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The Model of Critical, Creative, and Computational Thinking Among Pre-Service Teachers in Indonesia and Malaysia

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ABSTRACT

The primary purpose of this study is to examine the characteristics that most strongly predict pre-service teachers' Computational Thinking (CT) skills. The significance of investigating potential correlations between Critical Thinking (CI) and Creative Thinking (CE) skills cannot be overstated. Using a Structural Equation Model, we constructed a model that investigates the components of the issue and pre-service teachers' CT skills. The data were collected from 1,245 pre-service teachers in mathematics education and social science programs in Indonesia and Malaysia. A correlational survey approach was employed, and the CI, CE, and CT scales were administered to the respondents. Results showed that competence in CI and CE was predicted in CT. CI skills are the most important when predicting CT skills, while CE skills are just moderately so. Future research in ASEAN nations may gain insights by examining the influence of an integrated technological strategy on educators' attitudes toward their role in fostering CI, CE, and CT skills.

Keywords: Computational thinking, creative thinking, critical thinking, structural equation model

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Introduction

The improvements in information and communication technologies have significantly influenced various aspects of daily life, including the economy, social behavior, and education. Information has become one of the most valuable global resources. Societies with access to information and the capacity to employ it effectively have advanced more swiftly and generated greater output than others, owing to the global increase in the value and importance of information. Future robust societies will comprise individuals who can: a) adeptly and efficiently utilize suitable technologies to obtain accurate information in the appropriate context; b) possess mastery in critical thinking (CI); c) exhibit proficiency in creative thinking (CE) skills; and d) demonstrate cognitive flexibility and computational thinking (CT). Changwong et al. (2020) and Setiawati and Corebima (2020) contend that robust communities require all members, regardless of age, to acquire fundamental CI and CE skills, as well as basic CT skills to navigate daily challenges.

Operationally, CI in this article encompasses the dimensions of clarity, precision, completeness, relevance, and accuracy, which collectively reflect higher-order cognitive inquiry skills. These dimensions align with established critical thinking frameworks that emphasize analytical rigor, reflective judgment, and intellectual discipline as foundations of effective reasoning and decision-making in educational contexts (Changwong et al., 2020). Within preservice teacher education, CI is viewed as a foundational competence that supports pedagogical reasoning, problem solving, and the development of advanced thinking skills, including computational and analytical thinking. Whereas CE is operationalized through the dimensions of fluency, flexibility, elaboration, and originality, which represent key components of creative thinking processes. These dimensions are consistent with contemporary creativity theories that view creative thinking as a dynamic interaction between divergent thinking, problem representation, and idea refinement (Aini & Aini, 2023).

Meanwhile, all pre-service teachers are required to develop critical thinking skills, as stipulated in the 2019 Education Vision document of the Indonesian Ministry of National Education for 2023. Increased focus has been directed towards equipping pre-service teachers with education that encompasses CI acquisition, CE employment, and combined strategies for CI and CE. The motivation for this technique is the need to develop production-related skills, including data processing abilities (Abidin & Herman, 2023). In 2019, the mathematics education and social science curricula in Malaysia were updated to incorporate contemporary best practices. The objective was to cultivate individuals whose CI and CE are enhanced by the digital competencies and programming skills acquired in high school, while ensuring that secondary school pupils acquire CT skills (Hamidi et al., 2023).

The significance of cultivating critical thinking skills in education is emphasized, along with the identification of factors that facilitate the acquisition of effective creative inquiry skills (Putri & Dwi, 2023; Voon et al., 2022) and creative expression abilities in mathematics and science domains (Murcia et al., 2020). Moreover, numerous studies have indicated that further research is necessary at the K5-12 level (Dwi et al., 2024; Paf & Dinçer, 2021). This research aims to determine how CI and CE skills in mathematics education and social science classes contribute to CT skills.

To accomplish this objective, we examined whether these characteristics predict pre-service teachers' critical thinking skills and investigated the explanatory and predictive relationships between these variables (CI and CE) and pre-service teachers' critical thinking skills.

Framework of Study

The study framework includes descriptions of the relationships among CE and CT skills, CI and CE skills, and CE and CT skills. However, the theory's hypotheses warrant consideration.

Recent research by Malik and Ubaidillah (2020) and Sukarso et al. (2022) highlights a connection between CI and CE skills. According to Malik and Ubaidillah (2020), both CI and CE involve four stages: preparation, incubation, illumination, and verification. Similarly, Sukarso et al. (2022) emphasize that CI and CE skills are developed through deliberate design and focus on these stages. The illumination phase is associated with generating new ideas, while the verification phase involves refining and evaluating them (Adeyemi, 2021). Therefore, a deeper understanding of the distinct components of CI and CE skills can enhance comprehension of their roles in effective problem-solving.

Meanwhile, by examining and contrasting the two models, a clearer understanding of the breadth and limitations of CT skills, as well as the contexts in which their application is both appropriate and ethically justified, can be gained. Research provides evidence of pre-service teachers' CI and CT abilities. For instance, Psycharis et al. (2020) found that when comparing pre-service teachers' CT and CI skills, improvements in CT positively influenced CI. Several scholars have suggested a connection between CT proficiency and CI development. However, existing literature on this relationship remains limited, with only one study to date identifying a significant correlation (Oyelere et al., 2022).

Regarding the relationship between creative thinking (CE) and computational thinking (CT), initial results revealed an intriguing link between CE and CT skills, both within and beyond the CT domain (Sukarso et al., 2022). CT competence is reflected in a student's capacity to analyze information, utilize real-world data, and evaluate its credibility. Comprehending such knowledge requires integrating creative thinking grounded in analytical reasoning and factual understanding. Developing CE skills naturally complements the cultivation of CT skills, as CT provides the cognitive foundation for creativity. Aziz (2023) describes CT skills as the conceptual process through which individuals identify patterns, algorithms, and abstractions to assess their effectiveness. Therefore, training based on CT principles can strengthen pre-service teachers' CE capabilities. Given their close interrelationship, further investigation into the connection between CE and CT skills is essential.

Consequently, this study aims to address this research gap based on the proposed conceptual framework.:

H1: There is a connection between CI and CE skills.

H2: There is a connection between CI and CT skills.

H3: There is a connection between CE and CT skills.

Figure 1

The Research Framework

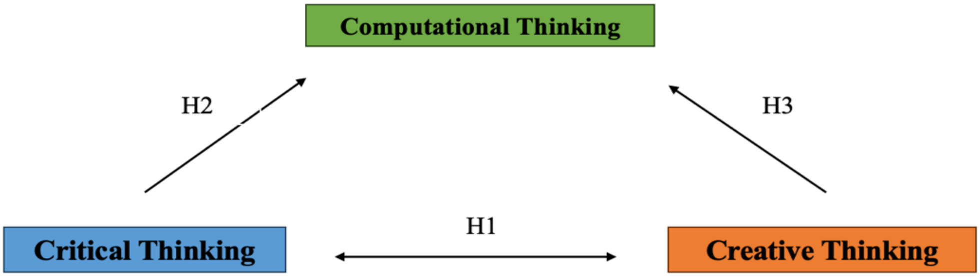

Figure 1 displays the study model, which was inspired by existing scientific literature.

Research Questions

A deeper understanding of the components of CT, CI, and CE skills enables us to better grasp how they function in problem-solving. As a result, the research posed the following questions:

RQ1: Are there any connections between CI and CE skills?
RQ2: Are there any connections between CI and CT skills?
RQ3: Are there any connections between CE and CT skills?

Participants

A total of 1,245 pre-service teachers from Universitas Muhammadiyah Purwokerto (Indonesia) and Universiti Teknologi Malaysia (Malaysia) participated in the study. The mathematics education program and the school of education program were included in the sample. Their average age was 18.75 (SD = 2.48), and they were selected using convenience sampling. Men comprised 48.11% of the sample, and women 646 (51.89%). The information was gathered during the 2023-2024 academic year from semesters 2, 4, 6, and 8.

Methodology

Research Design

This study employed a quantitative cross-sectional survey design. A questionnaire-based quantitative approach was considered appropriate due to the large population and sample size. (Hu et al., 2017). The measurement models for CI, CE, and CT skills focused on fundamental concepts, topics, and cross-curricular dimensions. Data collected from 1,245 participants were analyzed using Structural Equation Modeling (SEM) in AMOS, with SPSS used for integration. Participants were informed that their involvement was voluntary and that they could withdraw at any stage without any negative consequences. The SEM analysis examined the measurement model with respect to factor loadings, convergent validity, composite reliability, and discriminant validity.

According to Byrne (2019), the Confirmatory Factor Analysis (CFA) is the measurement model component. It requires the researcher to specify the number of factors and which observed variables (CI, CE, and CT skills) load onto each factor prior to analysis. Subsequently, a factor loading regression weight (β) of .708 or higher indicates that the proposed factor is appropriate. An Average Variance Extracted (AVE) value greater than .500 and an external loading value of at least .4 are recommended, while a composite reliability (CR) exceeding .708 meets the reliability criteria. Kline (2017) notes that discriminant validity is achieved when the square root of AVE surpasses the intercorrelation among constructs. Model fit was evaluated using several indices, including Chi-Square (CMIN), Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), Normed Fit Index (NFI), and Tucker-Lewis Index (TLI). The model is considered a good fit when the Chi-Square (CMIN) significance value exceeds .050; values between .800 and .890 are considered acceptable. RMSEA values below .100 indicate a fair fit, with values under .080 regarded as good (Strajhar et al., 2019).

Instruments and Data Collection

Study instruments included the CI Skills Scale, CE Skills Scale, and CT Skills Scale. Tool data is here. Pre-service teachers can use the CT scale to test their CT skills (Kotsopoulos et al., 2017). They detected 22 items in four groups: Decomposition (4), Pattern Recognition (4), Abstraction (4), and Algorithms (6). Participants rate their ideas on a 5-point Likert scale. This study has a Cronbach's alpha reliability coefficient of .87, compared to .86 in the previous survey. Original Turkish CI Skills scale (Heard et al., 2020).

Fifteen elements comprise the five: Clarity, Accuracy, Completeness, Relevance, and Intellectual honesty, with three items each. Participants also rank their thoughts on a 5-point Likert scale. The current evaluation's Cronbach's alpha reliability coefficient was 83, up from 86. The CE Scale has four areas: fluency (four items), flexibility (four items), elaboration (four items), and originality (four items) (Ramalingam et al., 2018). In contrast to the previous studies.86 Cronbach's alpha reliability coefficient, this research found 86. Participants grade their ideas on a 5-point Likert scale.

Data Analysis

The data analysis employed a rigorous Structural Equation Modeling (SEM) approach, comprising descriptive statistics, Confirmatory Factor Analysis (CFA) for construct validation, and SEM for hypothesis testing. This sequential approach ensured that both the measurement and structural models met acceptable standards of validity, reliability, and overall model fit (Strajhar et al., 2019). First, prior to SEM estimation, the dataset was systematically screened to confirm accuracy, completeness, and suitability for multivariate analysis. Descriptive statistics, including means, standard deviations, skewness, and kurtosis, were calculated to assess data normality, while Pearson correlation analysis was conducted to examine preliminary associations among Cognitive Intelligence (CI), Creative Expression (CE), and Computational Thinking (CT). Second, CFA was conducted to validate the latent constructs of CI, CE, and CT. Construct validity was assessed through factor loadings (FL), Composite Reliability (CR), and Average Variance Extracted (AVE). Convergent validity was established through satisfactory FL, CR, and AVE values, while discriminant validity was confirmed as the square root of each construct's AVE exceeded its correlations with other constructs. Finally, SEM analysis using AMOS was performed to test the hypothesized relationships among CI, CE, and CT. Model fit was evaluated using multiple goodness-of-fit indices, including the Chi-square to degrees of freedom ratio (χ^2/df), Goodness of Fit Index (GFI), Adjusted GFI (AGFI), Normed Fit Index (NFI), Comparative Fit Index (CFI), Tucker–Lewis Index (TLI), and Root Mean Square Error of Approximation (RMSEA), ensuring a comprehensive assessment of model adequacy.

Findings

Table 1 shows the results for convergence validity, composite reliability, and normalcy. CT skills were also linked to CI and CE skills. The results for the variables demonstrated convergent validity (AVE > .5), composite reliability (CR > .701), and data normality (skewness and kurtosis values within the range of -1 to +1). According to the results, all factors are highly correlated.

The Association between Study Constructs

Table 1 presents the means, standard deviations, and correlation matrices for the variables under investigation.

According to Table 1, CI and CE skills were positively and strongly associated (r=.142, p <.01). CI and CT skills have a substantial relationship (r=.131, p<.05), while CE and CT skills have a favorable association (r =.134, p<.01). Whereas, CT skills significantly effect constructions (CI and CE skills), as illustrated in Table 2 by crucial ratio values. Significant correlations were found between CI, CE, and CT (β = .065, C.R. = 16.314; β = .063, C.R. = 15.035; and β = .087, C.R. = 13.521), respectively.

Table 1

Statistical Description of This Study

Variable	M	SD	Skew	Kurt	Critical Thinking	Creative Thinking	Computational Thinking
Critical Thinking	3.46	1.25	-.35	1.57			
Creative Thinking	3.53	1.42	-.41	1.63	.142**		
Computational Thinking	3.16	1.51	-.04	1.74	.131*	.134**	

**Correlation is significant at the .05 level (1-tailed)*

***Correlation is significant at the .01 level (2-tailed)*

Table 2

Coefficient of Regression Values

Constructs			Estimate	SE	CR	p
Creative thinking	<-->	Critical thinking	.931	.065	16.314	.000*
Computational thinking	<--	Critical thinking	.724	.063	15.035	.000*
Computational thinking	<--	Creative thinking	.925	.087	13.521	.000*

**significant at p<.01 (2-tailed)*

Confirmatory Analysis of Study Constructs

The confirmatory factor analysis in this study included the constructs of CI, CE, and CT skills. We checked CR and AVE values, as well as factor loading, for each construct.

Table 3 presents the validation results of the confirmatory factor analysis (CFA) for CI, CE, and CT skills. The findings indicate that the CFA achieved satisfactory outcomes. All constructs demonstrated acceptable factor loadings (FL), composite reliability (CR), and average variance extracted (AVE). Specifically, Table 3 reports that the factor loadings ranged from .733 to .928, with a composite reliability (CR) of .942 and an average variance extracted (AVE) value of .784. In contrast, the confirmatory factor analysis (CFA) results for CE skills. The analysis outcomes indicate that the CFA met the acceptable criteria. All constructs demonstrated satisfactory levels for factor loadings (FL), composite reliability (CR), and average variance extracted (AVE). As shown in Table 4, the factor loadings ranged from .714 to .973, with a composite reliability (CR) value of .742 and an average variance extracted (AVE) value of .833. Subsequently, the results of the confirmatory factor analysis (CFA) for CT skills were obtained. The findings indicate that the CFA remained within the acceptable limits. The factor loadings ranged from .731 to .982, with a composite reliability (CR) value of .713 and an average variance extracted (AVE) value of .881. All constructs met or surpassed the required standards for factor loadings (FL), composite reliability (CR), and average variance extracted (AVE).

Table 3

The Critical, Creative, and Computational Thinking Confirmatory Analysis

Constructs	Sub-constructs	Items	FL	CR	AVE
Critical Thinking	Clarity	Cla1	.784	.942	.784
		Cla2	.847		
		Cla3	.733		
	Accuracy	Accu1	.833	.742	.842
		Accu2	.831		
		Accu3	.742		
	Completeness	Comp1	.844	.752	.885
		Comp2	.811		
		Comp3	.844		
	Relevance	Relv1	.781	.741	.841
		Relv2	.788		
		Relv3	.844		
	Intellectual honesty	Intel1	.928	.735	.874
		Intel2	.891		
		Intel3	.913		
Creative Thinking	Fluency	Flue1	.891	.783	.833
		Flue2	.833		
		Flue3	.871		
		Flue4	.833		
	Flexibility	Flex1	.783	.744	.842
		Flex2	.914		
		Flex3	.893		
		Flex4	.811		
	Elaboration	Elab1	.893	.733	.831
		Elab2	.714		
		Elab3	.744		
		Elab4	.973		
	Originality	Orig1	.788	.721	.892
		Orig2	.873		
		Orig3	.785		
		Orig4	.873		
Computational thinking	Decomposition	Decom1	.844	.713	.881
		Decom2	.871		
		Decom3	.783		
	Pattern Recognition	Patt1	.833	.773	.814
		Patt2	.871		
		Patt3	.733		
	Abstraction	Abs1	.982	.711	.834
		Abs2	.731		
		Abs3	.844		
	Algorithms	Alg1	.833	.713	.831
		Alg2	.815		
		Alg3	.835		

Path Analysis of Relations Between Study Constructs

Figure 2 shows the route model. It reveals the interconnections among various elements, including CI, CE, and CT skills. Table 4 details fit indices and goodness-of-fit criteria.

Table 4

The Study of Goodness of Fit Values

Fit Values	Good Fit Values	Values Reached
χ^2/df	χ^2/df ≤ 3	2.540
RMSEA	0 < RMSEA < .05	.065
GFI	.90 < GFI ≤ 1	.940
AGFI	.90 < AGFI ≤ 1	.931
NFI	.90 < NFI ≤ 1	.983
CFI	.90 < CFI ≤ 1	.979
TLI	.90 < TLI ≤ 1	.972

Fit indices are effective in assessing structural equation models, as they indicate how well the model aligns with the observed data (Byrne, 2019; Strajhar et al., 2019). The strongest correlation coefficient (β = .75) was observed between CI skills and CT abilities. Among the four latent variables, the CE skills subfactor had the highest factor loading, ranging from .94 to .95. This variable comprises three components, with CI skills showing the lowest factor loading (.75–.81). As a result, the latent values for the CT skills sub-construct ranged between .75 and .87.

The results confirm the null hypothesis (H1) that CI and CE skills are substantially associated (β = .471; p <.05). Pre-service teachers' CI skills automatically improve CE. A β-value of .75 and a p-value of .01 supported the null hypothesis (H2). This suggests that CI

Figure 2

The Structural Model of The Study

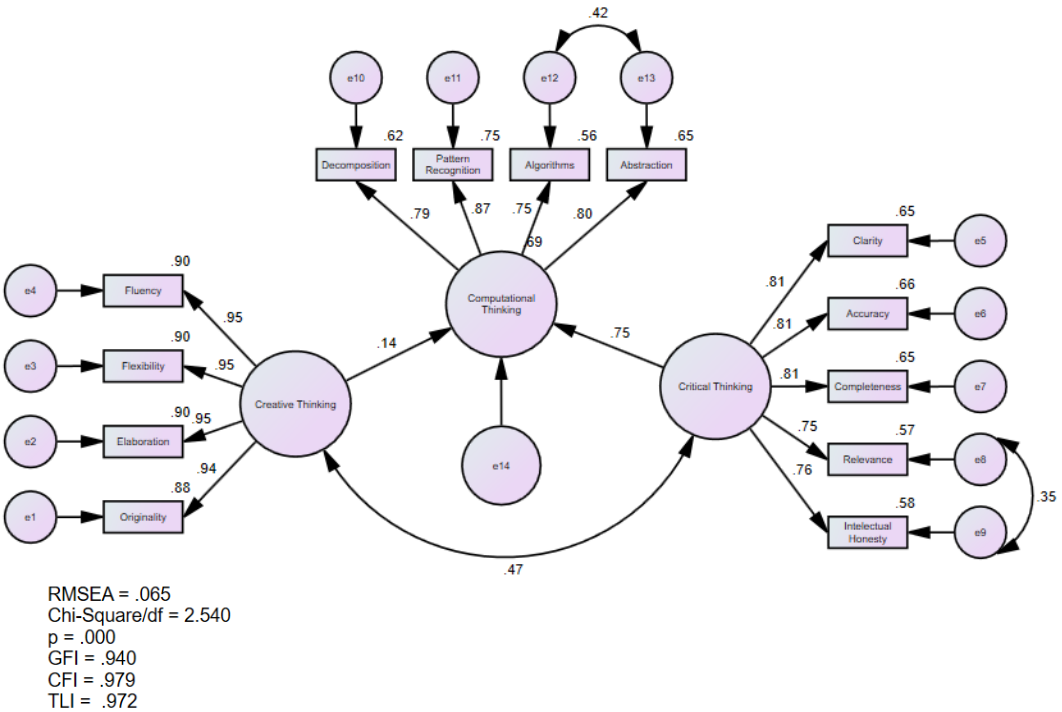

Table 5

The Result of the Study Hypotheses

Hypotheses	Path	β	SE	CR	p *)	Supported?
H1	Critical thinking ← Creative thinking	.471	.048	3.184	.042	Yes
H2	Critical Thinking ← Computational thinking	.754	.056	2.454	.002	Yes
H3	Creative thinking ← Computational thinking	.142	.072	2.410	.031	Yes

competency strongly predicts CT competency. Thus, pre-service teachers who perform well in CI are likely to perform well in CT. The null hypothesis (H3) was not rejected, given a β-value of .14 and a p-value < .01. This indicates that pre-service teachers' CE skills strongly and significantly predict their CT skills. Thus, CEs are likely to study using CT skills. Table 5 provides the details of the study's hypotheses.

Discussion

Relationships among Cognitive Intelligence, Creative Expression, and Computational Thinking

The findings reveal a positive and significant association among Cognitive Intelligence (CI), Creative Expression (CE), and Computational Thinking (CT) skills. CI exhibited a strong correlation with CT proficiency, indicating that preservice teachers with higher cognitive inquiry capabilities demonstrated more advanced critical thinking skills. Similarly, CE skills in mathematics and social science were positively associated with CT skills, suggesting that preservice teachers with stronger academic performance in these domains also possessed higher levels of critical thinking. Although CE skills were significantly related to CT, they were a weaker predictor than CI.

The strong association between CI and CT aligns with prior research indicating that advanced cognitive development enhances critical thinking and reasoning abilities (Bower et al., 2022; Voon et al., 2022). Previous studies have also emphasized that CI underpins reasoning processes in both mathematical and social science contexts, thereby supporting the present findings (Adeyemi, 2021; Changwong et al., 2020; Oyelere et al., 2022). Furthermore, the observed relationship between CE and CT is consistent with literature highlighting the role of creative engagement in supporting critical and computational thinking, particularly in technology-enhanced learning environments. Collectively, these results suggest that strengthening preservice teachers' CI and CE, particularly through tasks that emphasize clarity, relevance, and problem-solving, may enhance CT competencies.

Measurement Model Evaluation: Confirmatory Factor Analysis

The CFA results indicated that the CI, CE, and CT constructs achieved acceptable standardized factor loadings, composite reliability (CR), and average variance extracted (AVE), demonstrating strong construct validity. The CI construct showed high reliability across indicators of clarity, completeness, relevance, and accuracy, confirming its robustness as a measure of cognitive inquiry skills.

Similarly, CE constructs, comprising fluency, adaptability, elaboration, and originality, demonstrated strong contributions to the latent variable, reflecting the multidimensional nature of creative expression. The CT construct, represented by pattern recognition, decomposition, algorithms, and abstraction, also exhibited consistent validity indicators and contributed meaningfully to the overall measurement model.

The validated CFA model confirms that CI, CE, and CT are theoretically and statistically coherent constructs. Strong latent values within the CE construct align with previous studies emphasizing the importance of creativity and digital competence in developing 21st-century skills (Aini & Aini, 2023; Hamidi et al., 2023; Richado et al., 2023). Likewise, the robustness of CT indicators supports earlier findings that computational thinking skills, particularly pattern recognition and decomposition, underpin higher-order cognitive reasoning (Adeyemi, 2021; Changwong et al., 2020; Oyelere et al., 2022). These results affirm the suitability of the measurement model for assessing preservice teachers' higher-order thinking skills in technology-integrated educational contexts.

Structural Model and Path Analysis Results

Path analysis results demonstrate that CI skills are the strongest predictor of CT skills, exhibiting the highest regression weights in the structural model. CT competencies were significantly predicted by key components, including decomposition, pattern recognition, algorithms, and abstraction. Although CE skills were positively associated with CT, their predictive influence was weaker than that of CI. Within the CE construct, elaboration, flexibility, and fluency showed the strongest latent effects, whereas CI was most strongly represented by clarity, precision, and completeness.

These findings indicate that CI is the primary cognitive driver of CT performance, supporting theoretical perspectives that emphasize logical structure, analytical clarity, and intellectual rigor as essential foundations of critical thinking (Eragamreddy, 2023). The strong predictive contribution of CT components further reflects global research highlighting decomposition and abstraction as central elements of computational reasoning (Handayani et al., 2020).

The relatively weaker predictive effect of CE on CT is consistent with mixed evidence from prior studies; however, CE remains a meaningful contributor, particularly in learning environments that require creativity-driven problem-solving and innovation. Overall, the structural model underscores the importance of cultivating CI and CT through structured cognitive tasks, digital literacy development, and authentic, technology-supported learning experiences.

Implications for Future Research

This study highlights the interconnected roles of Cognitive Intelligence (CI), Creative Expression (CE), and Computational Thinking (CT) in shaping imaginative and meaningful learning experiences facilitated by teachers. The findings open several promising avenues for future research to deepen understanding of how these higher-order thinking skills develop and interact across educational contexts.

Future studies may explore how preservice teachers intentionally cultivate creative thinking among their students, particularly by examining the role of early imagination in fostering cognitive and creative development (Aziz, 2023). Longitudinal research designs could investigate how imaginative engagement in early learning stages contributes to the progressive development of CI, CE, and CT skills over time.

Such approaches would provide valuable insights into the developmental trajectories of these competencies across different educational levels.

On the other hand, in shaping imaginative and meaningful learning experiences facilitated by teachers, offering several directions for future research, particularly within the context of ASEAN teacher education. Future studies could explore how teacher education institutions across ASEAN countries intentionally integrate CI, CE, and CT into preservice teacher preparation through curriculum design, innovative pedagogies, and technology-enhanced learning environments. Comparative and cross-national research may also examine how cultural contexts, local wisdom, and educational policies influence the development of creativity and computational thinking in teacher candidates. In addition, longitudinal studies are recommended to investigate how imaginative engagement during early teacher training contributes to the sustained development of higher-order thinking skills as preservice teachers transition into professional practice. Such research would provide valuable insights into designing interdisciplinary and culturally responsive teacher education models that strengthen innovation, digital competence, and creative pedagogy in ASEAN classrooms.

In technology-rich learning environments, further research is needed to examine how learners' creativity influences the development of CT skills. Investigating the reciprocal relationship between creative engagement and computational problem-solving may clarify how digital tools and innovative pedagogies support the integration of creativity and computation. This line of inquiry is particularly relevant as educational technologies increasingly shape learning experiences and instructional practices.

Consistent with prior research suggesting that learner autonomy and problem-based exploration support the development of CI and CE skills (Amaliyah et al., 2023), future studies could examine instructional strategies that promote problem-solving. Experimental or mixed-methods research could help identify which pedagogical approaches most effectively strengthen the synergy among CI, CE, and CT. Moreover, future research may benefit from examining how integrated, technology-based approaches to CI and CE influence teachers' professional beliefs, instructional decision-making, and perceptions of their pedagogical roles. Understanding how teachers conceptualize their responsibilities in fostering higher-order thinking could inform teacher education programs and professional development initiatives.

Finally, given the limited empirical research on the development of preservice teachers' CT skills, further studies should investigate how core CT components, such as decomposition, pattern recognition, algorithms, and abstraction, evolve in relation to CI and CE as preservice teachers progress through their training. Longitudinal and cross-disciplinary studies could offer a more comprehensive understanding of how these skills co-develop, thereby informing the design of curricula that intentionally integrate cognitive, creative, and computational thinking competencies..

Conclusion

Our research contributes to the growing body of literature by exploring how various factors, specifically pre-service teachers' Creative Imagination (CI) and Creative Expression (CE) skills, affect their Critical Thinking (CT) abilities within mathematics and social science education programs. The strong association found between pre-service teachers' CI skills and their CT abilities across both disciplines provides further evidence of the intrinsic link between critical thinking and the cognitive capacities required to address challenges in these domains. Additionally, the positive correlation observed between CE and CT skills highlights the importance of fostering mathematics and social science learning from an early stage. Among all factors, CI skills emerged as the strongest predictor of CT skills, underscoring the importance of training pre-service teachers through pedagogical approaches that stimulate the cognitive processes essential for developing strong critical thinking abilities.

Building on the findings of this study, it is recommended that teacher education programs place stronger emphasis on instructional approaches that intentionally cultivate pre-service teachers' CI, CE, and CT skills, as these abilities were shown to significantly influence the development of CI. Because CI emerged as the strongest predictor of CT, training models should incorporate learning experiences that promote ideation, exploration, visualization, and imaginative reasoning, particularly within mathematics and social science contexts. Additionally, programs should integrate structured opportunities for creative expression, such as project-based learning, reflective tasks, and multidisciplinary activities, to strengthen the positive link between CE and CT observed in this study. Early and continuous exposure to cognitively stimulating learning environments is also recommended, as foundational engagement in mathematics and social science may enhance CT development over time. Finally, curriculum designers and policymakers should consider embedding CI and CE-oriented strategies into teacher preparation curricula to ensure that future educators are equipped with the cognitive tools necessary for nurturing critical thinking in their own classrooms.

Recommendations

Despite these contributions, several methodological limitations should be acknowledged. First, the study relied on a moderate sample size drawn from a limited institutional context, which may restrict the generalizability of the findings to preservice teachers in other regions, educational systems, or subject specializations. Future studies employing larger and more diverse samples across multiple institutions or countries would strengthen the external validity of the results. Second, the study utilized self-reported questionnaire measures, which may be subject to response bias and may not fully capture participants' actual cognitive and creative performance. Incorporating performance-based assessments, classroom observations, or mixed-methods approaches could provide a more comprehensive understanding of CI, CE, and CT development.

Third, the cross-sectional research design limits the ability to draw causal inferences regarding the developmental relationships among CI, CE, and CT. While the SEM analysis revealed significant associations and predictive pathways, longitudinal designs are needed to examine how these skills evolve over time and to better understand their directional influences. Additionally, although the measurement model demonstrated acceptable validity and reliability, the constructs were operationalized within specific indicators that may not encompass the full complexity of creative imagination, creative expression, or critical thinking across diverse learning contexts.

Taking these limitations into account, it is recommended that teacher education programs place greater emphasis on instructional approaches that intentionally cultivate CI, CE, and CT skills. Given that CI emerged as the strongest predictor of CT, teacher training models should incorporate learning experiences that promote ideation, exploration, visualization, and imaginative reasoning, particularly in mathematics and social science instruction. Furthermore, structured opportunities for creative expression, such as project-based learning, reflective inquiry, and interdisciplinary tasks, should be embedded within curricula to strengthen the positive relationship between CE and CT identified in this study.

■ ■ ■

Statements and Declarations

1. **Ethical Approval**
   This study received ethical approval from the appropriate institutional ethics committee with reference number: C9.VIII/305-S.Pb/LPPM/VII/2023. Informed consent was obtained from all participants, participation was voluntary, and data were collected anonymously. All procedures adhered to established ethical standards for research involving human participants..
2. **Funding details.**
   This work was supported by The Research and Community Service Holding of Universitas Muhammadiyah Purwokerto, Indonesia, in collaboration with Universiti Teknologi Malaysia, Malaysia, for the funding with project number A.11-III/6607-S.Pj./LPPM/II/2024.
3. **Declaration of Generative AI.**
   During the preparation of this work, the author(s) used ChatGPT.com tools to enhance the readability and language of the manuscript. After utilizing this tool/service, the author(s) thoroughly reviewed and edited the content as necessary and take full responsibility for the final content of the published article.
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References

Abidin, Z., & Herman, T. (2023). The computational thinking in elementary school in the Indonesia new curriculum: A teacher's perspective. *Sekolah Dasar: Kajian Teori Dan Praktik Pendidikan*, *32*(02), 178–185. https://journal2.um.ac.id/index.php/sd/article/view/41727

Adeyemi, S. B. (2021). Developing critical thinking skills in pre-service teachers: A mandate for higher education in Nigeria. *European Journal of Educational Research*, *1*(2), 155–161. http://www.akademikplus.com/eujer/index.html

Aini, M., & Aini, M. (2023). Enhancing creative thinking and communication skills through engineering design process (EDP) learning model: A case study. *BIOEDUKASI*, *21*(1), 21. https://doi.org/10.19184/bioedu.v21i1.38022

Amaliyah, F., Supeno, S., & Wahyuni, S. (2023). The profile of creative thinking skills of junior high school pre-service teachers in science learning about alternative energy. *Jurnal Paedagogy*, *10*(3), 675. https://doi.org/10.33394/jp.v10i3.7444

Aziz, R. (2023). Creativity in higher education: The effect of personality on pre-service teachers' creative thinking skills. *Thinking Skills and Creativity Journal*, *6*(1), 44–51. https://doi.org/10.23887/tscj.v6i1.54916

Bower, M., Wood, L. N., Lai, J. W. M., Howe, C., & Lister, R. (2022). Improving the computational thinking pedagogical capskills of school teachers. *Australian Journal of Teacher Education*, *42*(3), 53–72. https://doi.org/10.14221/ajte.2017v42n3.4

Byrne, B. M. (2019). *Structural equation modeling with amos: Basic concepts, applications and programming*. Routledge.

Changwong, K., Sukkamart, A., & Sisan, B. (2020). Critical thinking skill development: Analysis of a new learning management model for Thai high schools. *Journal of International Studies*, *11*(2), 37–48. https://doi.org/10.14254/2071

Dwi I. R., Susetyarini, E., Jaya Miharja, F., Raya Tlogomas, J., & Java, E. (2024). Developing STEM-PjBL worksheet to lift pre-service teachers' critical, creative, and computational thinking skill. *Research and Development in Education*, *4*(1), 86–101. https://doi.org/10.22219/raden.v

Eragamreddy, N. (2023). Teaching creative thinking skills. *International Journal of English Language & Translation Studies*, *11*(2), 124–145. www.eltsjournal.orgwww.eltsjournal.org

Hamidi, A., Mirijamdotter, A., & Milrad, M. (2023). A complementary view to computational thinking and its interplay with systems thinking. *Education Sciences*, *13*(2), 1–16. https://doi.org/10.3390/educsci13020201

Handayani, S. A., Rahayu, Y. S., & Agustini, R. (2020). Improving pre-service teachers' creative thinking skills through Google Classroom assisted GO_KAR Model during the Covid-19 Pandemic. *International Journal of Engineering Research and Technology*, *13*, 4616–4621. http://www.irphouse.com

Heard, J., Scoular, C., Duckworth, D., Ramalingam, D., & Teo, I. (2020). *Critical thinking: Skill development framework.* The Australian Council for Educational Research Ltd.

Hu, C.-P., & Chang, Y.-Y. (2017). John W. Creswell, research design: Qualitative, quantitative, and mixed methods approaches. *Journal of Social and*

Administrative Sciences, *4*(2), 205–207. https://doi.org/10.1453/jsas.v4i2.1313

Kline, R. B. (2017). *Principles and practice of structural equation modeling*. The Guilford Press.

Kotsopoulos, D., Floyd, L., Khan, S., Namukasa, I. K., Somanath, S., Weber, J., & Yiu, C. (2017). A pedagogical framework for computational thinking. *Digital Experiences in Mathematics Education*, *3*(2), 154–171. https://doi.org/10.1007/s40751-017-0031-2

Malik, A., & Ubaidillah, M. (2020). Pre-service teachers critical-creative thinking skill: A multivariate analysis of experiments and gender. *International Journal of Cognitive Research in Science, Engineering and Education*, *8*(Special Issue 1), 49–58. https://doi.org/10.23947/2334-8496-2020-8-SI-49-58

Murcia, K., Pepper, C., Joubert, M., Cross, E., & Wilson, S. (2020). A framework for identifying and developing children's creative thinking while coding with digital technologies. *Issues in Educational Research*, *30*(4), 1395–1417. https://www.iier.org.au/iier30/murcia2-abs.html

Oyelere, S. S., Agbo, F. J., & Sanusi, I. T. (2022). Developing a pedagogical evaluation framework for computational thinking supporting technologies and tools. *Frontiers in Education*, *7*(4), 22–37. https://doi.org/10.3389/feduc.2022.957739

Paf, M., & Dinçer, B. (2021). A study of the relationship between secondary school pre-service teachers' computational thinking skills and creative problem-solving skills. *TOJET: The Turkish Online Journal of Educational Technology*, *20*(4), 1–15. https://files.eric.ed.gov/fulltext/EJ1313467.pdf

Psycharis, S., Kalovrektis, K., & Xenakis, A. (2020). A conceptual framework for computational pedagogy in steam education: Determinants and perspectives. *Hellenic Journal of STEM Education*, *1*(1), 17–32. https://doi.org/10.51724/hjstemed.v1i1.4

Putri, M.E., & Dwi, K.Y. (2023). Integrating STEAM education and computational thinking: Analysis of pre-service teachers' critical and creative thinking skills in an innovative teaching and learning. *Southeast Asia Mathematics Education Journal*, *13*(1), 1–18. https://journal.qitepinmath.org/index.php/seamej/article/view/241/0

Ramalingam, D., Anderson, P., Duckworth, D., Scoular, C., & Heard, J. (2018). Creative thinking: Definition and structure. *Journal of Digital Learning in Teacher Education*, *4*(5), 44–58. https://research.acer.edu.au/ar_misc/43

Richado, R., Dwiningrum, S. I. A., & Wijaya, A. (2023). Computational thinking skill for mathematics and attitudes based on gender: Comparative and relationship analysis. *Pegem Egitim ve Ogretim Dergisi*, *13*(2), 345–353. https://doi.org/10.47750/pegegog.13.02.38

Setiawati, H., & Corebima, A. D. (2020). Empowering critical thinking skills of the pre-service teachers having different academic ability in biology learning of senior high school through PQ4R - TPS strategy. *The International Journal of Social Sciences and Humanities Invention*, *4*(2), 31–44. https://doi.org/10.18535/ijsshi/v4i5.09

Strajhar, P., Schmid, Y., Liakoni, E., Dolder, P. C., Rentsch, K. M., Kratschmar, D. V., Odermatt, A., Liechti, M. E., Ac, R., No, N., No, C., Oramas, C. V., Langford, D. J., Bailey, A. L., Chanda, M. L., Clarke, S. E., Drummond, T. E., Echols, S., Glick, S., … Mogil, J. S. (2019). Structural equation modeling basic assumptions and concepts: A novices guide. *Nature Methods*, *7*(6), 20–35. www.eajournals.org

Sukarso, A., Artayasa, I. P., Bahri, S., & Azizah, A. (2022). Provision of creative teaching materials in improving creative disposition and creative thinking skills of high school pre-service teachers. *Jurnal Penelitian Pendidikan IPA*, *8*(6), 2728–2736. https://doi.org/10.29303/jppipa.v8i6.2514

Voon, X. P., Wong, S. L., Wong, L. H., Khambari, M. N. M., & Syed-Abdullah, S. I. S. (2022). Developing computational thinking competencies through constructivist argumentation learning: A problem-solving perspective. *International Journal of Information and Education Technology*, *12*(6), 529–539. https://doi.org/10.18178/ijiet.2022.12.6.1650

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