher scores indicating a higher level of MA. The Cronbach's Alpha coefficient for the scale was .95, as reported by Akın et al. (2007). In the current study, the Cronbach's Alpha coefficient for the entire scale was found to be .89.

CT Standards Scale

In the study, the CT Standards Scale (CTSS) was utilized to measure the CT skills of PSTs. The CTSS, developed by Aybek et al. (2015), comprises three sub-dimensions that reflect the standards of CT skills: 1. Depth, breadth, and competence; 2. Precision and accuracy; 3. Significance, relevance, and clarity. The scale is structured as a five-point Likert-type scale, ranging from "strongly disagree" to "strongly agree", and includes 42 items. The 12 negatively worded statements within the scale are reverse-scored. Scores on the CTSS can range from a minimum of 42 to a maximum of 210. The Cronbach's Alpha coefficient for the scale was reported as .75 by Aybek et al. (2015). In the present study, the Cronbach's Alpha coefficient for the scale was found to be .72.

Data analysis

The data analysis was conducted using a statistical package program. Initially, the normality of the distribution of the mean scores for MA and CT skills of PSTs was assessed. This assessment utilized skewness and kurtosis values, along with the Kolmogorov-Smirnov (K-S) test. The K-S test results indicated that the mean scores for MA and CT skills of PSTs conformed to a normal distribution across gender, academic year, and academic achievement subcategories ($p > .05$). However, the total mean scores for MA deviated from normality ($p = .03 < .05$), but such deviation is not problematic in sufficiently large sample sizes (e.g., 30+), as per Pallant (2016). Moreover, all skewness and kurtosis coefficients for the specified subcategories fell within the ±1.0 range, aligning with a normal distribution. Parametric tests were therefore applied to the statistical calculations of the obtained scores. Descriptive statistics, independent sample t-tests, and one-way analysis of variance (ANOVA) were employed for the analysis of data deemed normally distributed. Evaluation intervals for the mean scores were calculated to contextualize the levels of MA and CT skills of PSTs. The levels for mean scores were defined as very low, low, medium, high, and very high (respectively 1.00-1.79, 1.80-2.59, 2.60-3.39, 3.40-4.19, 4.20-5.00). For comparisons involving more than two groups, the Tukey HSD post-hoc test was utilized upon confirmation of variance homogeneity to identify the group responsible for differences. A significant level of .05 was maintained for all statistical procedures. Effect sizes were determined using the partial eta-squared statistic (η^2) to facilitate group comparisons. The corresponding eta-squared values were interpreted as follows: .01 indicated a small, .06 signified a medium, and .14 represented a large effect (Pallant, 2016).

Subsequently, correlation analysis was used to analyze the relationship between MA and CT skills of PSTs. It was observed that the necessary assumptions (level of measurement, related pairs, independence of observations, normality, linearity and equal variance) were not violated before applying correlational techniques. Pearson correlation coefficient was calculated. The correlation coefficient was interpreted as small when r = .10-.29, moderate when r = .30-.49, and strong (large) when r = .50-1.0 (Pallant, 2016). Besides, a simple linear regression analysis was conducted to ascertain the extent to which PSTs' MAs predicted their CT skills

Results

Findings on the levels of MA and CT skills of PSTs

Descriptive findings concerning the MA and CT skills of PSTs are presented in Table 1.

Table 1. Descriptive statistical analysis of MA and CT skills of PSTs

Variable	N	Mean±SD	Min	Max
MA	218	3.53 ± .29	2.85	4.17
CT skills	218	3.63 ± .34	2.79	4.57

Table 1 indicates that the mean scores for MA and CT skills of PSTs are 3.53 and 3.63, respectively, placing both sets of skills at a high level.

Findings on whether MA and CT skills of PSTs differ by gender, academic year, and academic achievement

In exploring whether MA and CT skills of PSTs vary by gender, the independent samples t-test results are presented in Table 2.

Table 2. Independent samples T Test results for MA and CT skills of PSTs by gender

Variable	Gender	N	Mean±SD	df	t	p	η^2
MA	Female	162	3.55 ± .27	216	1.32	.19	.01
	Male	56	3.49 ± .34				
CT skills	Female	162	3.69 ± .32	216	5.00	< .001	.01
	Male	56	3.44 ± .33				

Table 2 reveals that there is no statistically significant difference in PSTs' MA scores across genders [$t_{(216)}$=1.32; p> .05]. Additionally, the eta squared value suggests that the effect size of the gender-related differences in MA scores is small (η^2= .01). Conversely, CT skills of

PSTs exhibit a statistically significant difference by gender [$t_{(216)}$=5.00; p< .05], with female PSTs scoring higher than their male counterparts. However, the effect size of the difference in mean CT skills scores between genders is small (η^2= .01). The ANOVA results of the scores of MA and CT skills of PSTs by academic year are presented in Table 3.

Table 3. ANOVA results for MA and CT skills of PSTs by academic year

Variable	Year	N	Mean±SD	ANOVA F	df-between groups	df-within groups	p	η^2
MA	1	58	3.46 ± .30	7.12	3	214	< .001	.09
	2	52	3.46 ± .23					
	3	57	3.54 ± .31					
	4	51	3.68 ± .27					
CT skills	1	58	3.58 ± .34	.75	3	214	.52	.01
	2	52	3.63 ± .35					
	3	57	3.62 ± .35					
	4	51	3.66 ± .32					

Upon examining Table 3, it is observed that the mean scores of the PSTs for their MAs are highest in the fourth year (*M*=3.68) and lowest in the first and second years (*M*=3.46). Although the mean scores of the MAs of PSTs are relatively similar, there is a discernible trend of increasing scores with advancing academic years. It was also found that the MAs of PSTs differed significantly by academic year [$F_{(3\text{-}214)}$=7.12; p< .001]. This statistical significance is complemented by a practical difference in mean scores between the groups, which is considered to be moderate (η^2= .09). Prior to conducting post-hoc analysis to pinpoint the source of these differences, the homogeneity of variance for the MAs' mean scores was confirmed (F= 1.39; p= .25> .05). The Tukey HSD test results, as presented in Table 4, were then scrutinized to interpret the inter-class disparities.

Table 3 reveals that the peak mean score for CT skills of PSTs occurs in the fourth year (*M*=3.66), with the lowest mean score recorded in the first year (*M*=3.58). Moreover, the mean scores for CT skills across the academic years are closely aligned. Furthermore, no significant difference was found in the CT skills of PSTs by academic year [$F_{(3\text{-}214)}$= .75; p> .05]. The lack of statistical significance, coupled with a small effect size between group means (η^2= .01), suggests that PSTs exhibit consistent CT skills irrespective of their year in the academic program.

Table 4. Tukey HSD Test results for MA of PSTs by academic year

Grade(I)	Grade(J)	Mean difference(I-J)	p	Difference
1	2	- .00	1.00	
	3	- .08	.46	
	4	- .22	< .001*	4>1
2	1	. 00	1.00	
	3	- .08	.50	
	4	- .22	.001*	4>2
3	1	.08	.46	
	2	.08	.50	
	4	- .14	.045*	4>3
4	1	.22	< .001*	4>1
	2	.22	.001*	4>2
	3	.14	.045*	4>3

According to the results of the Tukey HSD test detailed in Table 4, MAs of fourth-year PSTs showed a significant difference from the mean MA scores of first-year ($p< .001$), second-year ($p< .05$), and third-year ($p< .05$) PSTs. This difference is in favor of fourth year PSTs. The ANOVA results of the scores of PSTs on MA and CT skills by academic achievement are presented in Table 5.

Table 5. ANOVA results for MA and CT skills of PSTs by academic achievement

Variable	Academic achievement	N	Mean±SD	ANOVA				
				F	df-between groups	df-within groups	p	η^2
MA	Low	51	3.43 ± .28	11.68	2	215	< .001	.10
	Medium	82	3.48 ± .30					
	High	85	3.64 ± .26					
CT skills	Low	51	3.51 ± .34	16.09	2	215	< .001	.13
	Medium	82	3.54 ± .34					
	High	85	3.78 ± .28					

Examination of Table 5 reveals that PSTs with high academic achievement possess the highest mean score for MAs (*M*=3.64), while those with low academic achievement have the lowest (*M*=3.43). Furthermore, a significant difference in MAs among PSTs was observed according to the academic achievement variable [$F_{(2\text{-}215)}=11.68$; $p< .001$], with an effect size indicating medium to high differences between the group means ($\eta^2= .10$).

Concurrently, the highest mean score for CT skills is also held by PSTs with high academic achievement (*M*=3.78), with the lowest attributed to those with low academic achievement (*M*=3.51). Similarly, PSTs' CT skills differed significantly based on academic achievement [$F_{(2\text{-}215)}=16.09$; $p< .001$], with the effect size for these differences being just below the large level ($\eta^2= .13$). The Tukey HSD test was conducted to identify the sources of these differences in MAs and CT skills relative to academic achievement, with results presented in Table 6. Prior to the Tukey HSD test, homogeneity of variance was confirmed for both MAs ($F= .49$; $p= .62> .05$) and CT skills ($F= 1.63$; $p= .20> .05$).

Table 6. Tukey HSD Test results for MA and CT skills of PSTs by academic achievement

Variable	Achievement(I)	Achievement(J)	Mean difference(I-J)	p	Difference
MA	Low	Medium	- .06	.49	
		High	- .22	< .001*	High>Low
	Medium	Low	.06	.49	
		High	- .16	.001*	High> Medium
	High	Low	.22	< .001*	High>Low
		Medium	.16	.001*	High> Medium
CT skills	Low	Medium	- .02	.91	
		High	- .27	< .001*	High>Low
	Medium	Low	.02	.91	
		High	- .24	< .001*	High> Medium
	High	Low	.27	< .001*	High>Low
		Medium	.24	< .001*	High>Medium

Results from the TUKEY HSD test indicate a significant difference in the MAs of PSTs across different academic achievements. PSTs with high academic achievement demonstrate significantly greater MAs compared to their peers with low ($p< .001$) and medium ($p< .05$) academic achievements. Similarly, the CT skills of PSTs with high academic achievement are significantly differ from those with medium ($p< .001$) and low ($p< .001$), with the advantage favoring the former group.

Findings on the relationship and prediction of MA and CT skills of PSTs

The relationship between MA and CT skills of PSTs was analyzed by correlation analysis and the findings are shown in Table 7.

Table 7. Correlation analysis results for MA and CT skills of PSTs

		CT skills
MA	r	.617**
	p	.000
	N	218

** $p< .01$

Table 7 demonstrates that there is a strong, positive and statistically significant correlation between MA and CT skills ($r= .62$, $N=218$, $p< .001$). These results suggest a relationship where an increase in PSTs' MA is associated with an enhancement in their CT skills, and conversely, a decrease in MA corresponds to a reduction in CT skills. Finally, a simple linear regression analysis was performed to ascertain how PSTs' MAs predicted their CT skills, with the findings detailed in Table 8.

Table 8. Simple linear regression analysis results on MA predicting CT skills

Predicted variable	Predicting variable	B	Standard error	β	t	p
CT skills	Constant	1.09	.22		4.92	< .001
	MA	.72	.06	.62	11.53	< .001

Table 8 reveals a significant and robust relationship between PSTs' MAs and their CT skills ($R = .62$, $R^2 = .38$). The MAs of PSTs are significant predictors of their CT skills [$F_{(1\text{-}216)} =132.94$, $p< .01$], explaining 38% of the variance in CT skills. The regression analysis posits the following predictive equation for CT skills:

$$(CT) = .72 \times (MA) + 1.09.$$

Discussion and conclusions

The study's findings affirm that PSTs exhibit a high level of MA. These results align with previous research indicating that PSTs have high levels of MA (e.g., Baş, 2016; Deniz et al., 2014; Hashmi et al., 2019; Özturan-Sağırlı et al., 2020; Wafubwa et al., 2022). Given the critical role of teachers as facilitators in the development of students' MA (Karlen et al., 2023), the high MA levels observed in PSTs are considered favorable. This assertion is supported by Dignath and Büttner (2018), who found that PSTs with strong metacognitive knowledge and MA are more likely to employ and develop effective problem-solving strategies. Moreover, Kramarski and Kohen (2017) further suggest that the advancement of students' MA is contingent upon teachers possessing high levels of MA. In fact, mathematics teachers need to use metacognitive strategies in the classroom and model them for students. For this reason, mathematics teachers and PSTs are expected to understand the role of metacognition in problem-solving and to demonstrate high MA. PSTs with high MA are more successful in monitoring comprehension (Wafubwa et al., 2022; Zohar & Ben-Ari, 2022). The results of Laamena and Laurens' (2021) study, however, do not align with the findings of this study. Laamena and Laurens reported that PSTs had low levels of MA. This discrepancy may be due to methodological differences, as this study assessed PSTs' MA using a self-report scale, whereas others (e.g., Dignath & Büttner, 2018; Laamena & Laurens, 2021) employed qualitative data collection methods for a more in-depth analysis.

The study determined that the CT skill level of PSTs was high. This finding suggests that PSTs exhibit a questioning approach to knowledge, think analytically during problem-solving processes, and possess the ability to evaluate situations independently. High levels of CT skills are desirable in future teachers, as they can significantly influence the development of CT skills within society, beginning at the primary education level (Ellerton, 2015). The results of this study are consistent with other studies that have reported high CT levels among PSTs (Deringöl, 2017; Kandemir, 2017). However, there are also studies presenting contrasting results. Some research indicates that PSTs' CT dispositions/skills are at low or average levels (As'ari et al., 2017; Biber et al., 2013; Incikabi et al., 2013; Rott, 2021; Yorgancı, 2016; Yüksel et al., 2013). For instance, As'ari et al. (2017) analyzed PSTs' responses to mathematical tasks and found their CT tendencies to be at a low level, classifying them as non-critical thinkers. These discrepancies in findings may be attributed to differences in measurement tools and the characteristics of the sample groups.

The study also revealed that the MAs of PSTs do not significantly differ by gender, aligning with previous studies that reported no gender disparity in PSTs' MAs (Baş, 2016; Deniz et al., 2014; Hashmi et al., 2019; Özturan-Sağırlı et al., 2020; Stewart et al., 2007). However, this study observed that female PSTs scored higher overall than their male counterparts. In contrast, some studies have reported higher MAs in men compared to women (Gutierrez & Montoya, 2023; Lemieux et al., 2019). For instance, Lemieux et al. (2019) found that men are better than women at evaluating their own learning performance, suggesting that women may be less likely to make corrective checks in the future. Gutierrez and Montoya (2023) also noted that men demonstrated greater awareness of their knowledge and cognitive organization. These discrepancies in findings may be attributed to methodological differences; for example, these studies considered MA as a facet of self-regulation, employed task-based observations and measurements, and did not specifically focus on mathematics teaching departments. Additionally, cultural influences and adherence to traditional gender roles may contribute to the variability in research outcomes (e.g., Gutierrez & Montoya, 2023).

Another finding of the study indicated that the CT skills of female PSTs are significantly higher than those of their male counterparts. This result aligns with previous research suggesting that female PSTs exhibit superior CT skills compared to males (Deringöl, 2017; Yorgancı, 2016). Conversely, some studies have reported higher CT skills in male undergraduate students (Zhao et al., 2024). For instance, Zhao et al. (2024) suggested that men may be more prone to making snap judgments than women, potentially due to their level of self-efficacy. Additionally, several studies found no significant difference in CT skills between genders among PSTs (Biber et al., 2013; Incikabı et al., 2013; Kandemir, 2017; Yüksel et al., 2013) or university students (Liu & Pásztor, 2022, 2023). Notably, a comprehensive meta-analysis by Liu and Pásztor (2022) concluded that gender does not significantly impact CT skills. While some research did not reveal statistically significant differences, they still reported higher CT skills in women compared to men (Biber et al., 2013; Yüksel et al., 2013). Studies in cultural psychology have posited that CT is culturally contingent, suggesting that societal gender roles may influence CT skills (Gutierrez & Montoya, 2023). Therefore, cultural values within societies can be considered one of the factors contributing to the differences in CT skills according to gender.

Another result of the study is that there is a significant difference in MAs of PSTs according to the academic year. In other words, the academic year is an effective variable in MAs of PSTs. Fourth-year PTSs had significantly higher MAs than the first, second, and third years. The related literature corroborates the existence of a significant difference in MAs of PSTs according to the academic year (Ekici et al., 2019; Sezgin-Memnun & Akkaya, 2012). This finding suggests that undergraduate education bolsters PSTs' MAs. It is posited that PSTs' MAs are cultivated through the education, mathematics, and mathematics education courses they undertake throughout their education, as well as by scrutinizing their field and professional knowledge. Moreover, the fourth-year PSTs gain teaching experience by undertaking internships in schools and conducting lessons. It is anticipated and desirable for the level of MA to increase with age and experience (Karlen et al., 2023). Indeed, studies indicate that PSTs' problem-solving experiences enhance their MAs (Dignath & Büttner, 2018; Zohar & Ben-Ari, 2022). Thus, it can be inferred that one of the reasons for the disparity among fourth-year PSTs is teaching experience. Contrary to these findings, some studies in the literature concluded that there was no significant difference in the MAs of PSTs according to the academic year (e.g., Baş, 2016; Deniz et al., 2014; Özturan-Sağırlı et al. 2020; Stewart et al., 2007).

The study found no significant difference in the CT skills of PSTs when compared across academic years. This outcome is noteworthy as it has implications for the contribution of mathematics teacher training programs to students' CT skills. The absence of courses incorporating CT or higher-order thinking skills in mathematics teacher training programs in Türkiye could explain this finding. Alternatively, the pedagogical methods and techniques employed by university faculty might contribute to this result, as the lack of teaching methods that cultivate CT or higher-order thinking skills is considered a barrier to developing such skills (Carter et al., 2023). The results of the current study align with previous research indicating that the CT skills of PSTs do not vary by academic year (Incikabi et al., 2013; Liu & Pásztor, 2022; Yüksel et al., 2013). For instance, Liu and Pásztor's (2022) meta-analysis found no differences in CT skills among undergraduate students based on academic year. However, other studies have observed variations in CT skills among PSTs according to academic year (Kandemir, 2017; Yorgancı, 2016). In general, social research involving different samples from various countries and cultures is complex. These studies encompass different time periods, as well as social and educational backgrounds. Therefore, differences between studies on the same topic are understandable in this context.

Another outcome of this study is the significant difference in MAs of PSTs according to their academic achievement. This finding suggests that PSTs with higher academic achievement levels possess significantly greater MAs compared to those with low or medium levels. This result corroborates the findings of studies suggesting that PSTs with high academic performance also exhibit elevated MAs (Dennis & Somerville, 2023). Dennis and Somerville stated that individuals with higher MAs think more strategically, which correlates with better performance and greater success. The current study's outcomes are consistent with previous research exploring the relationship between MAs and PSTs' academic achievements, such as GPA. These studies have consistently found statistically significant correlations between MAs and academic performance (Ekici et al., 2019; Özturan-Sağırlı et al., 2020; Muncer et al., 2022). For instance, Muncer et al. (2022) reported a modest yet significant correlation between MAs and academic achievement in their meta-analytical studies.

In the study, it was observed that the CT skills of PSTs varied significantly according to academic achievement. Supporting this result, meta-analysis studies have found CT skills to be moderately and positively correlated with the academic achievement of students at different educational levels (Fong et al., 2017). The current study's results suggest that PSTs with high academic achievement have significantly higher CT skills than those with low and medium academic achievement. The undergraduate curriculum for PSTs is centered on learning and teaching mathematics, a discipline that inherently demands inquiry and justification. Therefore, it can be inferred that PSTs with high achievement in mathematics content knowledge and pedagogical content knowledge also exhibit high CT skills. Su et al. (2016) noted, CT skills can be developed during the process of learning mathematics, as these skills are essential when finding possible solutions, explaining the reasons, and justifying the results in the process of addressing mathematical problems. Besides, Le and Chong (2024) determined that CT skills play a crucial role in achieving academic success among higher education students.

The study's additional findings pertain to the relationship between MA and CT skills of PSTs. It was determined that a strong, positive, and significant correlation exists between MA and their CT skills of PSTs. This suggests that an increase in MA of PSTs is likely to correspond with an enhancement in their CT skills, and conversely, a decrease in MA would imply diminished CT skills. This observation corroborates the theoretically posited relationship between MA and CT skills. First of all, metacognition is often conceptualized as critical analysis of thought, a perspective supported by Flavell (1979) and Kuzle (2018). Similarly, Schoen (1983, cited in Halpern, 1998) considered the development of knowledge as CT and the process of organizing knowledge as metacognition. CT, being a high-level cognitive process that fosters elaborate thinking, is associated with elements beyond the cognitive domain, including metacognition (Rivas et al., 2022).

The study observed that the CT skills of PSTs varied significantly according to academic achievement. Supporting this result, meta-analyses have found CT skills to be moderately and positively correlated with academic achievement across various educational levels (Fong et al., 2017). The current study's findings suggest that PSTs with high academic achievement possess significantly higher CT skills compared to those with low or medium academic achievement. The undergraduate curriculum for PSTs focuses on learning and teaching mathematics, a discipline that inherently demands inquiry and justification. Therefore, it can be inferred that PSTs who excel in mathematics content knowledge and pedagogical content knowledge also exhibit high CT skills. As noted by Su et al. (2016), CT skills can be developed during the process of learning mathematics, as these skills are essential for finding possible solutions, explaining reasoning, and justifying results when solving mathematical problems. Moreover, Le and Chong (2024) determined that CT skills play a crucial role in achieving academic success among higher education students.

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Halpern, 1998) viewed the development of knowledge as CT and the process of organizing knowledge as metacognition. CT, being a high-level cognitive process that fosters elaborate thinking, is associated with elements beyond the cognitive domain, including metacognition (Rivas et al., 2022).

Furthermore, the study's outcomes align with literature that demonstrates a positive relationship between MA and CT dispositions/skills. Consistent with the current study's results, research has identified positive and significant correlations between MAs and their CT skills of PSTs (Karaoğlan-Yılmaz et al., 2019; Kozikoğlu, 2019), as well as among undergraduate students (Soliemanifar et al., 2022). For example, Facione (1990) emphasized that individuals with a high level of MA would also have high CT skills. Contrastingly, Ossa et al. (2023) presented an opposing view, failing to find a direct link between MA and CT in their study. Ossa et al. explained the possible reason for this result by the fact that they used a measurement tool that may not be sensitive to CT tasks. Therefore, it can be said that the evidence for the relationship between MA and CT skills needs to be explained with more data.

Finally, regression analysis revealed that MAs of PSTs significantly predicts their CT skills, accounting for 38% of the variance in CT skills. This finding aligns with previous research indicating that MA is a predictive variable for PSTs' (Akcaoğlu et al., 2023; Kozikoğlu, 2019) and undergraduate students' CT dispositions/skills (Brown, 2004; Ellerton, 2015; Halpern, 1998). In this regard, Halpern (1998) incorporated both MA and CT into his four-stage model, highlighting metacognitive monitoring skills as essential for CT development. Furthermore, MA encompasses self-awareness and planning functions that direct the application of thinking skills. Ellerton (2015) argues that MA is necessary for the realization of self-regulation, which is one of the CT skills. Because, self-examination and self-correction, which are sub-skills of self-regulation, cannot be realized without MA. In concordance, Akcaoğlu et al. (2023) emphasized the important role of MA in the development of CT skills by revealing that MA significantly predicts CT skills. Furthermore, the study's outcomes align with literature demonstrating a positive relationship between MA and CT dispositions/skills. Consistent with the current study's results, research has identified positive and significant correlations between MAs and CT skills in PSTs (Karaoğlan-Yılmaz et al., 2019; Kozikoğlu, 2019), as well as among undergraduate students (Soliemanifar et al., 2022). For example, Facione (1990) emphasized that individuals with high levels of MA would also possess high CT skills. In contrast, Ossa et al. (2023) presented an opposing view, failing to find a direct link between MA and CT in their study. Ossa et al. explained this result by suggesting that the measurement tool they used may not have been sensitive to CT tasks. Therefore, it can be said that further data are needed to better explain the relationship between MA and CT skills.

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Several studies have indicated that developing CT skills is challenging without MA (Brown, 2004; Magno, 2010). In this regard, Magno (2010) argued that an organizational structure like MA is necessary for the acquisition of CT skills. Similarly, Rivas et al. (2022) stated that CT depends on the proper functioning of MA mechanisms and on being aware of processes, actions, and emotions. Rivas et al. emphasized the crucial role of MA in the development of CT and demonstrated that CT skills improve with the use of metacognition. Additionally, some studies have shown that undergraduate students with high MA are better critical thinkers and are more capable of using appropriate metacognitive strategies during CT processes (Ku & Ho, 2010).

Limitations and future directions

In this section, limitations of the study and suggestions for the results are presented. Initially, this study has some limitations that can be addressed with additional studies. Firstly, in this study, MAs and CT skills of PSTs were measured with self-report instruments. While self-report instruments have limitations, such as the potential for social conformity bias, they offer the advantage of collecting data from a larger number of PSTs compared to alternative methods such as observation and interviews. Nonetheless, future studies may employ task-based interviews, observations, or multiple methods to minimize the disadvantages of self-reports and further validate the findings presented in this study. Secondly, the current study utilized a non-experimental research design. Moreover, the findings provided empirical information to explain the relationship between MA and CT skills. Due to the cross-sectional design of this study (measured at a single time point), the developmental trajectory of MA and CT skills could not be explored. Consequently, there is a discernible need for longitudinal research with PSTs. Such studies could yield insights into the impact of teacher education programs on the evolution of MA and CT skills. Furthermore, experimental studies designed in the future could establish a causal link between MA and CT skills. Upcoming research might investigate changes in MA and CT skills of PSTs, employing both quantitative and qualitative methods before and after a course that incorporates elements likely to influence these skills, such as problem-solving activities.

Thirdly, this study examined the unidirectional relationship between MA and CT skills of PSTs. Even though findings provide evidence for the relationship between MA and CT skills, further investigation is needed to explore motivational variables such as self-efficacy and autonomy that may mediate this relationship, as well as other potential interconnections from a causal standpoint. Lastly, the current study’s focus on MA and CT skills of PSTs in relation to gender, academic year, and academic achievement presents a limitation. Future studies should consider additional factors-such as parents’ educational level, age, and family income-that could substantially influence MA and CT skills of PSTs. Furthermore, it has been reported that MA and CT skills, along with related factors, are shaped by cultural norms and expectations (Gutierrez & Montoya, 2023). Therefore, it is recommended that multicultural studies be conducted to ascertain the degree to which the findings of this study can be generalized across different cultural contexts.

Implications and recommendations

In essence, the results of this study offer implications for stakeholders in teacher education programs and policy makers, providing essential insights for the enhancement of mathematics teacher education. Accordingly, it is crucial that teacher education programs integrate courses and activities that foster MA and CT skills, thereby elevating PSTs' proficiency in these areas. Equipping teachers with robust MA and CT skills empowers students to develop these competencies, which, in turn, can notably improve their mathematical problem-solving performance and overall mathematics achievement.

For mathematics teachers, MA is indispensable in effectively teaching problem-solving (Dignath & Büttner, 2018). CT skills represent a commitment to general thinking and reasoning abilities, forming a basis for decision-making and problem-solving (Romero-Ariza et al., 2024). Consequently, stakeholders and faculty members within teacher education programs are encouraged to prioritize MA and CT skills within the educational curriculum.

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Conflict of Interest: The authors declare no conflicts of interest.

Informed Consent: Informed consent was obtained from all subjects involved in the study.

Data availability: The data presented in this study are available on request from the corresponding author.

References

Akcaoğlu, M. Ö., Mor, E., & Külekçi, E. (2023). The mediating role of metacognitive awareness in the relationship between critical thinking and self-regulation. *Thinking Skills and Creativity, 47*, Article 101187. https://doi.org/10.1016/j.tsc.2022.101187

Akın, A., Abacı, R., & Çetin, B. (2007). The validity and reliability of the Turkish version of the metacognitive awareness inventory. *Educational Sciences: Theory & Practice, 7*(2), 671-678.

As'ari, A. R., Mahmudi, A., & Nuerlaelah, E. (2017). Our prospective mathematic teachers are not critical thinkers yet. *Journal on Mathematics Education, 8*(2), 145–156. https://doi.org/10.22342/jme.8.2.3961.145- 156

Aybek, B., Aslan, S., Dincer, S., & Arısoy, B. C. (2015). Critical thinking standards scale for the teacher candidates: Study of validity and reliability. *Educational Administration: Theory and Practice, 21*(1), 25-50.

Baş, F. (2016). Pre-service secondary mathematics teachers' metacognitive awareness and metacognitive behaviours in problem solving processes. *Universal Journal of Educational Research, 4*(4), 779-801.

Biber, A. C, Tuna, A., & İncikabi, L. (2013). An investigation of critical thinking dispositions of mathematics teacher candidates. *Educational Research, 4*(2), 109-117.

Brown, T. (2004). *Critical thinking and learning: an encyclopedia for parents and teachers: Bloom's taxonomy and critical thinking.* Greenwood Press.

Carter, R. A., Zhang, L., Hunt, T. L., Bloom, L., Wilder, T. L., Yang, S., & Parsons, C. (2023). Educator preparation: A multi-discipline analysis of standards to promote critical thinking. *Teachers & Teaching: Theory & Practice, 29*(4), 422–438. https://doi.org/10.1080/13540602. 2023.2191184

Deniz, D., Küçük, B., Cansız, Ş., Akgün, L., & İşleyen, T. (2014). Examining metacognitive awareness of prospective secondary school mathematics teachers in terms of some variables. *Kastamonu Education Journal, 22*(1), 305-320.

Dennis, J. L., & Somerville, M. P. (2023). Supporting thinking about thinking: Examining the metacognition theory-practice gap in higher education. *Higher Education*, *86*(1), 99-117. https://doi.org/10.1007/s10734-022-00904-x

Deringöl, Y. (2017). Determining critical thinking standards of teacher candidates. *Igdır University Journal of Social Sciences*, *13*, 44-65.

Desoete, A., & De Craene, B. (2019). Metacognition and mathematics education: An overview. *ZDM, 51*(4), 565-575.

Dignath, C., & Büttner, G. (2018). Teachers' direct and indirect promotion of self-regulated learning in primary and secondary school mathematics classes, Insights from video-based classroom observations and teacher interviews. *Metacognition and Learning, 13,* 127–157. https://doi.org/10.1007/s11409-018-9181-x

Ekici, F., Ulutaş, B., & Atasoy, B. (2019). An investigation of preservice teachers' levels of metacognitive awareness in terms of certain variables. *Bartın University Journal of Faculty of Education, 8*(3), 1035-1054. https://doi.org/10.14686/buefad.566640

Ellerton, P. (2015). Metacognition in critical thinking: Some pedagogical imperatives. In M. Davis (Ed.), *Palgrave handbook of critical thinking in higher education* (pp. 409–426). Palgrave Macmillan.

Ennis, R. (2018). Critical thinking across the curriculum: A vision. *Topoi, 37*(1), 165-184.

Facione, P. A. (1990). *Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction.* The California Academic Press.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149-1160. https://doi.org/10.3758/BRM.41.4.1149

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist, 34*(10), 906–911.

Fong, C. J., Kim, Y., Davis, C. W., Hoang, T., & Kim, Y. W. (2017). A meta-analysis on critical thinking and community college student achievement. *Thinking Skills and Creativity*, *26*, 71–83. https://doi.org/10.1016/j.tsc.2017.06.002

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). *How to design and evaluate research in education*. McGraw-Hill.

Gutierrez, A. P., & Montoya, D. (2023). Exploring the relation between metacognition, gender and personality in Colombian University students. *Psykhe, 32*(2), 1-21. https://doi.org/10.7764/psykhe.2021.30793

Halpern, D. F. (1998). Teaching critical thinking for transfer across domains: Dispositions, skills, structure training and metacognitive monitoring. *American Psychologist, 53*(4), 449-455.

Halpern, D. F. (2014). *Thought and knowledge: An introduction to critical thinking* (5th Ed.). Psychology Press.

Hashmi, A., Khalid, M., & Shoaib, A. (2019). A cross-sectional study of assessing metacognitive knowledge and metacognitive regulatory skills among prospective teachers and its relation to their academic achievement. *Bulletin of Education and Research, 41*(2), 215- 234.

Incikabi, L., Tuna, A., & Biber, A. C. (2013). An analysis of mathematics teacher candidates' critical thinking dispositions and their logical thinking skills. *Journal of International Education Research, 9*(3), 257–267.

Kandemir, M. A. (2017). Investigation of critical thinking tendency levels of classroom and elementary mathematics teacher candidates in terms of some variables. *Turkish Studies, 12*(6), 453-474.

Karaoğlan-Yılmaz, F. G., Yılmaz, R., Üstün, A. B, & Keser, H. (2019). Examination of critical thinking standards and academic self-efficacy of teacher candidates as a predictor of metacognitive thinking skills through structural equation modelling. *Journal of Theoretical Educational Science, 12*(4), 1239-1256.

Karlen, Y., Hirt, C. N., Jud, J., Rosenthal, A., & Eberli, T. D. (2023). Teachers as learners and agents of self-regulated learning: The importance of different teachers' competence aspects for promoting metacognition. *Teaching and Teacher Education, 125,* Article 104055.

Kozikoglu, I. (2019). Investigating critical thinking in prospective teachers: Metacognitive skills, problem solving skills and academic self-efficacy. *Journal of Social Studies Education Research, 10*(2), 111-130.

Kramarski, B., & Kohen, Z. (2017). Promoting pre-service teachers' dual self-regulation roles as learners and as teachers: Effects of generic vs. specific prompts. *Metacognition and Learning, 12*(2), 157-191.

Ku, K. Y. L., & Ho, I. T. (2010). Metacognitive strategies that enhance critical thinking. *Metacognition and Learning, 5,* 251–267.

Kuzle, A. (2018). Assessing metacognition of grade 2 and grade 4 students using an adaptation of multi-method interview approach during mathematics problem-solving. *Mathematics Education Research Journal, 30,* 185–207. https://doi.org/10.1007/s13394-017-0227-1

Laamena, C. M., & Laurens, T. (2021). Mathematical literacy ability and metacognitive characteristics of mathematics pre-service teacher. *Infinity Journal*, *10*(2), 259-270.

Le, V. H., & Chong, S. L. (2024). The dynamics of critical thinking skills: A phenomenographic exploration from malaysian and vietnamese undergraduates. *Thinking Skills and Creativity*, *51*, Article 101445. https://doi.org/10.1016/j.tsc.2023.101445

Lemieux, C. L., Collin, C. A., & Watier, N. N. (2019). Gender differences in metacognitive judgments and performance on a goal-directed wayfinding task. *Journal of Cognitive Psychology, 31*(4), 453-466. https://doi.org/10.1080/20445911.2019.1625905

Liu, Y., & Pásztor, A. (2022). Effects of problem-based learning instructional intervention on critical thinking in higher education: A meta-analysis. *Thinking Skills and Creativity, 45,* Article 101069. https://doi.org/10.1016/j.tsc.2022.101069

Liu, Y., & Pásztor, A. (2023). Survey on the influential demographic factors of Chinese undergraduate students' critical thinking disposition: Evidence from plausible values. *Thinking Skills and Creativity*, *50,* Article 101397. https://doi.org/10.1016/j.tsc.2023.101397

Magno, C. (2010). The role of metacognitive skills in developing critical thinking. *Metacognition Learning, 5*(2), 137-156. https://doi.org/10.1007/s11409-010-9054-4.

Ministry of National Education. (2017). *General competencies of teaching profession.* General Directorate of Teacher Training and Development.

Muncer, G., Higham, P. A., Gosling, C. J., Cortese, S., Wood-Downie, H., & Hadwin, J. A. (2022). A meta-analysis investigating the association between metacognition and math performance in adolescence. *Educational Psychology Review, 34*, 301–334.

Ossa, C. J., Rivas, S. F., & Saiz, C. (2023) Relation between metacognitive strategies, motivation to think, and critical thinking skills. *Frontiers in Psychology, 14,* Article 1272958. https://doi.org/10.3389/fpsyg.2023.1272958

Özturan-Sağırlı, M., Baş, F. & Bekdemir, M. (2020). The relationship between teacher candidates' metacognitive awareness levels and achievements. *Journal of Bayburt Education Faculty, 15*(29), 1-22. https://doi.org/10.35675/befdergi.464806

P21. (2019). Framework for 21st century learning definitions. http://static.battelleforkids.org/documents/p21/P21_Framework_DefinitionsBFK.pdf.

Pallant, J. (2016). *SPSS survival manual: A step by step guide to data analysis using SPSS program* (6th Ed.). McGraw-Hill Education.

Peter, E. E. (2012). Critical thinking: Essence for teaching mathematics and mathematics problem solving skills. *African Journal of Mathematics and Computer Science Research, 5*(3), 39-43. https://doi.org/10.5897/AJMCSR11.161

Rivas, S. F., Saiz, C., & Ossa, C. (2022). Metacognitive strategies and development of critical thinking in higher education. *Frontiers in Psychology*,13, Article 913219. https://doi.org/10.3389/fpsyg.2022.913219

Romero-Ariza, M., Quesada-Armenteros, A., & Estepa-Castro, A. (2024). Promoting critical thinking through mathematics and science teacher education: The case of argumentation and graphs interpretation about climate change. *European Journal of Teacher Education, 47*(1), 41-59. https://doi.org/10.1080/02619768.2021.1961736

Rott, B. (2021). Inductive and deductive justification of knowledge: Epistemological beliefs and critical thinking at the beginning of studying mathematics. *Educational Studies in Mathematics, 106*(1), 117-132.

Schraw, G., & Dennison, R. S. (1994). Assessing metacognitive awareness. *Contemporary Educational Psychology, 1*9, 460-475.

Schoenfeld, A. H. (2016). Learning to think mathematically: Problem solving, metacognition, and sense making in mathematics (reprint). *Journal of Education*, *196*(2). https://doi.org/10.1177/002205741619600202

Sezgin-Memnun, D., & Akkaya, R. (2012). An investigation of pre-service primary school mathematics, science and classroom teachers' metacognitive awareness in terms of knowledge of and regulation of cognition. *Journal of Theoretical Educational Science, 5*(3), 312-329.

Soliemanifar, O., Nikoubakht, A., & Shaabani, F. (2022). The relationship between trait mindfulness and critical thinking: The mediating effect of metacognitive awareness. *Psychological Studies, 67*(2), 139–149. https://doi.org/10.1007/s12646-021-00633-8

Stewart, P. W., Cooper, S.S., & Moulding, L. R. (2007). Metacognitive development in professional educators. *The Researcher, 21*(1), 32-40.

Su, H. F., Ricci, F.A., & Mnatsakanian, M. (2016). Mathematical teaching strategies: Pathways to critical thinking and metacognition. *Journal of Research in Education and Science, 2*(1), 190-200.

Urban, M., & Urban, K. (2024). Does metacognition matter in creative problem-solving? A mixed-methods analysis of writing. *The Journal of Creative Behavior*. Advanced online publication https://doi.org/10.1002/jocb.630

Veenman, M. V. J., & van Cleef, D. (2019). Measuring metacognitive skills for mathematics: Students' self-reports vs. online assessment methods. *ZDM Mathematics Education, 51*(4), 691–701. https://doi.org/10.1007/s11858-018-1006-5

Wafubwa, R. N., Csíkos, C., & Opoku-Sarkodie, R. (2022). In-service mathematics teachers' conception and perceptions of metacognition in their teaching experience. *SN Social Sciences, 2*(2), 1-21.

Wilson, D., & Conyers, M. (2016). *Teaching students to drive their brains: Metacognitive strategies, activities, and lesson ideas*. ASCD.

Yorgancı, S. (2016). Critical thinking dispositions of pre-service mathematics teachers. *Participatory Educational Research, 3*(3), 36-46.

Yüksel, N. S., Sarı-Uzun, M., & Dost, Ş. (2013). Critical thinking tendencies of prospective mathematics teachers. *Hacettepe University Journal of Education, Special issue* (1), 393-403.

Zhao, Y., Liu, Y., & Wu, H. (2024). Relationships among critical thinking disposition components of Chinese undergraduates: A moderated mediating effect analysis. *International Journal of Educational Research, 124,* Article 102306. https://doi.org/10.1016/j.ijer.2023.102306

Zohar, A., & Ben-Ari, G. (2022). Teachers' knowledge and professional development for metacognitive instruction in the context of higher order thinking. *Metacognition and Learning, 17,* 855-895. https://doi.org/10.1007/s11409-022-09310-1