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Examination of Creative Thinking Skills and Critical Thinking Dispositions of Pre-Service Mathematics Teachers

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Abstract

Creative and critical thinking play a central role in mathematics teaching and learning. These two forms of higher-order thinking contribute to individuals' problem-solving, decision-making, and knowledge generation processes. Teachers, in particular, have a significant role in fostering students' creative and critical thinking. In this context, the purpose of this study is twofold. First, it aims to examine the levels of creative thinking skills (CTSs) and critical thinking dispositions (CTDs) of pre-service mathematics teachers (PSTs), and the potential effects of gender and academic achievement on them. The second aim is to determine the relationship between the CTS and CTD of PSTs. Employing a quantitative research methodology, the study was structured around correlational model. It involved 205 PSTs, using the "How Creative Are You?" and "CTD Scale" for data collection. The data were analyzed through descriptive statistics, independent sample t-test, one-way analysis of variance, correlation analysis, and simple linear regression analysis. The findings revealed that the CTS levels of PSTs were above average, while their CTD levels were high. It was determined that CTSs and CTDs of PSTs did not differ significantly according to gender, while they differed significantly according to academic achievement. A medium, positive, and significant correlation was found between CTSs and CTDs of PSTs. Furthermore, CTSs of PSTs were identified as a significant predictor of their CTDs, explaining 23% of the variance in CTDs.

Keywords: Creative Thinking, Critical Thinking, Pre-Service Teacher, Mathematics Education, Higher Education

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INTRODUCTION

Technological developments signify changes in the skills demanded by the business world. In this context, creativity and critical thinking are among the skills expected of individuals by 2025 (World Economic Forum, 2020). At this point, it should be noted that education is the source of the development of these skills expected from individuals. In recent years, educational systems have intensely focused on thinking skills. Therefore, developing students' thinking skills has become one of the primary goals of education (Organisation for Economic Co-operation and Development [OECD], 2019).

Creative and critical thinking play a central role in the teaching and learning of mathematics. Creative thinking provides students with different ways of solving problems, enabling a deeper understanding of mathematical concepts. This helps students develop more flexible and versatile thinking skills (Leikin & Sriraman, 2022). Critical thinking, on the other hand, strengthens the ability to question the validity of mathematical arguments and to test hypotheses logically (Peter, 2012). Consequently, the integration of these two thinking skills into mathematics education is vital, not only for students to memorize information but also for them to analyze knowledge and produce innovative solutions. Thus, mathematics teachers play a significant role in fostering students' creative thinking and critical thinking. Pre-service mathematics teachers should prepare themselves to support both their own creative and critical thinking skills and those of their future students (Baumanns & Rott, 2024; Han & Abdrahim, 2023; Rott, 2021). Therefore, the main aim of the current study is to examine the creative thinking skills (CTSs) and critical thinking dispositions (CTDs) of pre-service mathematics teachers.

Literature Review

Creative thinking in mathematics education and the role of the teacher

Creativity is a popular term of the 21st century and a significant part of education (Zhan et al., 2024). While creativity is defined as the ability to produce original and useful products (Foster & Schleicher, 2022), it also refers to establishing connections between existing knowledge (Leikin & Sriraman, 2022). Creative thinking, on the other hand, is the process by which individuals use their current knowledge and experiences to produce new, original, and valuable solutions (Feldhusen, 1995). In PISA 2021, creative thinking is defined as the competency to engage efficiently in generating, evaluating, and improving ideas that could result in original and effective solutions, advancements in knowledge, and imaginative expressions (OECD, 2019). Creative thinking skills (CTSs) involve the mental activities that form in the subconscious mind of an individual (Wechsler et al., 2018).

Creative thinking is not limited only to fields like art or design but is also highly significant in more structured disciplines such as science, engineering, and mathematics. In Krutetskii's (1968/1976) study, mathematical creativity is considered a component of high mathematical abilities. Mathematical creativity is characterized by features like fluency, flexibility, and originality. These features encompass a person’s ability to generate multiple solutions and engage in creative problem-solving (Silver, 1997). In general, mathematical creativity is defined as the ability to find original, flexible, and varied ways of thinking during problem-solving (Leikin & Sriraman, 2022). Mathematical creativity is a trait that needs to be developed in school mathematics and is associated with problem-solving and problem-posing processes (Leikin & Elgrably, 2020; Urban et al., 2024). Encouraging creative thinking in mathematics courses allows students to grasp abstract concepts better, produce original solutions, and approach mathematical processes from a broad perspective by enhancing their problem-solving skills (Baumanns & Rott, 2024; Bicer et al., 2023; Urban et al., 2024).

In recent years, there has been an emphasis on how important teachers' abilities to apply creative thinking are for enriching students' learning processes (Han & Abdrahim, 2023). Creative teachers play a crucial role in fostering student creativity (Wang & Jia, 2023). In this context, pre-service mathematics teachers need to possess the skills to support both their own mathematical creativity and the creative thinking abilities of their future students (Baumanns & Rott, 2024). Finally, the development of mathematical creativity during the transition process from being mathematics learners to becoming mathematics teachers is essential for successful mathematics teaching (Bicer et al., 2023).

Critical thinking in mathematics education and the role of the teacher

Critical thinking is regarded as an essential quality of the 21st century. Different definitions of critical thinking exist in the literature. Facione (1990) defined critical thinking as purposeful and self-regulating judgment. This definition views critical thinking not only as an analytical process but also as the continuous questioning and development of one's own thoughts (Ennis, 2018). Watson and Glaser (1980) emphasized that critical thinking should be evaluated in terms of both skill and disposition. Critical thinking skills refer to an individual's ability to analyze complex problems, evaluate information from a critical perspective, and reach an objective conclusion. The critical thinking dispositions (CTDs), on the other hand, reflects an individual's willingness and readiness to use this skill (Lipman, 2003; Tishman & Andrade, 1996). In other words, CTD reflects a person's attitude and motivation toward effectively utilizing critical thinking skills (Ennis, 2018).

Mathematics education involves high-level cognitive processes such as problem-solving, analysis, and reasoning. The development of these cognitive processes is achieved through students' ability to question, analyze, and make logical inferences about information. At this point, critical thinking comes into play. The integration of critical thinking into mathematics education enables students not only to produce algorithmic solutions but also to deeply understand mathematical processes and develop alternative solutions (Schoenfeld, 2016). Critical thinking guides students in the mathematical problem-solving process and helps them analyze problems more deeply (Halpern, 2014). Additionally, critical thinking improves problem-solving skills in mathematics education, allowing students to understand and interpret mathematical concepts from a critical perspective (As'ari et al., 2017).

Mathematics teachers are the guides in developing critical thinking skills in students. Teachers' abilities to direct students' thinking processes and encourage deep reflection on mathematical concepts play a crucial role in students' acquisition of critical thinking skills. A teacher with critical thinking skills can help students analyze problems, reach logical conclusions, and critically evaluate the challenges they encounter in this process (Paul & Elder, 2006). For pre-service teachers, having CTDs and skills will facilitate their ability to guide students' problem-solving processes in the classroom (Romero-Ariza et al., 2024). In this context, developing the CTDs and skills of pre-service mathematics teachers plays an important role in helping students acquire higher-order thinking skills (As'ari et al., 2017). Equipping students with critical thinking skills is a fundamental mission of contemporary higher education systems in this century (Le & Chong, 2024). Accordingly, teacher education must prioritize critical thinking for societal development, as future teachers can influence the critical thinking skills of an entire society, starting from K-12 education (Ellerton, 2015).

The intersection of creative and critical thinking in mathematics education

Creative and critical thinking are two modes of thinking in educational settings that both complement each other and sometimes offer different perspectives. The key element in the thinking process is awareness of how the mind produces and evaluates ideas. If we had only creative thinking, we would accumulate a lot of unnecessary and unnecessary knowledge. In this context, critical thinking plays a role in evaluating ideas generated through creative thinking (Paul & Elder, 2006). Thus, while creative thinking enables the generation of new ideas and innovative solutions (Wechsler et al., 2018), critical thinking involves the process of analyzing, evaluating, and testing the validity of these ideas (Wang & Jia, 2023). It is emphasized that the combination of these two skills contributes to individuals' problem-solving, decision-making, and knowledge production processes (Thornhill-Miller et al., 2023).

Creative thinking is considered a part of critical thinking and plays a critical role in the development of innovative abilities (Anderson et al., 2022; Cropley, 2003). Addressing both forms of thinking together in education contributes to raising more well-equipped individuals (Wechsler et al., 2018). Teachers, in turn, should guide their students by balancing these two skills to foster both creative and critical thinking abilities (Fisher, 2013). Particularly in mathematical thinking, creative thinking enhances the ability to generate solutions through different approaches, while critical thinking tests the validity and applicability of these solutions (Paul & Elder, 2006). In the context of mathematics teachers and pre-service teachers, the importance of both creative and critical thinking is emphasized. By integrating their subject knowledge with CTSs, pre-service teachers can find innovative ways to solve mathematical problems (Baumanns & Rott, 2024). At the same time, pre-service teachers must evaluate the validity of these solutions with a critical perspective (Halpern, 2014; Peter, 2012). Therefore, creative thinking holds an important place in the critical thinking process, and when both thinking skills are considered together, a deeper problem-solving process takes place (Cropley, 2003). Providing learning environments where teachers can develop both skills can make significant contributions to mathematical thinking and teaching processes (Paul & Elder, 2006). In this context, the fact that creative and critical thinking mutually nourish and enhance each other should be considered in the design of mathematics curricula (Paul & Elder, 2006; Wang & Jia, 2023).

The present study

The purpose of this study is twofold. First, it aims to examine the levels of CTSs and CTDs of pre-service mathematics teachers (PSTs), and the potential effects of sociodemographic (e.g., gender) and academic variables (e.g., academic achievement) on them. The second aim is to determine the relationship between the CTS and CTD of PSTs.

The gender variable has been addressed in studies examining CTSs of PSTs (e.g., Abraham, 2016; Baer & Kaufman, 2008; Cenberci, 2018; Erdoğan & Yıldız, 2021; Kozikoğlu & Küçük, 2020; Taylor & Barbot, 2021). However, there are very few studies in Türkiye that examine the effect of gender on the CTSs of PSTs. Gender has also been frequently considered in studies investigating the CTDs of PSTs (e.g., Biber et al., 2013; Deringöl, 2017; Erdoğan, 2020; Incikabi et al., 2013; Kandemir, 2017; Liu & Pásztor, 2022; Yorgancı, 2016). However, the results regarding the effect of gender on both CTSs and CTDs are inconsistent.

The results of studies investigating the effect and relationship between academic achievement and CTSs are also inconsistent (e.g., Ai, 1999; Akpur, 2020; Bicer et al., 2021; Schoevers et al., 2018). Most of these studies have sampled university, elementary, or high school students. Some studies have focused on the effect of academic achievement on the CTDs or skills of PSTs (e.g., Erdoğan, 2020; Erdoğan & Yıldız, 2021). Limited studies have examined the effect of academic achievement on the CTDs of PSTs. Considering that both ways of thinking are one of the key skills in mathematics education, it was thought that taking PSTs as a sample would contribute to the related literature.

The relationship between creative and critical thinking has also been explored, but most studies investigating this relationship have been conducted with university students (e.g., Baker et al., 2001; Gök & Erdoğan, 2011; Siburian et al., 2019; Thornhill-Miller et al., 2023; Wechsler et al., 2018). Creative and critical thinking are important higher-order thinking skills in the process of mathematics teaching. Teachers play a central role in developing both of these thinking modes. Therefore, the CTSs and CTDs of PSTs can be seen as significant predictors of their future teaching practices in mathematics classrooms. In this context, analyzing the evidence on the relationship between CTSs and CTDs from the perspective of PSTs is important for expanding the literature on mathematics education.

Considering the inquiry-based nature of mathematics and its demand for creativity, it is noteworthy that there are relatively few studies conducted on both CTSs and CTDs with PSTs. Therefore, this study is significant in terms of expanding and contributing to the mathematics education literature. Additionally, it is anticipated that the study will provide insights into the effectiveness of teacher education programs. Furthermore, the findings from this study are expected to offer preliminary information for future efforts aimed at developing the CTSs and CTDs of PSTs. In line with the aims described above, the following sub-questions will be addressed:

1. What are the levels of CTSs and CTDs of PSTs?

2. Do the CTSs and CTDs differ significantly according to the gender and academic achievement variables?

3. Is there a relationship between CTS and CTD? Do CTS predict CTD?

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 CTSs and CTDs of PTSs

Sample

The sample of the study consists of 205 PSTs. The PSTs were studying in the elementary mathematics teacher education program at the education faculty of a state university located in Turkey's Eastern Anatolia region. A power analysis was conducted to determine the sample size. For a significance level of .05 and the recommended power level of .80, a sample size of 205 was found to be sufficient (Christensen et al., 2014). Of the PSTs, 144 were female (70.24%) and 61 were male (29.76%). The distribution across the academic years was as follows: 55 (26.83%) in the first year, 52 (25.37%) in the second, 54 (26.34%) in the third, and 44 (21.46%) 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 (24.87%) demonstrated low, 70 (34.15%) moderate, and 84 (40.98%) high levels of academic achievement. Participation of the PSTs in the study was voluntary. Additionally, the age range of the PSTs was between 18-23, with an average age of 19.80.

Instruments

The "How Creative Are You?" scale, developed by Whetton and Cameron (2002), was used to determine the CTSs of PSTs. Whetton and Cameron stated that the scale provides information about CTSs by characterizing individuals' traits, attitudes, values, motivations, and interests. Additionally, the researchers indicated that the scale was developed to help identify individuals' creative personalities. The "How Creative Are You?" scale was adapted into Turkish by Aksoy (2004), and its validity and reliability were tested. The scale is unidimensional. It consists of 40 items, with 39 being rating-type and one being categorical, and the scoring for each item varies. The lowest possible score for the 39 items is -2, and the highest is 4. In the 40th item, participants are asked to select 10 adjectives from a list of 54 that best describe themselves. The values of the adjectives in the 40th item range from 0 to 2 points. PSTs participating in the study were asked to choose the option closest to them from agree, neutral, and disagree for each item in the scale. The scoring of the scale is done based on predetermined points according to participants' responses. The explained variance ratio of the single-factor scale is 45%. The Cronbach's Alpha reliability (internal consistency) coefficient of the scale was .94 (Aksoy, 2004). In this study, the reliability coefficient for the 39 items was calculated as .78. The score range for the scale varies between 0 and 116.

To measure the CTDs of PSTs, the Critical Thinking Disposition Scale (CTDS) developed by Sosu (2013) was used. The CTDS was adapted into Turkish by Akın et al. (2015). The scale is designed in a five-point Likert format and consists of 11 items. There are no reverse-coded items in the CTDS. The scale has two sub-dimensions: Critical Openness and Reflective Scepticism. The highest possible score on the CTDS is 55. Akın et al. (2015) calculated the Cronbach's Alpha internal consistency coefficients of the scale for the sub-dimensions of Critical Openness, Reflective Scepticism, and the overall scale as .68, .75, and .78, respectively. In the current study, the reliability coefficients were calculated as .83, .84, and .89, respectively.

Data analysis

The analysis of the obtained data was conducted using a statistical software package. First, the normality of the scores obtained from the data collection tools was examined using skewness and kurtosis values and formal normality tests (Shapiro-Wilk [S-W] test and Kolmogorov-Smirnov [K-S] test). The skewness values for the CTS scores of PSTs, including all subcategories of the variables for gender and academic achievement level, as well as the total scale scores, ranged from -.51 to .32, and the kurtosis values ranged from -.43 to -.03. For the CTD scores, the skewness values ranged from -.46 to .44, and the kurtosis values ranged from -1.20 to -.06, respectively. While skewness and kurtosis values within ±1.0 are considered excellent limits for measurements, values within the ±2.0 range are considered acceptable limits (George & Mallery, 2001). Hence, the skewness and kurtosis values fall within the acceptable limits for normal distribution. Additionally, the results of the K-S and S-W tests for the total scores indicated that the values were not statistically significant ($p > .05$). These results show that the CTS and CTD scores of PSTs exhibit normal distribution in terms of both subcategories and total scale scores.

Due to the normal distribution of the data, parametric tests were used for data analyses. An independent samples t-test was applied to compare the mean values of two groups, while a one-way analysis of variance (ANOVA) was used to compare the mean values of more than two groups. Post-hoc techniques were employed to determine where the differences between groups occurred. Additionally, evaluation intervals were calculated to interpret the CTD levels of PSTs. Accordingly, when evaluating the average scores for the 11-item CTDS, the following ranges were considered: Very high (4.20x11=46.2–5.00x11=55), High (3.40x11=37.4–4.19x11=46.9), Medium (2.60x11=28.6–3.39x11=37.29), Low (1.80x11=19.8–2.59x11=28.49), Very low (1.00x11=11–1.79x11=19.69). Effect sizes were also calculated in the study. In this context, partial eta-squared (η^2) effect size statistics were used. The obtained eta-squared values were interpreted as small effect ($\eta^2 = .01$), medium effect ($\eta^2 = .06$), and large effect ($\eta^2 = .14$) (Pallant, 2016).

Correlation analysis was employed to examine the relationship between CTSs and CTDs of PSTs. Before applying correlational techniques, the necessary assumptions such as measurement level, related pairs, independence of observations, normality, linearity, and equi-variance were examined. After confirming that the data followed a linear relationship and exhibited normal distribution, the Pearson correlation coefficient was calculated. The correlation coefficient was interpreted as follows: small ($r = .10–.29$), medium ($r = .30–.49$), and large ($r = .50–1.0$) (Pallant, 2016). A simple linear regression analysis was used to determine the extent to which PSTs' CTSs predicted their CTDs. Before performing the regression analysis, assumptions were reviewed. These assumptions included that the predictor (independent, CTS) and the predicted (dependent, CTD) variables are continuous and normally distributed, and that there is a linear relationship between these variables (Pallant, 2016). After the assumptions were tested and found to be met, regression analysis was conducted. A significance level of .05 was adopted for the study.

RESULTS

Findings on the levels of CTSs and CTDs of PSTs

Within the scope of the study's first sub-problem, descriptive findings concerning the CTSs and CTDs of PSTs are presented in Table 1.

Table 1. Descriptive statistical analysis of CTSs and CTDs of PSTs.

Variable	N	Mean ± SD	Min	Max
CTS	205	43.55 ± 8.75	21	66
CTD	205	42.59 ± 5.67	29	55

According to Table 1, the average score for the CTSs of PSTs is 43.55. Accordingly, the CTSs' level of the PSTs is above average. Additionally, the average score for the CTDs of PSTs is at a high level, with an overall average score of 42.59 on the scale.

Findings on whether CTSs and CTDs of PSTs differ by gender and academic achievement

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

Table 2. Independent samples T Test results for CTSs and CTDs of PSTs by gender.

Variable	Gender	N	Mean ± SD	df	t	p	η^2
CTS	Female	144	44.07 ± 8.24	203	1.32	.19	.01
	Male	61	42.31 ± 9.81				
CTD	Female	144	43.07 ± 5.26	203	1.87	.06	.02
	Male	61	41.46 ± 6.44				

As seen in Table 2, there is no significant difference between the average CTS scores of female (*M* = 44.07, SD = 8.24) and male PSTs (*M* = 42.31, SD = 9.81) [$t_{(203)}$=1.32, p= .19> .05]. When the calculated eta-squared value is examined, it is observed that the magnitude of the score difference between the groups is small (η^2 = .01). Additionally, there is no significant difference between the average CTD scores of female (*M* = 43.07, SD = 5.26) and male PSTs (*M* = 41.46, SD = 6.44) [$t_{(203)}$=1.87, p= .06> .05]. The magnitude of the difference between the group means is also small (η^2 = .02). The ANOVA results of the scores of CTSs and CTDs of PSTs by academic achievement are presented in Table 3.

Table 3. ANOVA results for CTSs and CTDs of PSTs by academic achievement.

	AA	N	Mean ± SD	ANOVA F	df-between groups	df-within groups	p	η^2
CTS	Low	51	39.00 ± 9.53	13.42	2	202	< .001	.12
	Medium	70	43.23 ± 7.96					
	High	84	46.57 ± 7.65					
CTD	Low	51	39.86 ± 6.88	11.06	2	202	< .001	.10
	Medium	70	42.44 ± 4.60					
	High	84	44.37 ± 5.00					

Note: AA=Academic Achievement

According to Table 3, a significant difference was found between the average CTS scores of PSTs based on the academic achievement level variable [$F_{(2-202)}$=13.42, p < .001]. Additionally, the effect size for the differences between group means was found to be just below the large level (η^2 =

.12). Before conducting the post-hoc analysis to determine the source of the differences, it was observed that the assumption of homogeneity of variance for the average CTS scores was met (F= 1.10, p = .33 > .05). To interpret the differences in mean scores according to academic achievement levels, the results of the Tukey HSD test given in Table 4 were examined.

When Table 3 is examined, a significant difference was found between the average CTD scores of PSTs based on the academic achievement level variable [$F_{(2-202)}$=11.06, p< .001]. Additionally, the effect size for the differences between group means was found to be close to the large level (η^2 = .10). It was observed that the assumption of homogeneity of variance for the average CTD scores was violated (F = 10.28, p < .05). To interpret the differences in mean scores according to academic achievement levels, the results of Tamhane's T2 test given in Table 4 were examined.

Table 4. Tukey HSD Test and Tamhane's T2 Test results for CTSs and CTDs of PSTs by academic achievement.

	Achievement(I)	Achievement(J)	Mean difference(I-J)	p	Difference
CTS	Low	Medium	-4.23	.02*	Medium>Low
		High	-7.57	< .001*	High>Low
	Medium	Low	4.23	.02*	Medium>Low
		High	-3.34	.04*	High> Medium
	High	Low	7.57	< .001*	High>Low
		Medium	3.34	.04*	High> Medium
CTS	Low	Medium	-2.58	.07	
		High	-4.51	< .001*	High>Low
	Medium	Low	2.58	.07	
		High	-1.93	< .04*	High> Medium
	High	Low	4.51	< .001*	High>Low
		Medium	1.93	< .04*	High>Medium

Results from the TUKEY HSD test indicate that the CTSs of PSTs with high academic achievement (*M* = 46.57, SD = 7.65) and moderate academic achievement (*M* = 43.23, SD = 7.96) are statistically significantly higher than those with low academic achievement (*M* = 39.00, SD = 9.53) (p < .05). Additionally, the CTSs of PSTs with high academic achievement are also significantly higher than those with moderate academic achievement (p = .04 < .05).

According to Table 4, the average CTD scores of PSTs with high academic achievement (*M* = 44.37, SD = 5.00) is statistically significantly higher than the average scores of those with moderate (*M* = 42.44, SD = 4.60) and low academic achievement (*M* = 39.86, SD = 6.88) (p < .05).

Findings on the relationship and prediction of CTSs and CTDs of PSTs

The relationship between CTSs and CTDs of CTSs was analyzed by correlation analysis and the findings are shown in Table 5.

Table 5. Correlation analysis results for CTSs and CTDs of PSTs

		CTD
CTS	r	.480**
	p	.000
	N	205

** p< .01

Table 7 demonstrates that there is a medium, positive and statistically significant correlation between CTSs and CTDs (r = .48, N = 205, p< .001). These findings indicate that as the CTSs of PSTs increase, their CTDs will also increase in parallel. Finally, a simple linear regression analysis was performed to ascertain how CTSs of PSTs predicted their CTDs, with the findings detailed in Table 6.

Table 6. Simple linear regression analysis results on CTSs predicting CTDs

Predicted variable	Predicting variable	B	Standard error	β	t	p
CTD	Constant	29.05	1.77		16.39	< .001
	CTS	.31	.04	.48	7.79	< .001

Table 6 reveals a significant and medium level relationship between CTSs and CTDs of PSTs ($R = .48$, $R^2 = .23$). The CTSs of PSTs are significant predictors of their CTDs [$F_{(1-203)} = 60.70$, $p < .01$], explaining 23% of the variance in CTDs. The regression analysis posits the following predictive equation for CTD: (CTD) = .31 x (CTS) + 29.05.

CONCLUSION AND DISCUSSION

In this study, the CTSs and CTDs of PSTs were examined. The findings of the study revealed that the CTSs levels of PSTs were "above average". This result can be seen as a positive prerequisite for training students with CTSs in the future. However, it is considered that this level could be even higher. This result may stem from the insufficient content in teacher education programs to support CTS. Moreover, the development of CTSs requires a combination of theory and practice. However, the limited opportunities for PSTs to apply these skills in the classroom may hinder their full development. Zhan et al. (2024) emphasize that the lack of classroom practice can negatively impact students' abilities to solve problems creatively and generate ideas. These factors may be potential reasons why the CTSs levels of PSTs are not higher. This result is consistent with previous studies. Studies indicate that the CTSs of PSTs are at an above-average (high) level (Cenberci, 2018; Çenberci & Yavuz, 2018).

According to the findings, it was determined that the CTDs levels of PSTs are high. This indicates that PSTs exhibit an inquisitive approach to knowledge, think analytically in problem-solving processes, and possess the ability to make independent evaluations. Specifically, activities focused on problem-solving, discussion, and argumentation enhance the CTDs of PSTs (Yuan & Liao, 2023). Therefore, the content of teacher education programs can play a significant role in developing PSTs' CTDs and skills. This result of the study aligns with Kandemir's (2017) findings, which revealed that PSTs have high CTDs. However, the study's result differs from other findings that suggest PSTs have low or average CTDs (As'ari et al., 2017; Biber et al., 2013; Incikabi et al., 2013; Rott, 2021; Yorgancı, 2016; Yüksel et al., 2013). It is thought that this difference in results may stem from factors such as the measurement tool used or the characteristics of the sample group.

One important finding of the study is that the CTSs of PSTs do not significantly differ according to the gender variable. This result indicates that gender is not a determining or influencing factor in the CTSs of PSTs. This may be a reflection of changing perceptions regarding gender equality policies and gender roles in education. For instance, in recent years, many countries have taken significant steps towards ensuring gender equality in their education systems (Rosa & Clavero, 2022). Furthermore, the insignificance of the effect of gender on CTSs may suggest that these skills are more based on individual differences. As Amabile and Khaire (2008) stated, CTSs are influenced by factors such as personal interests, motivation, experiences, and cognitive abilities. This result is consistent with previous findings indicating that the CTSs of PSTs do not differ by gender (Baer & Kaufman, 2008; Cenberci, 2018; Erdoğan & Yıldız, 2021; Kozikoğlu & Küçük, 2020; Taylor & Barbot, 2021; Tsai, 2013). In one of the recent studies, Taylor and Barbot (2021) reported no gender differences in five out of six creativity measures. Presenting a different perspective, Abraham (2016) suggested that gender differences in CTSs may partially stem from gender differences in other characteristics or cognitive abilities. However, there are some conflicting results in the literature regarding the gender variable. For example, Kaufman (2006) found that women demonstrated an advantage in the relationship between CTSs and gender. Ivcevic et al. (2022) stated that women performed more creatively than men in verbal tasks. On the other hand, Stoltzfus et al. (2011) argued that men's creative performance was higher than that of women. Results regarding the gender factor show inconsistency. Therefore, it seems difficult to generalize about the effect of the gender variable on CTSs.

In the study, it was determined that the CTDs of PSTs do not differ according to gender. This indicates that gender is not a determining factor in CTDs of PSTs. The fact that teaching strategies used in education are gender-neutral may contribute to the development of CTDs without gender differences. This result supports the findings of studies that indicate no significant differences in the CTDs of PSTs according to the gender variable (Biber et al., 2013; Incikabi et al., 2013; Kandemir, 2017; Leach & Good, 2011; Yüksel et al., 2013). A comprehensive meta-analysis by Liu and Pásztor (2022) reported no effect of gender on critical thinking. Moreover, Liu and Pásztor (2023) found that mathematics teachers' critical thinking did not differ by gender. Despite the frequent consideration of the gender variable in critical thinking studies, there are conflicting results. Some studies have found that the CTDs/skills of female PSTs are higher than those of males (Deringöl, 2017; Erdoğan, 2020; Yorgancı, 2016). King et al. (1990), however, found that males had significantly higher CTDs than females. King et al. attributed this to different educational experiences that may encourage males to think more critically. Zhao et al. (2024) found that men, depending on their level of self-efficacy, may be more likely to make spontaneous judgments compared to women. Cultural psychology studies suggest that critical thinking is culturally based and that gender roles in society influence CT skills (Dennett & DeDonno, 2021). In this context, the cultural values of societies can be considered one of the reasons for differences in CTDs according to the gender variable.

Another result of the study is that there is a significant difference between the academic achievement levels and CTSs of PSTs. Specifically, it was found that the CTSs of PSTs with high and moderate academic achievement were significantly higher than those with low academic achievement. Additionally, the CTSs of PSTs with high academic achievement were significantly higher than those with moderate academic achievement. High academic achievement is generally associated with more advanced cognitive capacity and problem-solving abilities. CTSs also require a high level of cognitive capacity. Therefore, CTSs can enhance students' success in more complex problem-solving tasks (Urban et al., 2024). Parallel to this result, Akpur (2020) revealed a positive and significant relationship between university students' CTSs and their academic achievement. Similarly, Bicer et al. (2021), who conducted a meta-analysis, reported a positive relationship between mathematical achievement and CTSs. However, while some studies have reported a positive relationship between CTSs and academic achievement in mathematics (e.g., Schoevers et al., 2018; Sebastian & Huang, 2016), others have reported no relationship (Ai, 1999) or even a negative relationship (Anderson et al., 1969; cited in Yang & Zhao, 2021). The lack of a consensus-based definition of creativity and CTSs has led to a variety of measurement approaches. In studies on CTSs, it is observed that researchers largely rely on divergent thinking tests, problem-solving tasks, or products to assess creativity (Jia et al., 2019). It is thought that the contradictory results regarding how CTSs of PSTs differ by gender and academic achievement stem from the different measurement tools used. The research designs, sample groups, and data collection methods employed in the studies may also lead to differences in the results.

The study determined that as the academic achievement levels of PSTs increased, their CTDs also increased. Furthermore, it was concluded that the CDSs of PSTs with high academic achievement were significantly higher than those with moderate and low academic achievement. CTDs requires advanced cognitive skills such as analysis, evaluation, and problem-solving. These skills are also critical for academic success. Thus, mathematical knowledge and solving mathematical problems enhance CTDs and decision-making abilities. All these factors support individuals in becoming more successful problem solvers (Ennis, 2018). According to Facione (2000), individuals with strong CTDs approach problems systematically and thoughtfully, which increases their academic success. This result of the study is consistent with findings from studies showing that the CDSs of PSTs significantly differ in favor of those with high academic achievement (e.g., Erdoğan, 2020). Similarly, Le and Chong (2024) emphasized that CTDs or skills play an important role in achieving academic success among higher education students.

The other findings of the study pertain to the relationship between CTSs and CTDs. Accordingly, it was found that there is a moderate, positive, and significant relationship between the CTSs and CTDs of PSTs. In light of these findings, it can be expected that as the CTSs of PSTs increase, their CTDs will also increase in parallel. This can be explained by the idea that CTSs may facilitate the effective use of critical thinking in problem-solving and analytical thinking processes. Considering that creative thinking involves generating new and original ideas, while critical thinking encompasses evaluating and testing these ideas, it can be said that there is a mutual and dynamic interaction between the two forms of thinking (Runco, 2007). Similarly, Thornhill-Miller et al. (2023) emphasized that these two forms of thinking are closely interconnected. While creative thinking produces alternative solutions, critical thinking evaluates these solutions and selects the most applicable one. Therefore, creative thinking and critical thinking are considered complementary cognitive processes. According to Paul and Elder (2006), who conceptually explain the reciprocal relationship between CTS and CTD, there is a mutual logic for both intellectual creativity and critical judgment. This result of the study aligns with findings that reveal a moderate and positive relationship between CTSs and CTDs (Gök & Erdoğan, 2011; Wechsler et al., 2018). Furthermore, in the literature, there are studies that have found a high and positive relationship between the CTSs and CTDs of PSTs (Siburian et al., 2019). Baker et al. (2001), however, stated in their study that there was no relationship between CTS and CTD. These differences in study results may be due to the measurement tools used by researchers. For example, the tests or questionnaires assessing CTSs and CTDs may have different psychometric properties (Cropley, 2003). Another possible reason for the contradictory results in the studies is that the research was conducted in different cultural and educational contexts. Wechsler et al. (2018) suggested that the education system and cultural factors could shape the relationship between creative thinking and critical thinking.

The regression analysis conducted in the study revealed that CTSs are a significant variable explaining CTDs. Accordingly, CTSs explain 23% of the variance in CTDs. This finding supports the theoretical similarities expressed between the two forms of thinking. Recent research results suggest that creative thinking is seen as a part of critical thinking and is emphasized as essential for the development of innovative abilities (Wang & Jia, 2023). In this context, Chang et al. (2015) stated that critical thinking involves creative thinking in the problem-solving process. Lipman (2003) noted that by nature, thinking is both critical and creative, as producing creative solutions or using strategies is followed by stages that require critical thinking, such as evaluation and decision-making. Similarly, Halpern (2006) conceptualized critical and creative thinking as processes that are not identical but complementary to each other.

Limitations and future directions

This section presents the limitations of the study and suggestions for its results. Firstly, this study has some limitations that can be addressed with further research. First of all, the CTSs and CTDs of PSTs in the current study were assessed through self-report instruments. Thus, despite the limitations posed by self-report instruments, such as social conformity, the advantage of collecting data from a larger number of PSTs compared to alternative methods like observation and interviews was utilized. Nonetheless, to minimize the disadvantages of self-reported data, future studies should adopt qualitative or multi-informant approaches.

Secondly, in this study, self-reports were obtained from a limited number of PSTs, and convenience sampling was used in determining the sample. To better support the results, it is recommended that future studies be repeated with a larger sample from different regions. Additionally, obtaining self-report data from pre-service elementary or high school teacher in future studies could provide interesting insights to expand the study's findings.

Thirdly, a non-experimental research design was adopted in the current study. Due to the cross-sectional design of this study, the developmental trajectory of creative thinking and critical thinking could not be explored. Therefore, there is a need for longitudinal studies with PSTs. Additionally, experimental studies could be designed to identify the factors influencing the CTSs and

CTDs of PSTs. Specifically, experimental studies should be conducted on how to develop the creative thinking and critical thinking of PSTs.

Fourthly, this study investigated the unidirectional relationship between the CTSs and CTDs of PSTs. Future studies could examine whether CTDs or skills predicts CTSs. Furthermore, variables such as metacognition, self-concept, and problem-solving skills, which might mediate this relationship, or the potential causal relationships between these variables should be investigated from a causal perspective.

Finally, the investigation of CTSs and CTDs of PSTs based on gender and academic achievement is considered a limitation of the study. Future studies should explore additional factors that might significantly influence these variables (e.g., parents' educational level, academic year, age, family income). Future research should investigate additional factors that may substantially impact CTSs and CTDs of PSTs development.

Implications and recommendations

In essence, the results of this study provide implications for stakeholders in teacher training programs and policymakers. The findings suggest that further improvements can be made in developing Future research should investigate additional factors that may substantially impact CTSs and CTDs of PSTs. In this regard, teacher training programs should be restructured to more deeply support creative thinking and critical thinking. PSTs should be offered classroom practice opportunities that will develop their CTSs and CTDs. Indeed, research has shown that problem-posing and solving practices, which are key components of basic teaching experiences, yield positive outcomes for prospective teachers' mathematical creativity and critical thinking (Baumanns & Rott, 2024; Bicer et al., 2023; Romero-Ariza et al., 2024). The results of this study also show that gender does not have a significant effect on CTSs and CTDs. This finding can be considered a positive indicator in terms of ensuring and maintaining gender equality in education. In this regard, educational policies should focus on practices that support gender equality and enable all students to develop their thinking skills (Rosa & Clavero, 2022).

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