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Creative self-efficacy, attitudes, creative style, and environmental literacy: Promoting mathematical creative thinking

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ABSTRACT

Creative thinking in mathematics is crucial for developing 21st-century skills, but students' mathematical creative thinking (MCT) is often underdeveloped due to insufficient focus on noncognitive factors such as creative self-efficacy (CSE), attitude toward mathematics (ATM), creative style (CST), and environmental literacy (ELT). This study explored the mediating roles of CST and ELT in the relationship between CSE, ATM, and MCT. A cross-sectional design was used, involving secondary school students from Indonesia who participated voluntarily through an online survey. Validated self-report instruments measured the constructs, and data collection followed ethical guidelines, with students providing consent. Structural equation modeling was employed to analyze the data. The results showed positive, significant relationships among CSE, ATM, CST, ELT, and MCT, with CST and ELT mediating the effects of CSE and ATM on MCT. These findings highlight the importance of noncognitive factors in fostering mathematical creativity and suggest strategies to enhance MCT through these factors.

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Attitude toward mathematics; creative self-efficacy; creative style; environmental literacy; mathematical creative thinking

Introduction

Creative thinking (CT) within the realm of mathematics is essential to nurture student competencies in the twenty first century. Put differently, for an extended period, mathematics education scholars and teachers have been investigating the primary factors that impact CT research. In term of mathematical creative thinking (MCT) is described as a complex cognitive process that plays a crucial role in concept across multiple fields, including mathematics (Suherman & Vidákovich, 2024b). The specific factors driving MCT in students are multifaceted and extend beyond cognitive factors alone. Although many researchers emphasize the importance of CT in mathematics education to foster innovative problem-solving skills and a deep understanding of mathematical concepts (Bicer et al., 2024), the role of noncognitive factors in influencing creativity in mathematics has gained attention.

Studies have shown that factors such as creative styles (Nurakenova & Nagymzhanova, 2024), attitude toward mathematics (Suherman & Vidákovich, 2024a), creative self-efficacy (Mou, 2024), and environmental literacy (Nuss, 2020) play crucial roles in nurturing mathematical creative thinking. With these factors, they shape how individuals approach and engage with math in a creative way (Thompson, 2024). By boosting creativity, confidence, and a positive mindset, they help people think outside the box and solve problems more effectively in mathematical contexts (Looi et al., 2024). Specifically, creative style (CST) refers to the distinctive manner in which individuals demonstrate their creativity and engage in creative behaviors (Fagan, 2004; Gabora et al., 2012). As for attitude toward mathematics (ATM), encompasses an individual's interest, confidence, enjoyment, motivation, and level of anxiety related to the subject (Suherman & Vidákovich, 2022a, 2024b). Regarding creative self-efficacy (CSE) is an essential self-belief that reflects an individual's confidence in their creative abilities and their capacity to produce innovative outcomes (Lamb et al., 2025; Slåtten, 2014). Environmental literacy (ELT) is the ability to apply environmental knowledge through actions and behaviors (Atabek-Yiğit et al., 2014; Incesu & Yas, 2024). However, there is a gap in research that integrates all these constructs into a comprehensive model to explore how noncognitive factors impact an individual's creativity in mathematics (Ji & Chang, 2024; Tubb et al., 2020; Xiang et al., 2024).

This study is grounded in social cognitive theory, which posits that behavior, cognitive processes, personal factors, and environmental influences interact dynamically and shape one another, ultimately affecting MCT (Wood & Bandura, 1989). Within this framework, CT and CST are crucial as they influence problem-solving strategies (Kuo et al., 2014;

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Ray & Romano, 2013), while self-concept theory which is product of this reflexive activity (Gecas, 1982) supports the inclusion of CSE as a significant factor in MCT development. Furthermore, environmental literacy is highlighted for its contribution to CT skills (Sigit et al., 2023), and ATM are incorporated based on expectancy-value theory (Fielding-Wells et al., 2017), which emphasizes the role of motivation and engagement in mathematical creativity. Collectively, these variables align with the theoretical foundation, providing a strong basis for examining their impact on MCT.

Previous research has documented that achievement in school-based mathematics is a function of various factors, including beliefs and self-efficacy (Bandura, 1997). However, there is currently very limited research into creativity in mathematics education, specifically the beliefs and efficacy that students hold regarding their creative capabilities in mathematics. This is despite widespread acknowledgment that mathematics is not only about rote learning of formulas and algorithms, but also about creative problem solving and exploratory investigation. Furthermore, students with higher creative self-efficacy and positive attitudes toward mathematics are more likely to develop MCT (Bicer et al., 2024). In recent decades, extensive research has been conducted on mathematics and creativity. Numerous inspirations from Torrance's studies have led to a variety of developments in the field of creativity such as Torrance Tests of Creative Thinking (Torrance, 1966), especially in mathematics. Despite this, only a few studies have discussed the factors affecting students' creative thinking in mathematics, which is essential in producing individuals who are able to think outside the box and find solutions to problems in unconventional ways.

Additionally, most studies on the relationship between self-efficacy and mathematics students' performance have primarily focused on problem-solving tests, particularly in the context of general achievement in mathematics. Special performances, such as students' creative thinking in mathematical problem solving, remain underexplored. Creative thinking in mathematics involves generating novel and original approaches to solve problems, often requiring students to think outside conventional methods and explore unconventional strategies (Suherman & Vidákovich, 2024a, 2024b; Wilson et al., 2021). In contrast, problem-solving skills focus on applying established techniques and logical reasoning to arrive at solutions (Chinofunga et al., 2025), emphasizing accuracy and efficiency rather than innovation. However, the role of CST and ELT in the relationship between CSE and ATM (Karwowski et al., 2018; Liu et al., 2021; Nguyen et al., 2023; Tsai et al., 2023) in promoting MCT has not been adequately explored. Then, in our study, the possible aims are to evaluate the role of creative style and environmental literacy in the relationship between creative self-efficacy, attitude toward mathematics and MCT. The study findings offer multifaceted implications for improving MCT education, highlighting the need for customized instructional strategies, interdisciplinary approaches, and a holistic integration of creativity and environmental literacy. By embracing these implications, stakeholders can foster a new generation of mathematically creative thinkers capable of tackling the diverse and interconnected challenges of the modern world.

Theoretical framework

Creative style (CST) and MCT

The CST has been a focus of philosophical and psychological inquiry for over thirty years. It is a term that is difficult to define, yet it is evidently recognized when seen. CST refers to the unique way in which individuals express their creativity (Gabora et al., 2012). Additionally, MCT refers to a complex cognitive process that plays a crucial role in problem-solving across multiple fields, including mathematics (Suherman & Vidákovich, 2024b). MCT refers to the capacity to develop original mathematical concepts, methods, or outcomes that may be new to the students, even if not to the wider academic field, by recognizing and applying appropriate mathematical patterns and structures (Bicer, 2021). It encompasses how individuals approach and manifest their creative endeavors (Nurakenova & Nagymzhanova, 2024). This concept distinguishes between different approaches to creativity, highlighting variations in the way individuals innovate and adapt in their creative processes (Hughes et al., 2018). While CST defines one's personal style of creative expression (Wechsler et al., 2012), CT refers to the cognitive process of generating new ideas (Suherman & Vidákovich, 2022b).

Previous studies have shown that the core characteristics of problem solving, namely creative thinking, are influenced by creative style (Tsai et al., 2023). In exploring the link between creative style and thinking skills, Piaw (2014) found a significant correlation between thinking style and creative thinking ability. Moreover, Gelade (1995) observed that creative style is more strongly correlated with certain measures of creativity. Studies imply that the creative style has a significant and positive impact on creative thinking, especially in mathematics. Therefore, we present the following hypothesis:

H1: Creative style predicts MCT

Attitude toward mathematics (ATM) and MCT

The ATM includes an individual's emotions toward the subject, personal beliefs about mathematics, and behaviors related to mathematical activities (Gómez-Chacón et al., 2024). It is crucial because students' positive attitudes toward mathematics correlate positively with their learning achievement (Wakhata et al., 2022). Student ATMs are gaining more attention due to their significant contribution to how they engage with and understand mathematics (Suherman & Vidákovich, 2022a).

Studies have demonstrated a positive correlation between a favorable attitude toward mathematics and the ability to think creatively in mathematical contexts (Suherman &

Vidákovich, 2024c), suggesting that students with positive attitudes toward the subject tend to exhibit higher levels of creative thinking. Research by Kurdal & Kaplan (2023) has informed that there is a strong and positive correlation between students' metacognitive awareness (i.e., thinking process) and their attitude toward mathematics. Similarly, there was a positive association of attitude toward mathematics with creative thinking in terms of fluency, flexibility, and originality (Suherman & Vidákovich, 2024a). Furthermore, the study by Nguyen et al. (2023) indicated a strong and positive relationship between attitude and preparedness for competition in STEM, including aspects such as creative thinking, problem-solving, and belief in competency. Therefore, we predicted that the attitude toward mathematics also significantly and positively influences creative thinking. Therefore, we present the following hypothesis:

H2: Attitude toward mathematics positively predicts MCT

Creative self-efficacy (CSE) and MCT

Creative self-efficacy refers to an individual's belief in their ability to produce creative results (Slåtten, 2014). It is a psychological attribute that significantly influences creative performance, emphasizing the importance of believing in one's creative potential to enhance creativity and innovation (Yan et al., 2022). Cultivating creative self-efficacy involves learning to believe in one's creative ability (Tierney & Farmer, 2002), which can positively impact creativity (Puozzo & Audrin, 2021), motivation (Karimi et al., 2022), and productivity (Thundiyil et al., 2016).

Research have consistently shown a strong correlation between students' mathematical creative ability and creative self-efficacy (Bicer et al., 2020). Engaging in complex experiences has been shown to enhance individuals' belief in their creative skills, thus promoting a deeper value for creativity (Puente-Diaz et al., 2020). Studies have invariably found a positive relationship between creative self-efficacy and creative thinking (Karwowski et al., 2018). This highlights the critical role of students' confidence in their creative problem-solving abilities in fostering creative thinking. In summary, creative self-efficacy is likely to be positively related to creative thinking skills in mathematics, especially. Again, we present the following hypohotesis:

H3: Creative self-efficacy positively predicts MCT

Environmental literacy (ELT) and MCT

ELT refers to the capacity to utilize environmental knowledge in practical actions and behaviors (Atabek-Yiğit et al., 2014; Incesu & Yas, 2024). Applying environmental scientific knowledge and environmental literacy to address environmental issues has become an essential necessity (Yeh et al., 2022), and underscoring the critical role that this literacy plays in promoting student creativity (Dewi et al., 2024). Education focused on nature has been shown to enhance students' reflective thinking skills (Aladağ et al., 2021). A study found that ELT in term of ecological literacy positively influenced students' creative thinking abilities, suggesting that an understanding of environmental issues can lead to more innovative creative thinking skills in mathematics (Sigit et al., 2023). Moreover, evidence supports the use of problem-based learning as a method to increase students' creative thinking, teamwork abilities, and understanding of environmental concepts (Nurwidodo et al., 2024). Lu (2017) posited that students' creativity grows in parallel with their environmental engagement, and the activities in natural settings outside the classroom positively influence students' creative and critical thinking. Furthermore, the use of e-modules for nature exploration has proven to be effective in advancing students' creative thinking skills and knowledge of the environment (Al-Muhdhar et al., 2021). Additionally, research by Farida et al. (2023) has indicated that environmental literacy positively influences mathematical thinking skills, particularly creativity. Research also found that environmental literacy impacts creativity, highlighting its crucial role in early childhood education (Ramulumo & Shabalala, 2024). Therefore, environmental literacy is expected to predict positive mathematical creative thinking. We present the following hypotheses:

H4: Environment literacy predicts MCT in a positive and meaningful way.

Mediating role of creative style and environmental literacy

Creative style and environmental literacy can act as potential mediators of creative thinking. Research indicates that there is a relationship between creativity, environmental literacy, and creative thinking skills. Although creativity education and environmental education have traditionally been separate fields, efforts are being made to bridge them. Studies have shown that students with higher environmental literacy tend to have better creative thinking skills (Al-Muhdhar et al., 2021). Additionally, creative personality traits can influence creative thinking, highlighting the interconnectedness of various factors in fostering creativity (Ayyildiz & Yilmaz, 2021). Furthermore, the relationship between creative self-efficacy and mathematical achievement can be mediated by creativity, since individuals with higher levels of creativity tend to have better results in academic performance (Liu et al., 2021). Even though the correlation is low, the results still suggest that creativity may play a role in linking creative self-efficacy and mathematical achievement, as individuals with higher creativity levels tend to perform better academically. This implies that fostering creativity through various learning environments and approaches can enhance students' self-belief in their creative abilities and their performance in mathematics.

Environmental literacy, which includes an understanding of the environment and its impact on individuals, can also influence creative thinking and self-efficacy in mathematics. By creating learning environments that promote independent thinking, curiosity, and diverse problem solving approaches, students can develop their creative mathematical thinking

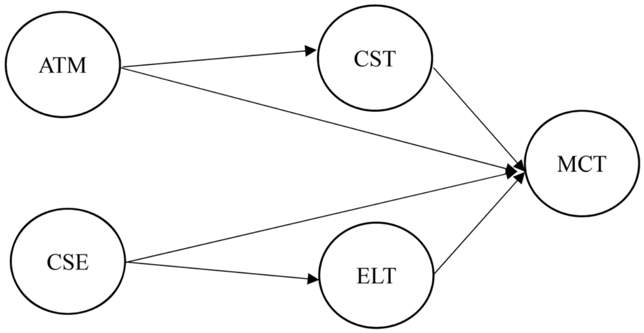

Figure 1. Conceptual model.

skills (Ali et al., 2021). This suggests that incorporating environmental literacy education into mathematics learning can provide students with the tools to think creatively and independently, thus enhancing their self-efficacy in mathematical problem solving. Therefore, creative style and environmental knowledge can be a mediator in creative thinking. Again, we present the following hypohotesis:

H5: Creative style and environmental literacy positively mediates the relationship between creative self-efficacy and attitude toward mathematics in promoting mathematical creative thinking.

The hypothesized structural model, including the exogenous, endogenous, and mediating constructs, is illustrated in Figure 1.

Methods

Participants and procedure

In our study, a cross-sectional approach was adopted. We enrolled 869 secondary students from various grades in Indonesia as voluntary participants, which aligns with ethical research principles, ensuring that participants engage willingly and provide authentic responses (Creswell, 2021). The demographic composition of our sample was 409 male and 460 female students (which represent 52.9% of the sample), with an age range between 11 and 15 years ($M = 13.32$ years, SD = 1.08). Participants were directed to an online platform where they accessed a consent form, entered their demographic details, and responded to questions measuring their self-efficacy in creativity, attitude toward mathematics, creative style, and creative thinking. mathematical. The time taken to complete this online survey was estimated to be between 20 and 40 min. The ethical clearance for this research was granted by the Ethics Committee of the Institutional Review Board of the University of Szeged. The characteristic of the students is as follows in Table 1.

Table 1. Characteristics of the participants.

Demografi of the participants		Frequency	Percentage (%)
Gender	Female	460	52.9
	Male	409	47.1
Grade	7th	295	33.9
	8th	286	32.9
	9th	288	33.1
Type of school	Public	441	50.7
	Private	428	49.3
Students' Place	City	457	52.6
	District	412	47.4
Ethnics	Batak	57	6.6
	Bugis	25	2.9
	Java	413	47.5
	Lampung	156	18.0
	Manado	51	5.9
	Minang	35	4.0
	Others	45	5.2
	Palembang	27	3.1
	Sundanese	60	6.9

Instruments

Attitude toward mathematics

The ATM inventory, adapted by Suherman & Vidákovich (2022a), consists of five items that assess an individual's interest, confidence, enjoyment, motivation, and anxiety level related to the subject. The ATM is a 5-point Likert-type scale, ranging from 1 (strongly disagree) to 5 (strongly agree). An example of the item is "I am really good at math", "I understand math", and "I can solve difficult math problems." In the current sample, we measured the instrument scale.

Creative style

In our research, the Creative Style Scale was assessed using an 8-item (Kumar et al., 1997). The responses to each item were captured on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). An example item is 'My creativity comes from self-discipline'. In our study, the evaluation of the instruments was evaluated both by validity and reliability.

Creative self-efficacy

In this study, creative self-efficacy among students was assessed using a six-item scale (Karwowski, 2012). Participants recorded their responses on a 5-point Likert scale that spans from 1 (strongly disagree) to 5 (strongly agree). An example of the item is: I am sure I can deal with problems that require creative thinking. In the context of this research, we also tested the validity and reliability of the items.

Environmental literacy

For this research, the instruments were evaluated using a set of six items (Mujib et al., 2023). Participants recorded their responses on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). An element of the scale states that "Environmental education should begin at the beginning of basic education to promote environmental awareness". Again, both validity and reliability will be examined.

Mathematical creative thinking

In this research, the assessment instrument was a test based on MCT within an ethnomathematics framework (MCTBE), notably incorporating the Tapis pattern. This approach to ethnomathematics, which delves into the cultural, social, and historical facets of mathematics, aims to offer a testing method that is both culturally relevant and inclusive, enhancing the evaluation of mathematical competence. The test, developed by Suherman & Vidákovich (2024a), evaluates four dimensions of creative thinking in mathematics: fluency, flexibility, originality, and elaboration. The responses were assigned based on the categorized answers. For example, a rating of 5 indicated the highest scores for fluency and flexibility. On the other hand, originality scores were determined using percentages. Specifically, scores exceeding 3% were given a value of 0, scores between 2% and 3% were assigned a score of 1, scores between 1% and 2% received a score of 2, and scores below 1% were allocated a score of 3. Regarding elaboration, the scores were either 1 or 2. Again, we also examined the reliability and validity of the instrument.

Statistical analyses

First, SPSS 29.0 was used to organize the data and perform descriptive and correlation analyzes. In the second stage, Partial Least Squares Structural Equation Modeling (PLS-SEM) was applied using SmartPLS version 4 to test the hypothesized model. PLS-SEM is gaining popularity for estimating structural equation models (Hair et al., 2014). Moreover, it focuses on maximizing the explained variance in dependent variables, making it particularly suitable for exploratory research (Hair et al., 2019). Subsequently, the Smart PLS Version 4 software employed structural equation modeling (SEM) to examine the relationships within the model. To evaluate the fit of the model, several indices were used, including the chi-square statistic, the comparative fit index (CFI), the Tucker-Lewis index (TLI), the root mean square error of approximation (RMSEA) and the standardized root mean square residual (SRMR). An acceptable model fit was established based on the cutoff criteria of CFI $\geq$ 0.90, RMSEA $\leq$ 0.08, and SRMR $\leq$ 0.06 (Hu & Bentler, 1999). Lastly, statistical software R was applied to analyze student performance through density graphs, providing a nuanced understanding of the data distribution.

Results

Internal reliability and validity

In this study, the assessment of the instrument construct's validity utilized confirmatory factor analysis. Table 2 presents the correlations between indicators and their latent constructs, in addition to the reliability and convergent validity of the measurement model used. The load factors of the elements ranged from 0.576 to 0.919, indicating the greater degree to which each indicator reflects the underlying construct. The highest loading values in this study were close to 1, indicating a stronger association between the indicator and the latent variable. The table also includes the reliability measures. The table further presents reliability metrics such as Cronbach's alpha, composite reliability, and extracted average variance (AVE), which assess the internal

Table 2. Factor loading and convergence validity of the variables.

Variables		Outer loads	Cronbach's Alpha	Composite Reliability	AVE
Attitude toward mathematics			0.855	0.896	0.635
	A1	0.802			
	A2	0.858			
	A3	0.820			
	A4	0.675			
	A5	0.817			
Creative self-efficacy			0.776	0.842	0.472
	C1	0.664			
	C2	0.654			
	C3	0.631			
	C4	0.724			
	C5	0.697			
	C6	0.744			
Environmental literacy			0.734	0.811	0.418
	E1	0.578			
	E2	0.608			
	E3	0.654			
	E4	0.713			
	E5	0.713			
	E6	0.602			
Creative style			0.875	0.901	0.536
	T1	0.628			
	T2	0.776			
	T3	0.727			
	T4	0.733			
	T5	0.833			
	T6	0.584			
	T7	0.786			
	T8	0.755			
Mathematical creative thinking-based ethnomathematics test			0.860	0.883	0.655
	El	0.919			
	Fl	0.803			
	Fx	0.784			
	Or	0.717			

consistency and reliability of the measurement model. Cronbach's alpha evaluates the correlation among items within each construct, ranging from 0.734 to 0.875, with higher values indicating greater reliability. Composite reliability, another measure of internal consistency, is deemed acceptable when it exceeds 0.70. AVE indicates the proportion of variance explained by latent variables relative to measurement error, with AVEs ranging from 0.418 to 0.655.

Discriminant validity

A discriminant validity assessment was carried out to determine whether latent factors demonstrate empirical distinctions from each other. The HTMT (Heterotrait-Monotrait ratio) method was used to assess discriminant validity. Table 3 summarizes the results, revealing values ranging from 0.039 to 0.808. Therefore, discriminant validity is established for all values below 0.90 (Henseler et al., 2015).

Descriptive statistics of the data

Table 4 shows the mean (M), standard deviation (SD), and Pearson's correlations for the main variables on different scales. From the data, it is observed that CSE shows a positive correlation with CST. Similarly, ATM is positively correlated with both CST and CSE. Consistent with expectations, ELT is significantly and positively correlated with CST, CSE, and ATM. On the contrary, MCTBE exhibits a negative correlation with CSE, ATM, and ELT. The Table 4 presents an interesting trend students' performance across various variables, with CST, ATM, and ELT each recording an average score of 3.61 and $SD = 0.48 - 0.53$. The CSE follows closely with $M = 3.48$ and $SD = 0.56$. On the contrary, the measures of creativity, such as fluency, flexibility, originality, and elaboration, exhibit a downward trend in average scores of 3.16 for fluency to 1.33 for elaboration. In particular, the *SD* for these measures (0.44–0.94). Lastly, MCTBE shows an average score of 2.06 with *SD* = 0.57.

The density plot in Figure 2 illustrates the distribution of student performance across variables such as ATM, CSE, CST, Elaboration, ELT, Flexibility, Fluency, MCTBE, and Originality. CST (green) and Elaboration (purple) have the highest peak densities (~0.75), indicating a strong concentration of student performance in specific value ranges. CSE (yellow) and Flexibility (blue) also show notable peaks (~0.55–0.65), suggesting strong performance trends. ELT (teal) and MCTBE (light green) display moderate densities (~0.5), while Fluency (light blue) and Originality (pink) have broader distributions with densities between 0.4 and 0.6. The overlap among variables suggests possible relationships, highlighting variations in student performance across different mathematical and environmental literacy factors.

Table 3. The discriminant of validity: heterotrait monotrait ratio (HTMT).

	ATM	CSE	CST	ELT	MCTBE
ATM					
CSE	0.165				
CST	0.808	0.213			
ELT	0.126	0.754	0.133		
MCTBE	0.039	0.069	0.028	0.056	

Structural model

SEM was used to examine the hypotheses proposed in this study, as shown in Figure 3. The goodness of fit of the model was evaluated through various indices: Chi-square = 1,634.953, $df = 4.431$, $p < .001$, CFI = 0.97, TLI = 0.96, RMSEA and SRMR were each recorded at 0.06, well within the acceptable limit of below 0.08, confirming the adequacy of the model (Hu & Bentler, 1999). The analysis of the coefficient revealed that MCTBE was affected by CST, CSE, ATM and ELT at 0.3% (R^2 = 0.003). Similarly, CST was explained by ATM and CSE in the amount of 51.8% (R^2 = 0.518). Furthermore, ELT was explained by CSE, which is approximately 38.4% (R^2 = 0.384). Lastly, CSE explained that ATM is approximately 1.6% (R^2 = 0.016).

Interestingly, the path coefficient analysis revealed significant associations among the variables, however, the low beta values were also present in these results. MCTBE showed a direct association with ATM and ELT, with coefficients and (β = 0.032, $p < .001$), respectively. However, MCTBE was negatively associated with CST (β = −0.029, $p < .001$) and CSE (β = −0.060, $p > .001$). On the contrary, CST had a positive association with ATM (β = 0.707, $p < .001$), and similarly, ATM was positively associated with CSE (β = 0.126, $p < .001$). Furthermore, ELT had a positive association with CSE (β = 0.620, $p < .001$), and CST also had a

Table 4. Median, standard deviation, and Person's correlation ($N = 869$).

Variables	*M*	*SD*	1	2	3	4	5	6	7	8	9
1. CST	3.61	0.53	–								
2. CSE	3.48	0.56	0.59**	–							
3. ATM	3.61	0.48	0.47**	0.56**	–						
4. ELT	3.61	0.48	0.47**	0.56**	1.00**	–					
5. Flue	3.16	0.87	−0.04	−0.10**	−0.07*	−0.07*	–				
6. Flex	2.22	0.94	−0.03	−0,05	−0.06	−0.06	0.52**	–			
7. Orig.	1.50	0.59	−0.07*	−0.07*	−0.09**	−0.09**	0.38**	0.59**	–		
8. Elab	1.33	0.44	−0.06	−0.11**	−0.07*	−0.07*	0.47**	0.56**	0.56**	–	
9. MCTBE	2.06	0.57	−0.06	−0.10**	−0.09**	−0.09**	0.78**	0.87**	0.76**	0.75**	–

CST: Creative style; CSE: Creative self-efficacy; ATM: Attitude toward mathematics; Flu: Fluency; Flex: Flexibility; Orig: Originality; Elab: Elaboration; MCT: Creative mathematicalCreative mathematical thinking.
Note. ** $p < .01$; * $p < .05$.

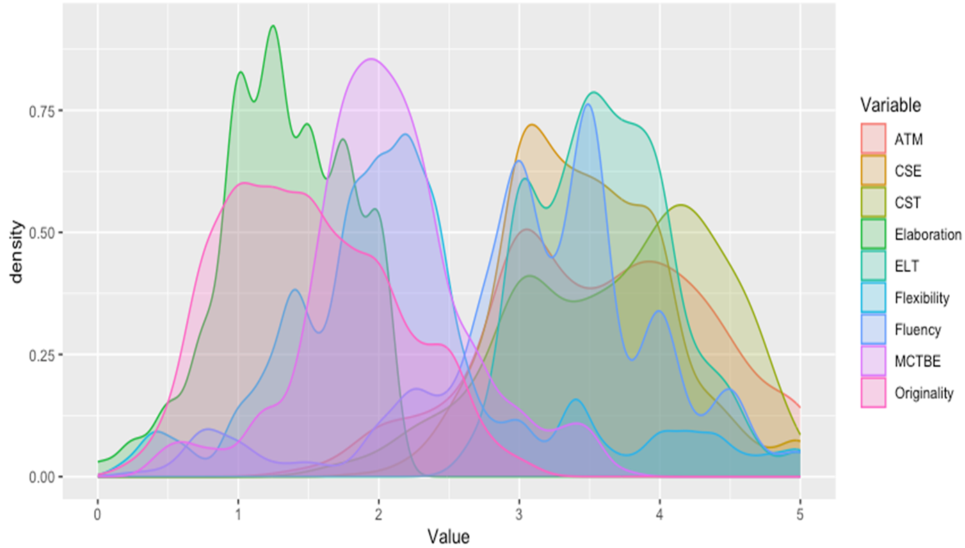

Figure 2. Density plot for the performance of the students.

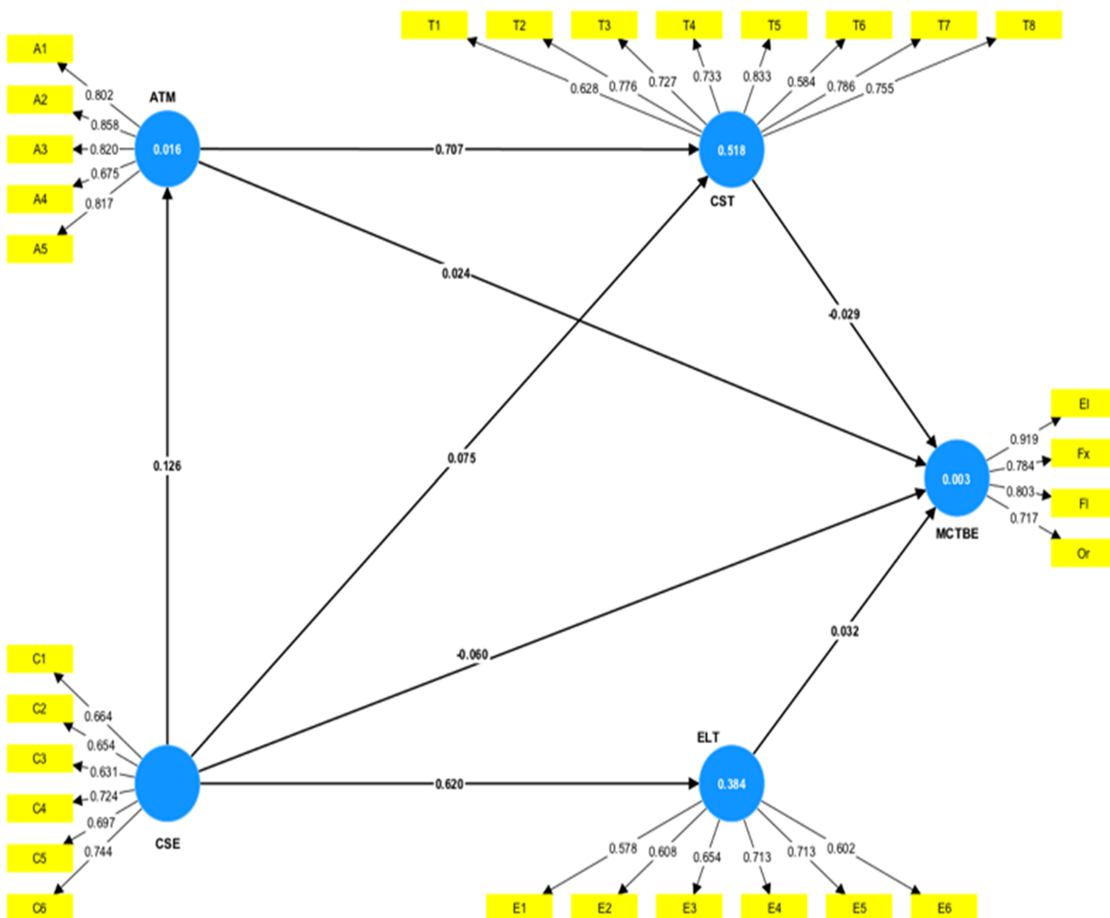

Figure 3. Standardized for each variable.

positive association with CSE (β = 0.075, p < .001). Furthermore, ATM was positively associated with MCTBE (β = 0.024, p < .001). Surprisingly, the mediating role of ELT had a positive indirect effect on the relationship between CSE and MCTBE (β=0.021, p < .001). However, CST was negatively associated with the relationship between ATM and MCTBE (β = −0.034, p < .001). Our study found that ATM positively mediated the association between CSE and MCTBE (β = 0.010, p < .001), as well as between CSE and CST (β = 0.190, p < .001).

Table 5 illustrates the specific indirect effects examined in this study. Through the Bootstrap method with 5000 iterations, we assessed the mediating influence of creative style and environmental literacy on the association between

Table 5. Specific indirect effect among variables.

Path	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	*p* values
CSE –> ATM –> MCTBE	0.003	0.003	0.008	0.384	>.05
CSE –> ELT –> MCTBE	0.020	0.021	0.032	0.632	>.05
CSE –> ATM –> CST –> MCTBE	−0.003	−0.002	0.006	0.463	>.05
CSE –> CST –> MCTBE	−0.002	−0.002	0.005	0.455	>.05
CSE –> ATM –> CST	0.089	0.090	0.025	3.536	<.001
ATM –> CST –> MCTBE	−0.021	−0.019	0.043	0.487	>.05

creative self-efficacy and attitude toward mathematics concerning the promotion of mathematical creative thinking. Our analysis revealed that the mediating effect of environmental literacy between CSE and MCTBE was not statistically significant ($\beta = 0.021$, $p > .05$). On the contrary, the creative style showed a negative mediation between ATM and MCTBE, as well as between CSE and MCTBE, with coefficients of ($\beta = -0.002$, $p > 0.05$) and ($\beta = -0.021$, $p > .05$), respectively. Furthermore, our results indicated that ATM played a mediator role in the relationship between CSE and CST, with a significant coefficient of ($\beta = 0.089$, $p < .001$).

The structural model representing the hypothesized interrelationships among the exogenous (CSE and ATM), mediating (CST and ELT), and endogenous (MCT) constructs is presented with the respective path coefficients (see Table 5). The analysis showed that several hypothesized direct and indirect effects were statistically non-significant, as indicated by their p-values exceeding .05. Specifically, the indirect effects of CSE on MCT through ATM ($\beta = 0.003$, $p > .05$), through ELT ($\beta = 0.020$, $p > .05$), through ATM and CST ($\beta = -0.003$, $p > .05$), and directly through CST ($\beta = -0.002$, $p > .05$) were all found to be insignificant. Similarly, the indirect effect of ATM on MCTBE *via* CST ($\beta = -0.021$, $p > .05$) was also not significant. However, a significant relationship emerged between CSE and CST mediated by ATM ($\beta = 0.089$, $p < .001$), suggesting that creative self-efficacy positively influences creative style when attitude toward mathematics acts as a mediator. These findings partially support the proposed model, highlighting the critical role of ATM in shaping CST, even though this pathway did not ultimately lead to significant changes in MCT through the full chain.

Discussion

The aim of the current study was to explore the indirect effect of creative self-efficacy and attitude toward mathematics in the promotion of creative mathematical thinking and as a mediator of creative style and environmental literacy.

Discussion of the hypothesis testing results

First, the results revealed a negative correlation between CST and MCT (hypothesis 1). Suherman & Vidákovich (2024b) showed that the creative style had a negative effect on general creativity in mathematics. This finding implies that certain approaches to creativity, as manifested through creative styles, may not align well with the promotion of mathematical creative thinking abilities, potentially impeding the development of innovative solutions and a deep understanding of mathematical concepts that did not match his own thinking (Kooloos et al., 2022). This implies that educators should adopt a diversified approach to teaching mathematics, catering to the various creative styles and preferences of students. In addition, it underscores the importance of creating a supportive learning environment where students feel encouraged to explore various creative approaches and think critically about mathematical problems.

In this study, we found that the attitude toward mathematics significantly and positively influences creative thinking in mathematics; this result supports Hypothesis 2. As we stated in the literature (Nguyen et al., 2023) that ATM has a power correlation with creative thinking in mathematics, as part of STEM. Studies have highlighted the importance of the cognitive and affective components of the attitude toward mathematics, emphasizing how beliefs about mathematics and cognitive processes play a role in shaping this attitude. Educators must strive to cultivate a classroom atmosphere that promotes curiosity, exploration, and a growth mindset toward mathematical concepts and problem solving. Furthermore, integrating creative thinking activities into the math curriculum can enhance students' creative problem-solving skills and foster a deeper understanding of mathematical concepts (Bicer et al., 2024).

On the contrary, creative self-efficacy was found to negatively influence creative thinking, according to Hypothesis 3. This result is corroborated by Royston & Reiter-Palmon (2019), who found that rigid creative mindsets negatively impact the quality and uniqueness of solutions, a relationship that creative self-efficacy mediates. The adverse effect of creative self-efficacy on creative thinking could be attributed to a complacency effect, suggesting that elevated self-confidence can reduce the incentive to pursue challenging tasks or explore innovative solutions. Understanding this relationship can guide educators in designing instructional strategies that foster a growth mindset toward creativity in mathematics (Bicer et al., 2022). Recognizing the potential detrimental effects of rigid creative mindsets, educators can implement interventions aimed at promoting a more flexible approach to problem solving. Encourage students to embrace challenges and explore diverse solutions, rather than rely solely on self-confidence (Yang et al., 2020), can help cultivate a more dynamic and innovative learning environment (Basdogan & Birdwell, 2024).

In our study, we found that environmental literacy has a positive predictive relationship with creative thinking in mathematics; as hypotheses 4. Research conducted by Wilson (2007) has noted that the presence of natural environments close to or within school grounds has a positive influence on students' recreational activities, resulting in a notable increase in creative pursuits. This means that environmental literacy, along with digital literacy, plays a significant role in influencing students' creative thinking abilities. Specifically, environmental literacy contributes to fostering creative thinking skills, highlighting the importance of considering environmental factors in enhancing creativity in mathematical contexts (Dewi et al., 2024). Importantly, we found that the creative style and environmental literacy mediate the relationship between creative self-efficacy and attitude toward mathematics in mathematical creative thinking; these results support Hypothesis 5. This means that students who possess a greater understanding of environmental literacy often exhibit enhanced abilities in creative thinking (Al-Muhdhar et al., 2021). Furthermore, the presence of creative personality traits has been shown to impact creative thinking, underscoring the complex relationship between multiple elements in nurturing creativity (Ayyildiz & Yilmaz, 2021).

Limitations and future research

This study comes with certain limitations that suggest avenues for further research. First, our participants were exclusively secondary students from Indonesia, which highlights the need for future research to involve more diverse samples. Second, due to its cross-sectional design, this study was unable to establish causality. Future research should aim to validate our findings using longitudinal and experimental approaches.

Third, the focus of this study on specific aspects of the variables in the literature may not capture the full spectrum of factors that influence mathematical creativity. Future research could broaden its scope to include other relevant variables, such as motivation, social economic status, parental education, and the impact of technology on education, to provide a more holistic view of the elements that contribute to MCT. Despite these constraints, our study illuminates how creative style and environmental literacy act as mediators in the relationship between creative self-efficacy and attitude toward mathematics in mathematical creative thinking. This highlights the potential benefits of these variables, which merits further attention from educators and researchers alike.

Conclusions

The study investigated how creative style and environmental literacy act as mediators between creative self-efficacy and attitude toward mathematics, affecting mathematical creative thinking. The research revealed a negative correlation between creative style and creative mathematical thinking. In contrast, a positive association was observed between the attitude toward mathematics and creative thinking in mathematics. Additionally, self-efficacy was found to negatively influence creative thinking, while environmental literacy demonstrated a positive predictive relationship with creative thinking in mathematics. Furthermore, the study found that creative style and environmental literacy serve as mediators in the relationship between creative self-efficacy and attitude toward mathematics with respect to mathematical creative thinking. The findings suggest that fostering a positive attitude toward mathematics and enhancing environmental literacy can be effective strategies in promoting mathematical creative thinking, even when creative self-efficacy and creative style have less direct influence. Educators should focus on strengthening students' engagement with mathematics and environmental issues to enhance their creative problem-solving abilities in this field.

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