Journal of the Indonesian Mathematics Education Society
JIMES, 2026, Vol. 4, no. 1, 1-23
ISSN: 2656-3479 (print), 2656-7253 (electronic)
URL: https://journal.unesa.ac.id/index.php/jimes

Integrating Collaborative Learning with Polya Problem-Solving Approach: A Model for Critical Thinking that Comprise of Pre-Service Teachers' Factors

Isaiah Dilor Dookurong[1*], Yarhands Dissou Arthur[2] & Emmanuel Akwertey[2]

[1]Department of Mathematics Education, McCoy College of Education, Nadowli, UWR, Ghana
[2]Department of Mathematics Education, Akenten Appiah-Menka University of Skill Training and Entrepreneurial Development, Tanoso-Kumasi, Ghana
[*]Email: dookurongisaiah2016@gmail.com

Submitted: 19 March 2026; Revised: 13 April 2026; Accepted: 18 April 2026

ABSTRACT

This study examined the effect of integrating collaborative learning with Polya's problem-solving approach on pre-service teachers' attitudes, engagement, and critical thinking skills in mathematics. Guided by a pragmatist paradigm, the study adopted mixed-method quasi-experimental design. The population comprised pre-service mathematics teachers, from which a purposive sample of 390 participants was selected. Quantitative data were collected at the pretest stage using a critical thinking achievement test and structured questionnaires measuring attitudes and engagement. Both qualitative and quantitative data were collected at the posttest stage through parallel critical thinking achievement test and open-ended responses respectively for classroom-based evidence. Quantitative data were analyzed using descriptive statistics and independent samples t-tests to establish baseline differences between groups, while qualitative data were analyzed thematically using Braun and Clarke's six-phase approach. The findings indicated that the integrated instructional approach improved pre-service teachers' attitudes toward mathematics, increased their engagement in learning activities, and enhanced their critical thinking skills. Qualitative evidence further revealed that active collaboration, positive learning dispositions, and sustained participation supported deeper understanding and higher-order thinking. The study contributes to mathematics teacher education by demonstrating how the integration of collaborative learning with Polya's problem-solving approach can strengthen instructional practices and foster the development of critical thinking among pre-service teachers. The findings provide empirical support for adopting integrated pedagogical strategies that promote engagement and meaningful learning in mathematics classrooms.

Keywords: *Collaborative Learning; Critical Thinking, Polya Problem-Solving Approach; Pre-Service Teachers; Mathematics Education*

How to cite: Dookurong, I.D., Authur, Y.D., Akwertey, E. (2026). Integrating Collaborative Learning with Polya Problem-Solving Approach: A Model for Critical Thinking that Comprise of Pre-Service Teachers' Factors. *Journal of the Indonesian Mathematics Education Society*, *4*(1), 1-23. https://doi.org/10.26740/jimes.v4n1.p1-23

INTRODUCTION

Critical thinking has increasingly been recognized as an essential competency for learners in the twenty-first century, particularly in mathematics education where problem solving, reasoning, and analytical thinking are fundamental to meaningful learning (Dookurong et al., 2025). Mathematics is not merely a body of procedural knowledge but a discipline that requires learners to interpret problems, formulate strategies, and justify solutions(Mahmud et al., 2021). Consequently, mathematics instruction must move beyond traditional teacher-centered approaches toward instructional practices that actively engage learners in inquiry, reasoning, and collaborative problem solving (Dookurong et al., 2025).

Despite the recognized importance of critical thinking in mathematics education, many classrooms still rely heavily on conventional teaching approaches that emphasize memorization and routine procedures (Setiana et al., 2021). Similarly, Arisoy & Aybek (2021) added that such instructional practices often limit students' opportunities to develop higher-order thinking skills and to engage deeply with mathematical concepts. Jesto et al. (2025) mentioned that the challenge is particularly evident in teacher education programs, where pre-service teachers are expected not only to acquire strong mathematical understanding but also to develop the pedagogical skills necessary to foster critical thinking among their future students. Addressing this issue requires innovative instructional approaches that promote active participation, collaborative interaction, and systematic problem-solving processes.

Another important concern in mathematics education relates to students' engagement and attitudes toward learning mathematics. Moussa & Saali (2022) stated that engagement plays a crucial role in effective learning because students who actively participate in classroom activities are more likely to develop deeper understanding and stronger reasoning abilities. This implies that one can only succeed in the study of mathematics if one brains interact effectively with mathematical concepts well. Similarly, Tarasenkova (2023) made it clear that students' attitudes toward mathematics significantly influence their motivation, persistence, and willingness to engage in challenging mathematical tasks. This implies that, these affective domain factors are particularly important in developing teacher education contexts, where pre-service teachers' experiences with mathematics may influence their future teaching practices and their ability to create supportive learning environments for their students.

In their paper, Hwang & Chen (2023) applaud that collaborative learning has been widely acknowledged as an effective instructional strategy that encourages students to work together to construct knowledge and solve problems. Rooted in social constructivist perspectives of learning, collaborative learning emphasizes dialogue, shared responsibility, and the co-construction of understanding among learners (Vygotsky, 1978). Through collaborative interaction, students exchange ideas, challenge assumptions, and refine their reasoning, thereby promoting deeper conceptual understanding (Ambussaidi & Yang, 2019). Collaborative environments also support the development of communication skills and shared problem-solving strategies that are essential for meaningful mathematical learning (Asare et al., 2024).

Complementing collaborative learning is the problem-solving framework proposed by Pólya (1952), which provides a structured approach to solving mathematical problems. Polya's model involves four essential stages: understanding the problem, devising a plan, carrying out the plan, and looking back to evaluating the solution. This framework has long been regarded as a cornerstone of mathematical problem-solving instruction because it encourages learners to approach problems systematically while reflecting on their reasoning processes (Mazana et al., 2019). When integrated effectively into classroom instruction, Polya's approach can help students develop analytical thinking, metacognitive awareness, and deeper mathematical understanding (Tegeh et al., 2022). This implies that maximum applications of structured approach to solving mathematical problems heightening the understanding of mathematics.

Attitudes toward teaching and learning are widely recognized as important factors influencing educational outcomes, particularly in the development of higher-order thinking skills such as critical thinking. In mathematics education, teachers' attitudes may influence how learning activities are structured, the level of interaction promoted in the classroom, and the extent to which students are encouraged to engage in analytical reasoning (Tarasenkova, 2023). Previous studies suggest that positive teaching attitudes contribute to supportive learning environments that encourage inquiry, reasoning, and reflective thinking among students. For example, Rashid & Qaisar (2017) and Milagros et al. (2026) found that instructional strategies promoting reflective questioning improved students' attitudes toward critical thinking and stimulated deeper engagement in learning processes. Similarly, Akar & Kara (2020) reported that students' attitudes toward critical thinking were associated with democratic classroom environments, suggesting that positive learning dispositions may contribute to the development of reasoning and analytical skills.

In addition to attitudes, instructional strategies play an important role in promoting critical thinking skills. Active learning approaches such as problem-based learning, inquiry-based learning, and collaborative learning have been widely recognized for their ability to encourage analytical reasoning and problem-solving abilities. For instance, Fitriani et al. (2020) demonstrated that integrating Problem-Based Learning with the Predict–Observe–Explain strategy significantly improved students' critical thinking skills in science education. These findings highlight the importance of structured problem-solving activities in fostering deeper cognitive engagement.

Research also highlights the importance of student engagement in the development of critical thinking. Engagement reflects learners' active involvement in classroom activities, including participation in discussions, collaborative problem solving, and reflective reasoning. Simonovic et al. (2022) found that factors such as confidence, motivation, and perceived value of critical thinking significantly influence students' reasoning abilities in online learning environments. Again, Ospankulova et al. (2025) reported that higher levels of engagement in project-based learning environments were associated with improved academic performance and cognitive development.

Recent studies also emphasize the effectiveness of collaborative learning and Polya's problem-solving strategies in enhancing mathematical thinking. Research exploring the interaction between group work and Polya's heuristics (Alvi & Nausheen, 2019; Andrade & Ching, 2020) indicates that structured collaboration supports conceptual reasoning and facilitates flexible movement through Polya's stages. Through peer interaction, learners are able to articulate strategies, justify reasoning, and negotiate meaning, processes that are essential for higher-order thinking.

Furthermore, collaborative learning has been shown to promote behavioral and social engagement through peer interaction and shared responsibility (Mingolo, 2024; Jamaluddin et al., 2022). Classroom experiments involving collaborative models such as Team Assisted Individualization (TAI), Jigsaw, and Parallel Achievement Division demonstrate increased levels of participation, dialogue, and motivation among students (Choirudin et al., 2025; Andrade & Ching, 2020). However, research also cautions that collaborative learning alone does not always guarantee deeper cognitive engagement. Without effective facilitation, clear task structures, and balanced participation among group members, collaboration may lead to uneven participation and reduced engagement among less confident learners (Wismath & Orr, 2015; Yapatang & Polyiem, 2022).

Polya's problem-solving framework, on the other hand, emphasizes systematic cognitive processes in solving mathematical problems. Studies suggest that Polya's stages promote metacognition, strategic reasoning, and reflective thinking (Alvi & Nausheen, 2019; Wahab et al., 2024). However, this approach primarily focuses on cognitive processes and may not sufficiently address the social and motivational aspects of learning. Some qualitative studies (Muslim et al., 2023) highlight the importance of group communication during Polya-based tasks, yet many of these studies do not rigorously measure the impact of collaborative interaction on engagement or critical thinking.

Although collaborative learning and Polya's problem-solving approach have independently demonstrated positive effects on students' learning outcomes, relatively few studies have examined the integration of these two instructional strategies within a unified instructional model. Existing research often focuses on either cognitive outcome such as critical thinking or affective variables such as attitudes and engagement separately. Consequently, there is limited empirical evidence regarding how an integrated instructional approach can simultaneously influence cognitive and affective learning outcomes in mathematics education.

Moreover, many previous studies have been conducted outside teacher education contexts or have focused primarily on students rather than pre-service teachers (Mazana et al., 2019). As future educators, pre-service teachers' engagement and attitudes toward mathematics are critical factors that may shape their instructional practices and influence how they support students' learning in their future classrooms. However, empirical research examining the combined effects of collaborative learning and Polya's problem-solving approach on pre-service teachers' engagement, attitudes, and critical thinking remains limited.

Additionally, findings from previous studies are often based on small samples, qualitative analyses, or limited experimental designs, making it difficult to draw clear conclusions about the effectiveness of integrated instructional models. Contextual factors such as class size, facilitator expertise, and students' prior mathematical knowledge may also influence the effectiveness of such instructional strategies. These challenges highlight the need for further empirical investigation into integrated instructional approaches that combine social interaction with structured problem-solving processes in mathematics education.

This study is grounded in constructivist learning theory, particularly the ideas of Piaget (1952) and Vygotsky (1978), which emphasize that learners actively construct knowledge through experience and interaction. This study is positioned within the growing body of research on improving critical thinking in mathematics education. Previous studies have examined the effects of collaborative learning and Polya's problem-solving approach independently on students' learning outcomes. However, limited studies have explored the integration of these two instructional strategies within a single framework, particularly among pre-service teachers. Unlike prior research, this study combines collaborative learning with Polya's structured problem-solving process and employs a mixed-methods approach to provide both statistical and experiential insights. This integrated perspective represents a novel contribution to the literature by offering a more comprehensive model for enhancing critical thinking in mathematics education. In mathematics education, this suggests that meaningful learning and critical thinking emerge when students actively explore and solve problems rather than passively receive information. Vygotsky's social constructivism further highlights the importance of collaboration and guided interaction within the Zone of Proximal Development, where learners achieve deeper understanding through support from others.

The purpose of this study proposes an instructional model that integrates collaborative learning with Polya's problem-solving approach to enhance critical thinking among pre-service teachers. The model considers both tutors' instructional practices and pre-service teachers' learning-related factors, recognizing that effective learning outcomes are influenced not only by instructional strategies but also by the interactions, attitudes, and engagement of learners within the classroom environment.

The findings of this study have important implications for mathematics teacher education and instructional practice. The integration of collaborative learning with Polya's problem-solving approach provides an effective pedagogical strategy for enhancing pre-service teachers' critical thinking, engagement, and attitudes toward mathematics. Teacher educators can adopt this integrated approach to promote active participation, structured reasoning, and reflective learning in mathematics classrooms. Additionally, the study highlights the need for curriculum designers to incorporate problem-solving and collaborative activities into teacher training programs to better prepare future teachers for learner-centered instruction. From a research perspective, the study offers a foundation for further investigations into integrated instructional models and their impact on other learning outcomes and educational contexts.

Research Objectives

This study seeks to achieve the following objectives: (1) to examine the effect of the integrated method on pre-service teachers' engagement in mathematics learning, (2) to determine its influence on pre-service teachers' attitudes toward mathematics learning, and (3) to identify its impact on pre-service teachers' critical thinking in mathematics.

METHODS

Research Design

This study adopted a mixed-method quasi-experimental design to examine the effect of integrating collaborative learning with Polya's problem-solving approach on pre-service teachers' engagement, attitudes toward mathematics, and critical thinking. The instructional intervention was implemented by integrating collaborative learning with Polya's four-step problem-solving approach in a structured and systematic manner. Pre-service teachers were organized into small heterogeneous groups to promote interaction and peer support throughout the learning process. The instructional procedure followed four main stages. First, in the understanding the problem stage, students worked collaboratively to interpret the problem, identify relevant information, and clarify mathematical concepts through group discussion and guided questioning by the instructor. Second, in the devising a plan stage, group members proposed multiple solution strategies, evaluated their feasibility, and collectively selected the most appropriate approach. Third, during the carrying out the plan stage, students collaboratively implemented the chosen strategies, actively engaging in peer explanation, reasoning, and error correction, while the instructor facilitated learning by providing scaffolding and feedback where necessary. Finally, in the looking backstage, groups reflected on their solutions, verified their results, considered alternative methods, and presented their findings to the class for further discussion. Throughout the process, the instructor played a facilitative role by encouraging participation, promoting critical questioning, and supporting reflective thinking. This integrated approach ensured active engagement, shared responsibility, and the development of higher-order thinking skills among the participants.

A quantitative pretest was administered on 390 pre-service teachers before the intervention to establish baseline levels of these variables, and the data were screened for reliability and accuracy using descriptive statistics and checks for missing values, outliers, and internal consistency. After the instructional intervention, qualitative data were collected through open-ended questionnaire to explore participants' experiences with the integrated instructional strategy. The open-ended questionnaire data were analyzed using thematic analysis to identify themes related to engagement, attitudes, and critical thinking. Although the design did include a quantitative posttest for statistical comparison, the combination of baseline quantitative data and qualitative insights provided a comprehensive understanding of the instructional intervention's impact.

Research Approach

This study employed a mixed-methods experimental design to investigate the effect of an integrated collaborative learning and Polya problem-solving approach on pre-service teachers' engagement, attitudes, and critical thinking in mathematics. The mixed-methods design was chosen to combine the strengths of quantitative and qualitative approaches, providing both baseline measures and rich insights into participants' experiences.

Pretest (Quantitative): Prior to the intervention, participants completed standardized assessments to establish baseline levels of critical thinking, engagement, and attitudes toward mathematics. These measures provided objective data on participants' initial learning outcomes and ensured a clear reference point for interpreting the effects of the instructional intervention.

Posttest (Qualitative): Following the intervention, open-ended questionnaire was conducted to explore participants' experiences and perceptions of the instructional strategy. The qualitative posttest aimed to capture the depth of participants' reflections, engagement in learning processes, and perceived changes in their thinking, which could not be measured through numerical assessments alone.

Justification: The combination of a quantitative pretest and both for posttest allow the study to (1) objectively assess baseline learning outcomes, (2) understand how participants experienced the integrated instructional method, and (3) provide explanatory insights into changes in attitudes, engagement, and critical thinking processes.

Data Analysis

Preliminary data screening is particularly important for the pretest because it establishes a reliable and accurate baseline of participants' learning outcomes, including critical thinking, engagement, and attitudes toward mathematics. Screening the pretest data ensures that errors, missing responses, or extreme outliers do not distort these baseline measures, which are critical for interpreting the impact of the instructional intervention. Since the pretest provides the reference point against which the effects of the integrated collaborative learning and Polya problem-solving approach are understood, ensuring its accuracy and validity is essential. Additionally, checking that assumptions for statistical analysis (e.g., normality, linearity, homoscedasticity) are met allows for credible and interpretable results. In short, preliminary screening of the pretest guarantees that the baseline data are trustworthy, forming a solid foundation for understanding changes in learning outcomes following the intervention.

Quantitative Pretest Analysis*:* Pretest data were analyzed using descriptive statistics to establish baseline measures of participants' critical thinking, engagement, and attitudes. Measures included means, standard deviations, and frequency distributions to summarize the initial learning outcomes. The quantitative data also underwent screening for reliability and validity, including checks for missing data, outliers, and internal consistency using Cronbach's alpha with criteria of 0.7. This ensured that the pretest results provided a valid and reliable foundation for interpreting the impact of the instructional intervention.

The posttest phase involved the integration of quantitative and qualitative data to examine the effects of the instructional intervention. Quantitative posttest data were analyzed using an independent samples t-test to determine the differences between groups after the intervention. In addition, qualitative data from open-ended questionnaires were analyzed thematically using the six-step procedure proposed by Braun & Clarke (2006). The responses were first coded line-by-line to identify meaningful statements related to participants' experiences with the integrated instructional approach. These codes were subsequently organized into broader themes reflecting engagement in learning activities, attitudes toward mathematics, and the development of critical thinking skills. The qualitative findings were then interpreted alongside the quantitative results, allowing the study to explain how participants experienced changes in these learning-related factors following the intervention. This integration of statistical results with thematic insights provided a comprehensive understanding of the posttest outcomes and strengthened the credibility of the study by combining objective measurement with rich descriptive evidence.

Justification: This analysis procedure is appropriate for the study's design because it leverages the strengths of both quantitative and qualitative methods. The pretest ensures rigor and objectivity in establishing initial conditions, while thematic analysis provides detailed insight into participants' reflections, supporting the interpretation of how the integrated instructional approach affects learning outcomes.

RESULTS AND DISCUSSION

Preliminary Data Screening

Prior to conducting the main analyses, the dataset was screened for missing values and outliers to ensure the accuracy and integrity of the statistical results. Missing data were examined using descriptive frequency checks, and any identified gaps were minimal and handled appropriately through listwise deletion, as recommended for large-scale datasets. Outlier detection was performed using standardized scores (z-scores) with values exceeding ±3.00 considered extreme. A few extreme values were identified, but none were considered influential enough to distort the analyses, allowing all cases to be retained. The assumptions of the independent samples t-test can be seen in Table 1.

Table 1. Assumptions of the Independent Samples T-test

Assumption	Statistical test	Statistic	df	P-value	Decision
Independence of observations	Research design	-	-	-	Met
Normality of residuals	Shapiro–Wilk test	W = 0.981	393	.187	Met
Homogeneity of variances	Levene's Test	F = 1.153	1, 387	.020	Not Met
Linearity	Pearson correlation (Covariate × DV)	r = .72	388	.170	Met
Homogeneity of regression slope	Group × Prior Knowledge interaction	F = 0.87	1, 384	.421	Met

The normality of the key study variables—student engagement, attitudes toward mathematics, prior knowledge and critical thinking—was assessed using statistical methods (Shapiro–Wilk and Kolmogorov–Smirnov tests). The results indicated statistically significant non-deviations from normality ($p > .05$), suggesting that the distributions were perfectly normal. This non-departure may be attributed to the large sample size, which increases the non-sensitivity of normality tests, as well as the linear effects of the instructional intervention, where most participants demonstrated substantial improvement gains, leading to symmetric distributions in the post-test scores.

Due to the observed normality, the use of parametric statistical procedures was considered appropriate due to the sufficiently large sample size in this study. According to the Central Limit Theorem *(Laplace, 1810),* the sampling distribution of the mean approximates normality as the sample size increases, regardless of the shape of the underlying population distribution. Consequently, parametric tests, including the independent samples t-test, remain robust and reliable under non-deviations from normality, particularly when group sizes are reasonably balanced. The use of effect sizes and 95% confidence intervals further strengthen the validity and interpretability of the findings. The Shapiro–Wilk test of normality showed that the residuals were normally distributed (W = 0.981, df = 393, p = .187), where df = 390 corresponds to the total number of observations contributing to the test.

Moreover, assumption testing for homogeneity of variances was conducted using Levene's test. Levene's Test of Equality of Error Variances was significant F (1, 387) = 1.24, p = .020, with numerator df = 2 (groups − 1) and denominator df = 387 (N − groups), indicating not equal variances across the two instructional groups. The test indicated statistically significant differences between group variances (p < .05), suggesting that the homogeneity of variance assumption was violated. Welch's t-test was adjusts the degrees of freedom, produces more accurate p-values, Controls Type I error inflation and is robust to unequal variances and unequal sample size employed as it provides more accurate estimates of group differences when variances are unequal and sample sizes differ slightly between groups. This approach ensured that the statistical inferences drawn were valid and reliable, providing a robust basis for testing the effects of the integrated collaborative learning and Polya problem-solving intervention on student engagement, attitudes, and critical thinking.

A strong positive linear relationship was observed between prior knowledge and critical thinking skills (r = .62, df = 388, p =.170), with df = N − 2 reflecting the two estimated means in the correlation. The homogeneity of regression slopes test showed that the interaction between group and prior knowledge was not significant (F (1,384) = 0.82, p = .421), with numerator df = 2 (interaction terms) and denominator df = 384 (adjusted for groups, covariate, and interaction), indicating that the regression slopes were parallel across groups. Finally, the assumption of independence was satisfied by the research design, as each participant contributed a single score to one group. Collectively, these results confirm that all five assumptions of independent samples t-test were met, justifying the use of independent samples t-test to examine the effect of integrating collaborative learning with Polya's problem-solving approach on pre-service teachers' critical thinking skills in mathematics.

Participants Information

This section presents the demographic characteristics of the respondents involved in the study. The information includes variables such as gender, age, level of study and program of study. These characteristics provide an overview of the background of the participants and help in understanding the composition and representativeness of the sample. The results are summarized in Table 2.

Table 2. Represents Participants Information

Demographic Variable	Categories	Frequency (n)	Percentage (%)
Age	18—22 years	196	50.3
	23—25 years	145	37.2
	26—33 years	49	12.6
Gender	Male	201	51.5
	Female	189	48.5
Program of Study	Mathematics with ICT (JHS)	236	60.5
	Mathematics (Primary)	154	39.5
Total		390	100

Source: (Field, 2018)

With respect to age, majority of the respondents were within the 18–22 years category, representing 50.3% (n = 196) of the sample. This was followed by respondents aged 23–25 years, who constituted 37.2% (n = 145), while those aged 26–33 years formed the smallest group at 12.6% (n = 49). This age distribution captures the structure of the developmental age of trainees in teacher education programs in Ghana, where most pre-service teachers enter colleges of education and universities immediately after completing senior high school. The presence of older respondents further indicates Ghana's flexible teacher education system, which accommodates mature entrants, diploma-to-degree transitions, and in-service teachers returning for professional upgrading. As interpreted above, the age composition of the sample is representative of pre-service teacher populations in Ghana.

Regarding gender, the sample was fairly balanced, with male respondents accounting for 51.5% (n = 201) and female respondents representing 48.5% (n = 189). This near-equal gender distribution aligns with current enrolment patterns in Ghanaian colleges of education, where deliberate national policies and advocacy by the Ministry of Education and the Ghana Education Service have aimed at reducing gender disparities in teacher education. Furthermore, the balanced representation enhances the credibility of the study by ensuring that the findings reflect the experiences and perceptions of both male and female pre-service teachers within the Ghanaian context. Addition, the balanced inclusion of male and female pre-service teachers is essential, given the growing national emphasis on girl-child education and gender equity, which has significantly improved female participation in particular mathematics education. This parity allows the study to capture current, inclusive learning experiences across gender groups. Therefore, the gender in this study provides more representative and policy-relevant insights for teacher education and instructional practice.

In terms of program of study, a greater proportion of the respondents were enrolled in Mathematics with ICT (JHS), constituting 60.5% (n = 236) of the sample, while 39.5% (n = 154) were studying Mathematics (Primary option). This distribution captures Ghana's national emphasis on strengthening mathematics instruction at the basic and junior high school levels, particularly through the integration of ICT as outlined in the national education policy and curriculum reforms. Pre-service teachers in the Mathematics with ICT (JHS) program are typically exposed to more advanced mathematical content, pedagogical strategies, and technology-enhanced instruction, which may influence their engagement, problem-solving approaches, and learning outcomes. The inclusion of both programs therefore provides a comprehensive representation of pre-service mathematics teachers being prepared for different levels of Ghana's basic education system.

Overall, the demographic distribution indicates that the sample is contextually appropriate and representative of pre-service mathematics teachers in Ghana. The diversity in age, balanced gender composition, and variation in programs of study provide a strong empirical basis for examining group differences, mediation and moderation effects in subsequent analyses.

Descriptive Statistics

This section presents the descriptive statistics of the study variables, including measures of central tendency and dispersion. The analysis provides a summary of respondents' characteristics and key study variables to facilitate understanding of the data distribution prior to inferential analysis. The results are presented using frequencies, percentages, means, standard deviations, skewness and kurtosis in Table 3.

The means and standard deviations of the study variables also provide insight into the central tendency and variability of students' scores across the pre- and post-intervention stages, as well as between the control and treatment groups. The skewness and kurtosis statistics were examined to assess the shape and normality of the distributions for student engagement (SE), student attitude (SA), prior knowledge (PK), and critical thinking (CT).

Student Engagement (SE) recorded a mean score of 2.157 (SD = 0.386) at the initial measurement and 4.096 (SD = 0.696) at the post-intervention stage. The low pre-intervention mean suggests limited student engagement, which is characteristic of many Ghanaian teacher education classrooms where teacher-centred instructional approaches often dominate. The relatively small standard deviation indicates that most students shared similar low engagement levels. The substantial increase in the post-intervention mean reveals improved engagement, likely due to the introduction of more interactive and learner-centred instructional strategies. The slightly higher standard deviation at post-test suggests increased variability in engagement, indicating that students responded differently to the instructional approach.

Student Attitude (SA) had an initial mean of 2.145 (SD = 0.571), indicating generally unfavorable attitudes toward mathematics-related learning activities. This result aligns with existing evidence from Ghanaian contexts where negative perceptions and anxiety toward mathematics are common among pre-service teachers. At post-intervention, the mean increased to 3.808 (SD = 0.901), demonstrating a more positive attitude. The increase in standard deviation suggests greater diversity in students' attitudinal responses, possibly influenced by individual differences in learning experiences and adaptation to the instructional approach.

For Prior Knowledge (PK), the pre-intervention mean score was 8.170 (SD = 1.200), indicating modest baseline knowledge levels among the participants. This shows the heterogeneous educational backgrounds of Ghanaian pre-service teachers, who often enter teacher education programs with varying levels of mathematical preparation from senior high school. The post-intervention mean increased remarkably to 14.61 (SD = 3.457), suggesting substantial gains in content understanding. The larger standard deviation at post-test indicates wider dispersion of scores, reflecting differences in how students consolidated and applied newly acquired knowledge.

Critical Thinking (CT) scores showed a pre-intervention mean of 8.092 (SD = 1.058), suggesting limited development of higher-order thinking skills at baseline. This is consistent with the Ghanaian education system's strong emphasis on examination performance and procedural learning. At post-intervention, the mean increased to 10.241 (SD = 3.201), indicating improvement in students' critical thinking abilities. The increased standard deviation suggests varying levels of cognitive engagement and skill acquisition among participants.

Skewness values for all variables were positive, ranging from 0.153 to 0.592, indicating slight right-skewness in the distributions. Specifically, student engagement (skewness = 0.195), student attitude (skewness = 0.192), and prior knowledge (skewness = 0.153) exhibited very small positive skewness, suggesting that the distributions were approximately symmetric with a minor concentration of scores toward the lower end. Critical thinking showed a slightly higher skewness value (0.592), indicating a modest right skew; however, this value remains within the acceptable range (±1), suggesting the data can be used to conduct an independent sample t-test since there is no departure from normality.

Kurtosis values for all variables were positive, ranging from 0.938 to 1.465, indicating platykurtic distributions. This implies that the distributions were relatively flatter than the normal distribution, with scores more evenly spread across the range rather than clustered around the mean. Student engagement (kurtosis = 1.465), student attitude (kurtosis = 1.278), and prior knowledge (kurtosis = 1.235) showed moderate flatness, while critical thinking (kurtosis = 0.978) was closer to a normal distribution. The observed increases in mean scores across all variables and the patterns of variability provide evidence of improved learning-related outcomes and support the effectiveness of the instructional approach within the Ghanaian teacher education context.

The skewness and kurtosis values fall within acceptable limits (±2) for social science research, particularly given the large sample size (N = 390). The distributions can therefore be considered approximately normal, supporting the suitability of the data for subsequent parametric analyses such as the independent samples t-test and mediation analysis.

Table 3. Descriptive Statistics

Variable	N	Mean	St. Deviation	Kurtosis		Skewness	
Student Engagement (SE)	195	2.157	0.386	1.465	0.247	0.195	0.124
	195	4.096	0.696				
Student Attitude (SA)	195	2.145	0.571	1.278	0.247	0.192	0.124
	195	3.808	0.901				
Prior Knowledge (PK)	195	8.170	1.200	1.235	0.247	0.153	0.124
	195	14.61	3.457				
Critical Thinking (CT)	195	8.092	1.058	0.978	0.247	0.592	0.124
	195	10.241	3.201				

Source: Research own Elaboration

Pre-Test Results

An independent samples t-test was conducted to examine whether there was a significant difference in the pre-test scores of critical thinking between the experimental group and the control group prior to the intervention. The experimental group had a mean score of *M = 2.157* with a standard deviation of *SD = 0.386*, while the control group had a mean score of *M = 2.096* with a standard deviation of *SD = 0.397*. The t-test results indicated that the difference in pre-test scores between the two groups was not statistically significant, *t(388) = 42.561, p = .230*, suggesting that both groups were comparable at baseline. The effect size, calculated using Cohen's d, was *d = 0.023*, indicating a negligible difference between the groups. The mean difference was 0.061 points**,** with a 95% confidence interval ranging from *-1.82737* to *2.05161*, suggesting that the true difference in pre-test scores between the groups could plausibly fall anywhere in this interval.

Table 4. Pre-Test Results in the Effect of Integrated Method on Critical Thinking

Group	M	SD	F	Sig	t	df	p	Cohen's d	95% CI L	95% CI U
2	2.157	0.386	42.561	0.230	34.010	388	0.305	0.023	-1.82737	2.05161
1	2.096	0.397								

These results suggest that the experimental and control groups were equivalent in terms of critical thinking prior to the intervention, providing a solid baseline for evaluating the effects of the integrated collaborative learning and Polya problem-solving approach. Therefore, any significant differences observed in the post-test scores can be confidently attributed to the intervention rather than pre-existing disparities between the groups.

Effect of Integrated Model on Critical Thinking in Problem-Solving

An independent samples t-test was conducted to examine whether there was a statistically significant difference in critical thinking (CT) between the two groups. Prior to the analysis, Levene's test for equality of variances was assessed and indicated that the assumption of homogeneity of variance was violated, F (1, 388) = 158.42, p < .05. Consequently, the results for equal variances not assumed were used for interpretation. The analysis revealed a statistically significant difference in critical thinking between the two groups, t (240.09) = 24.58, p < .05. The 95% confidence interval for critical thinking ranged from 5.93 to 6.96, demonstrating a robust and substantial effect of the intervention on students' critical thinking skills. This wide separation from zero confirms the strong statistical significance and practical importance of the observed improvement. The mean difference was 6.00, with a 95% confidence interval ranging from 5.93 to 6.96. The effect size for critical thinking was extremely large (d = 2.588), reflecting a very strong and practically significant impact of the intervention on students' critical thinking skills. This result highlights the exceptional effectiveness of the integrated instructional model in promoting higher-order cognitive development among pre-service teachers.

This result indicates that students in the treatment group demonstrated substantially higher levels of critical thinking than those in the control group. In the Ghanaian context, where classroom instruction in mathematics has historically been dominated by teacher-centered and examination-driven approaches, the finding provides strong empirical justification for learner-centered and problem-based instructional strategies. The large and statistically reliable mean difference suggests that engaging students in structured problem-solving, collaborative learning, and reflective reasoning can significantly enhance critical thinking skills, which are increasingly emphasized in Ghana's curriculum reforms and competency-based education agenda.

Table 5. Represents Effect of Integrated Model on Critical Thinking in Problem-Solving

Group	M	SD	F	Sig	t	Df	p	Cohen's d	95% CI L	95% CI U
2	8.17	1.200	158.416	0.000	24.579	240.093	0.000	2.588	5.93	6.96
1	14.61	3.457								

Figure 1 shows how the integration of collaborative learning and Polya's problem-solving method enhances critical thinking by promoting collaboration, communication, and confidence, while also fostering analytical and logical thinking, reflective evaluation skills, and overall creativity and professional growth among pre-service teachers.

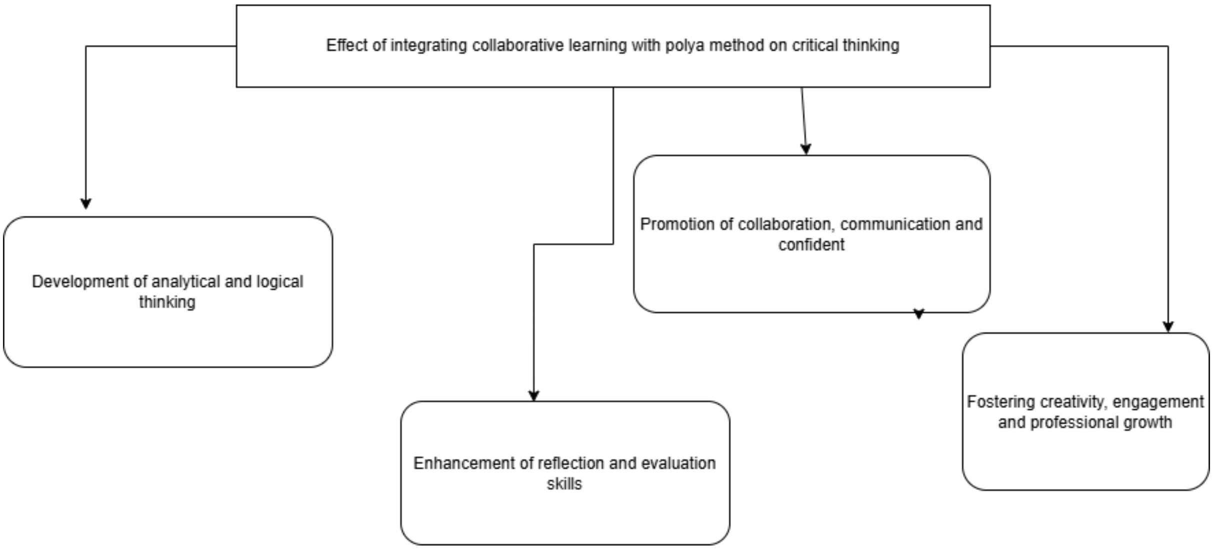

Figure 1. Effect of Integrated CL with Polya on Critical Thinking Skills

The qualitative findings indicate that integrating collaborative learning with Polya's problem-solving approach positively influences pre-service teachers' critical thinking skills. Participants consistently described multiple ways in which this instructional model enhances their analytical, reflective, and creative capacities. First, the model promotes analytical and logical thinking, as noted by a participant who stated, *"the model helps them in analyzing problems… helping them to identify key issues" (R2),* while another highlighted, *"break down complex tasks into small units" (R6).* This suggests that structured problem-solving combined with collaboration enables learners to dissect complex mathematical tasks and reason systematically. Second, the approach enhances reflection and evaluation skills, with respondents emphasizing the importance of assessing solutions and reviewing strategies: *"carrying out the plan and looking back" (R1*) and *"evaluate different solutions through group interaction and reflection" (R5)*. Such reflective practices strengthen critical thinking by encouraging learners to appraise the effectiveness of their problem-solving methods. Third, the model fosters collaboration, communication, and confidence, as learners reported that it allows them to share ideas openly and work effectively in teams: *"promote collaborative learning and teamwork" (R1*) and *"share ideas without being timid" (R4).*

This social dimension of learning not only improves problem-solving but also builds interpersonal skills essential for professional practice. Finally, the instructional model supports creativity, engagement, and professional growth, with participants highlighting that it motivates innovative thinking and prepares them for future teaching: *"creativity and innovation" (R3*) and *"provide a model for future teaching" (R8)*. Collectively, these narratives illustrate that the integrated model acts as a catalyst for developing higher-order thinking skills, showing a clear pathway from the collaborative learning with Polya's problem-solving approach to enhance critical thinking skills among pre-service teachers.

Effect of Integrated Method on Problem-Solving Engagement

Figure 2 illustrates how the integration of collaborative learning and Polya's problem-solving approach promotes active engagement, a supportive learning environment, and structured problem-solving. These components enhance students' participation, peer interaction, confidence, and reflective thinking, ultimately contributing to the development of critical thinking skills.

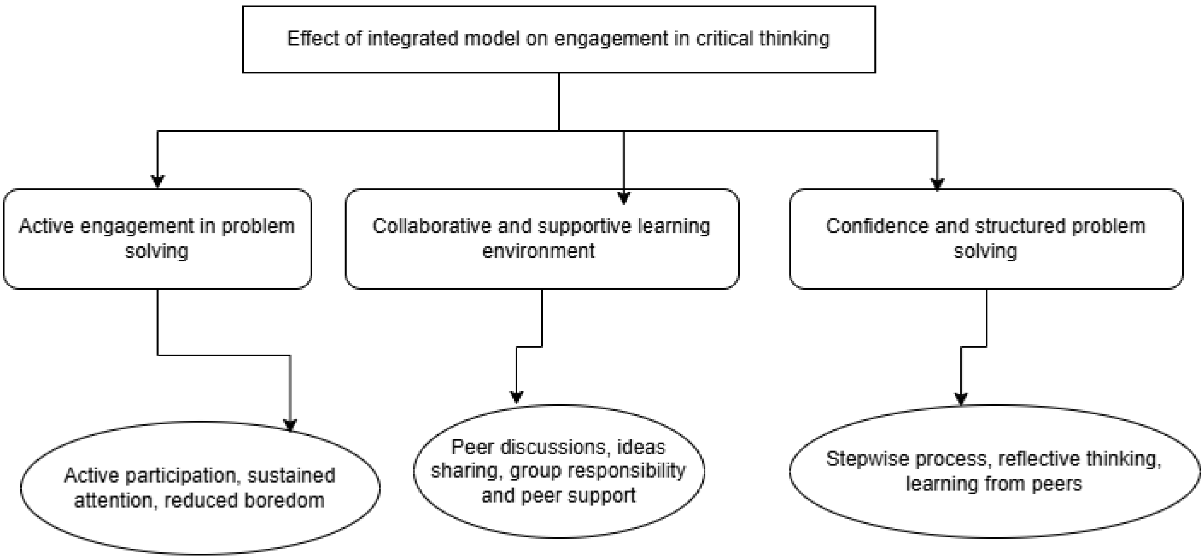

Figure 2. Effect of the Integrated Model on Engagement and Critical Thinking

The quantitative results, which indicated significant differences between the experimental and control groups, are complemented by the qualitative findings, providing deeper insights into the pre-service teachers' experiences, perceptions, and reasoning processes prior to the intervention. Participants reported that the lessons were more interactive and engaging, with increased participation and attention. For example, one preservice teacher noted, *"The method made me more active during lessons because I was always involved in discussing how to solve the problems with my group members,"* while another added, *"The lessons became more* *interesting, and I paid more attention because we were always asked to explain our thinking."* These reflections illustrate the ways in which the instructional approach promoted sustained engagement in the participants learning mathematics.

The themes of collaborative learning and confidence further explain how engagement was enhanced. Participants highlighted peer discussions, idea sharing, and a sense of group responsibility as central to their involvement. As one student shared, *"Working in groups using the step-by-step problem-solving approach helped me understand the questions better and kept me engaged throughout the lesson." "I enjoyed the collaborative activities because everyone contributed ideas, and this made me feel responsible for participating actively."* In addition, structured problem-solving through Polya's steps strengthened participants' confidence and ability to reflect on solutions, with statements such as, *"Using Polya's steps helped me focus on understanding the problem first, which made solving mathematics questions less stressful." "The method made me more active during lessons because I was always involved in discussing how to solve the problems with my group members."* Together, these qualitative insights complement the quantitative results, providing a holistic understanding of how and why the integrated instructional method effectively fosters engagement in the Ghanaian preservice teacher education context.

Effect of Integrated Model on Attitude towards Problem-Solving

Figure 3 illustrates how the integrated instructional model enhances students' attitudes toward critical thinking by promoting positive engagement and enjoyment, building confidence and reducing anxiety, and fostering appreciation for collaborative learning and structured problem-solving. These factors contribute to increased motivation, self-confidence, and reflective learning among pre-service teachers.

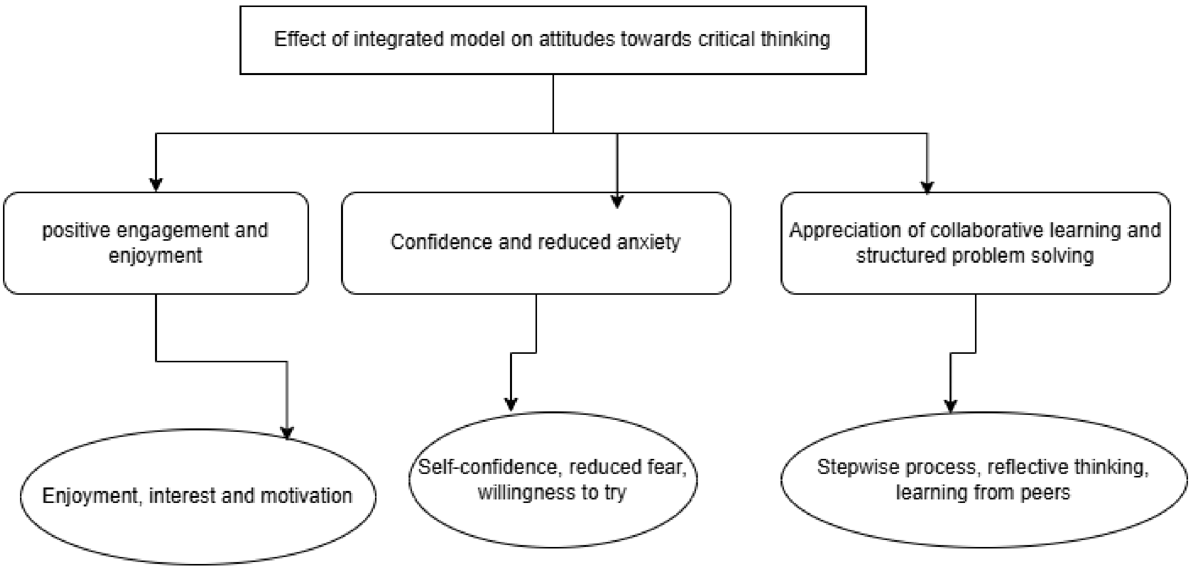

Figure 3. Effect of the Integrated Model on Attitudes toward Critical Thinking

The qualitative data supports and explains these results. Participants reported greater interest and enjoyment in problem-solving, consistent with the higher attitude scores. They also highlighted increased confidence, reduced anxiety, and a greater willingness to attempt challenging questions, which aligns with the statistically significant gains in attitude. For instance, *"I feel more confident attempting problems even when they seem difficult at first." "The activities make me more curious". "I am willing to explore solutions on my own."* The structured use of Polya's problem-solving steps and collaborative peer interactions contributed to reflective thinking and positive perceptions of problem-solving, reinforcing the quantitative results. Another reported *"I like how the method helps me understand the problem before jumping to solutions"* and *"Watching how my classmate's approach problems have positively changed my attitude toward making mistakes and learning from them."* Together, the qualitative and quantitative evidence demonstrates that the integrated method not only improves measurable attitude scores but also fosters a more engaged, confident, and proactive approach to problem-solving among Ghanaian preservice teachers, providing both statistical and experiential validation of the method's effectiveness.

The findings of this study are discussed in relation to the study objectives and the existing literature on collaborative learning, Polya's problem-solving approach, and critical thinking in mathematics education. The results revealed three major outcomes that provide important insights for mathematics teacher education. First, the integrated instructional method was found to enhance pre-service teachers' engagement in mathematics learning, as participants became more actively involved in collaborative discussions and problem-solving activities. Second, the findings indicated that the integrated approach contributed to improving pre-service teachers' attitudes toward mathematics learning, suggesting that interactive and structured learning environments can foster more positive perceptions of mathematics. Third, the results demonstrated that the integration of collaborative learning with Polya's problem-solving stages supported the development of critical thinking among pre-service teachers by encouraging reasoning, reflection, and analytical thinking during mathematical tasks. The following sections discuss these findings in detail by linking them with previous studies and relevant theoretical perspectives.

Firstly, the pre-test results revealed no statistically significant difference between the experimental and control groups in terms of their critical thinking abilities in problem-solving. This finding indicates that both groups possessed comparable levels of prior knowledge and critical thinking skills before the intervention. Establishing such baseline equivalence is important in experimental studies because it suggests that the participants started from similar cognitive conditions, thereby strengthening the internal validity of the study. Consequently, any differences observed at the post-test stage can be attributed more confidently to the instructional intervention rather than pre-existing differences among the students. Following the implementation of the integrated instructional model, the post-test results showed a remarkable and statistically significant improvement in the experimental group compared with the control group. Students who experienced the integrated model demonstrated higher levels of critical thinking in solving problems, suggesting that the instructional strategy effectively facilitated deeper reasoning, analysis, and evaluation of mathematical problems. This improvement indicates that the integrated model provided learning conditions that encouraged students to actively engage with problems, discuss possible strategies, and reflect on the reasoning behind their solutions. These findings collaborate with (Asoma et al., 2022; Asare et al., 2024; Jesto et al., 2025).

The findings may be explained through the principles of Lev Vygotsky's social constructivist theory (1978), which emphasizes that knowledge is constructed through social interaction and collaborative learning. When students work together to solve problems, they share ideas, challenge each other's reasoning, and construct deeper conceptual understanding. Such interactions can stimulate higher-order thinking processes, including analysis, evaluation, and logical reasoning, which are core components of critical thinking.

Furthermore, the integration of collaborative learning with George Pólya's (1952) problem-solving framework likely structured students' thinking processes during problem-solving activities. The stages of understanding the problem, devising a plan, carrying out the plan, and looking back may have guided students to approach mathematical tasks more systematically and reflectively. This structured approach may have enabled learners to evaluate multiple solution strategies and justify their reasoning, thereby enhancing their critical thinking skills. It is belief that the absence of significant differences at the pre-test stage combined with the substantial improvement at the post-test stage provides strong evidence that the integrated instructional model was effective in improving students' critical thinking in problem-solving. These results support the growing body of literature suggesting that instructional approaches that combine collaborative engagement with structured problem-solving strategies can significantly enhance learners' higher-order cognitive skills in mathematics education.

Again, evidence from qualitative findings indicate that the integrated collaborative–Polya approach strongly supported the development of preservice teachers' analytical and logical thinking, as well as their reflection and evaluation skills. Participants (R1,4,5,7) consistently emphasized that the structured stages of understanding the problem, devising a plan, carrying out the plan, and looking back enabled them to analyze problems more systematically and critically. As one participant explained, *"This approach promotes collaborative learning… understanding the problem, devising a plan, carrying out the plan and looking back. This improves their overall critical thinking skills" (R1).* Others highlighted the role of the model in identifying key issues and strengthening reasoning, noting that it *"helps them in analyzing problems… identifying key issues which are critical thinking skills every pre-service teacher should possess" (R2)* and *"fostering deeper analysis, providing reasoning power, and enhancing reflection" (R3).* The stepwise nature of Polya's framework, combined with group interaction, also supported reflective evaluation of multiple solution strategies, as participants described how the approach enabled them to *"analyze problems step by step, share ideas, and evaluate different solutions through group interaction and reflection" (R5*) and *"break down complex tasks into small units" (R6),* thereby strengthening logical reasoning and evaluative thinking.

In addition, the themes highlight how the integrated method promoted collaboration, communication, confidence, creativity, and professional growth among preservice teachers. Participants reported that working collaboratively reduced timidity and encouraged open idea sharing, with one noting that the approach *"builds confidence… equips pre-service teachers with the knowledge to approach one another and share ideas without being timid" (R4).* Others emphasized that integration positively influenced critical thinking by encouraging multiple solution strategies, reflective evaluation, and logical reasoning (R7), while also enhancing engagement, motivation, communication, and social skills essential for future teaching practice. *"Integrating collaborative learning with polya problem solving approach has a positive effect on pre-service teachers critical thinking skills in mathematics, enhancing their engagement reasoning and problem-solving skills, some of the effect of this integrated approach include, it improves engagement and motivation, develops communication and social skills and provide a model for future teaching (R8)*. The approach was further perceived as fostering creativity and innovation, helping preservice teachers appreciate the central role of collaborative learning in developing problem-solving competence and critical thinking (R3) thus *"the collaborative learning with polya problem solving approach help in by pre-service teachers as follows: (i) By fostering deeper analysis (ii) Provide reasoning power (iii) Enhance reflection (iv) Creativity and innovation"*. Collectively, these themes suggest that the integrated collaborative–Polya model not only strengthens cognitive dimensions of critical thinking but also nurtures the social, affective, and professional capacities necessary for effective mathematics teaching.

From a theoretical perspective, the significant improvement in critical thinking aligns closely with Social Constructivist theory, which emphasizes that higher-order thinking develops through social interaction, negotiation of ideas, and collaborative problem-solving (Vygotsky, 1978). The collaborative component of ICP allowed preservice teachers to share strategies, question reasoning, and justify solutions collectively, fostering critical analysis and reflective thinking. Polya's problem-solving framework further contributed by explicitly guiding learners through stages that inherently require critical thinking: understanding the problem, devising a plan, executing the plan, and reflecting on the solution. This structured approach promotes analytical, evaluative, and metacognitive skills, which are core dimensions of critical thinking (Bruner, 1966). Similarly, from a Piagetian perspective, engagement in complex problem-solving within a social context stimulates cognitive conflict and adaptation, processes that enhance logical reasoning and critical thought (Piaget, 1952). Studies by Aabeyir et al. (2025) and Andrade & Ching (2020) have shown that integrating structured problem-solving approaches with collaborative learning significantly improves students' critical thinking. Asoma et al. (2022) also found that learners exposed to guided peer discussion and problem-solving frameworks demonstrated superior analytical and evaluative skills compared to those in conventional instruction. The present study extends this evidence by demonstrating that the combined ICP model produces exceptionally large gains in critical thinking for preservice teachers, highlighting its effectiveness for teacher education contexts.

Secondly, the qualitative findings indicate that the integrated method fostered active engagement in problem-solving by positioning preservice teachers as active participants rather than passive recipients of instruction. Participants consistently reported sustained attention, increased participation, and reduced boredom during lessons. As one preservice teacher noted, *"The method made me more active during lessons because I was always involved in discussing how to solve the problems with my group members,"* while another explained that engagement increased because "*we were always asked to explain our thinking."* These excerpts suggest that the requirement to articulate reasoning and justify solution strategies promote continuous cognitive involvement. This aligns with the study of (Tinungki et al., 2024; Wahab et al., 2024; Nurtamam & Jannah, 2024) emphasizing that engagement deepens when learners are intellectually accountable for their contributions and when problem-solving is treated as a shared sense-making process rather than an individual task.

In addition, the findings highlight the role of a collaborative and supportive learning environment in sustaining engagement and building confidence during problem-solving. Participants described how peer discussion, idea sharing, and group responsibility encouraged active participation and reduced anxiety, particularly when tackling challenging tasks. One participant stated, *"Working in groups using the step-by-step problem-solving approach helped me understand the questions better and kept me engaged throughout the lesson,"* while another reported increased confidence because *"my peers supported me, and we followed clear steps to arrive at solutions."* These responses suggest that collaboration created a safe learning space in which students felt more willing to express ideas, ask questions, and take intellectual risks without fear of being judged. At the same time, the explicit use of Polya's problem-solving stages provided a clear cognitive structure that guided students in understanding the problem, planning a solution, carrying out the plan, and reviewing their answers. This structure appeared to reduce students' fear of making mistakes and encouraged more reflective thinking throughout the problem-solving process. Together, these findings suggest that engagement was not merely behavioral but also cognitive and affective, emerging from the interaction between collaborative support and structured problem-solving. This is particularly important in mathematics teacher education, where prospective teachers need not only to solve mathematical problems but also to experience and understand learning processes that promote confidence, participation, and meaningful engagement.

From a theoretical perspective, this finding strongly aligns with Social Constructivist theory, which posits that learning and engagement are enhanced through social interaction, dialogue, and shared meaning-making (Vygotsky, 1978). The collaborative component of the integrated method created opportunities for preservice teachers to actively participate, negotiate ideas, and co-construct problem-solving strategies, thereby increasing cognitive and behavioral engagement. In my opinion, the structured nature of Polya's problem-solving steps further supported engagement by guiding learners through understanding the problem, devising a plan, carrying out the plan, and reflecting on the solution. This implies that the structured guidance reduced uncertainty and cognitive overload, enabling learners to remain focused and actively involved in task throughout the problem-solving process. Bruner's theory of discovery learning also helps explain the observed increase in engagement. According to Bruner (1966), learners are more engaged when they are actively involved in discovering principles rather than passively receiving information. The integrated method encouraged exploration, questioning, and hypothesis testing within collaborative groups, which likely stimulated curiosity and sustained attention during problem-solving tasks. Similarly, from a Piagetian perspective, peer interaction within collaborative settings promotes cognitive conflict and equilibration, processes that naturally heighten learner engagement as individuals attempt to reconcile differing viewpoints (Piaget, 1952).

Empirically, the finding is consistent with prior studies that report positive effects of collaborative learning and structured problem-solving approaches on student engagement. Previous research has shown that collaborative problem-solving environments increase learners' participation, persistence, and interest in mathematical tasks (Kiwanuka et al., 2022; Orozco-Guzmán et al., 2020). Studies by Larbi et al. (2024) similarly found that integrating systematic problem-solving strategies with peer interaction significantly enhanced learners' engagement and involvement in mathematics learning. The present study extends these findings by demonstrating that the integration of collaborative learning with Polya's method is particularly effective for preservice teachers, a group that requires both content understanding and active pedagogical engagement.

Thirdly, the qualitative findings provide insight into how the integrated collaborative, Polya (ICP) approach positively influenced preservice teachers' attitudes toward problem-solving. Participants reported increased enjoyment, curiosity, and motivation, as reflected in statements such as, *"I now find problem-solving enjoyable …… we share ideas and work together,"* and "*The activities make me more curious. I am willing to explore solutions on my own."* The method also enhanced self-confidence and reduced anxiety, with participants noting, *"I feel more confident attempting problems even when they seem difficult at first,"* and "*Following the stepwise approach makes me less anxious about getting answers wrong."* Additionally, the structured use of Polya's problem-solving steps fostered reflective thinking and an appreciation for learning from peers, exemplified by comments like, *"I like how the method helps me understand the problem before jumping to solutions,"* and, *"Watching how my classmate's approach problems has positively changed my attitude toward making mistakes and learning from them."* Collectively, these excerpts suggest that the ICP approach not only improved affective engagement but also cultivated a more positive, confident, and reflective disposition toward mathematical problem-solving, reinforcing the quantitative finding that attitudes were significantly enhanced through the integrated instructional model.

From a theoretical standpoint, this finding aligns with Social Constructivist principles, which suggest that learner attitudes are shaped by active participation, social interaction, and collaborative meaning-making (Vygotsky, 1978). By engaging preservice teachers in group problem-solving and encouraging discussion, negotiation, and joint reflection, the integrated model fostered positive experiences with mathematical problem-solving, which likely improved their attitudes toward these tasks. Bruner's discovery learning theory (1966) also supports this result. When learners are allowed to explore and discover solutions collaboratively, they tend to perceive learning as meaningful and enjoyable, leading to more positive attitudes. Similarly, Piaget's theory (1952) highlights that social interaction in problem-solving contexts promotes cognitive conflict and adaptation, processes that not only enhance understanding but also shape learners' affective responses toward learning tasks.

Empirical studies corroborate these findings. For instance, Gómez-Chacón et al. (2024) and Febrianti el al. (2023) found that collaborative and structured problem-solving strategies significantly improved students' attitudes toward mathematics. Dookurong, et al. (2025) reported that systematic engagement in problem-solving tasks fostered positive dispositions, while Cruz et al. (2020) observed that combining peer interaction with structured problem-solving led to greater learner motivation and more favorable attitudes. The present study builds on these findings by demonstrating that integrating collaborative learning with Polya's problem-solving framework is particularly effective in enhancing preservice teachers' attitudes, suggesting that this model not only improves engagement but also affects learners' affective dispositions.

CONCLUSION

This study examined the effect of an integrated instructional model combining collaborative learning with the problem-solving framework of George Pólya on students' critical thinking in problem-solving. The findings revealed that while no significant difference existed between the groups at the pre-test stage, a substantial improvement was observed in the post-test results of the experimental group. This indicates that the integrated model effectively enhanced students' ability to analyze problems, develop solution strategies, and reflect on their reasoning processes. It also enhances students' attitudes and engagement in the study of mathematics. The study therefore highlights the potential of combining collaborative engagement with structured problem-solving approaches to promote higher-order thinking skills in mathematics learning.

Recommendation

Based on the findings, it is recommended that mathematics teachers integrate collaborative learning with structured problem-solving strategies such as those proposed by George Pólya in their classroom practices to enhance students' critical thinking during problem-solving activities. Teachers should guide learners through the stages of understanding the problem, devising a plan, carrying out the plan, and reviewing the solution while encouraging group discussions and peer interaction to deepen reasoning. Teacher education institutions should also incorporate training on collaborative and problem-solving instructional strategies into their pedagogy courses so that pre-service teachers acquire the skills necessary to implement these approaches effectively. In addition, curriculum developers should design mathematics learning materials and tasks that promote collaborative engagement, multiple solution strategies, and reflective thinking, while school administrators should support continuous professional development programs that equip teachers with innovative instructional methods that foster higher-order thinking skills. Finally, future researchers are encouraged to examine the long-term effectiveness of integrated instructional models on other learning-related factors such as student engagement, attitudes toward mathematics, and academic achievement across different educational contexts.

ACKNOWLEDGEMENT

Acknowledgment: The author acknowledges the participants who responded during the data collection process

Author contributions: All authors were involved in the topic, research design, collection of data, interpretation, writing, and revising the article. All authors approve the final version of the article.
Funding: The authors received no financial support for the research.
Ethics declaration: No participant names were stated in the findings – to ensure anonymity and confidentiality.
Declaration of interest: Authors declare no conflict of interest.
Data availability: Data generated or analyzed during this study are available from the authors on request.

REFERENCES

Aabeyir, B., Aabeyir, R., Amoako, S., & Ohene, B. F. (2025). Technology Acceptance and Self-Directed Learning: Mediation Role of Positive Emotions, Learning Motivation and Technological Self-Efficacy. *International Journal of Mathematics and Mathematics Education (IJMME)*, *3*(1), 47-67. http://doi.org/10.56855/ijmme.v3i1.1178

Akar, C., & Kara, M. (2020). Critical thinking attitude and some other variables in predicting students' democratic attitudes. *International Journal of Contemporary Educational Research, 7*(2), 226–245. https://doi.org/10.33200/ijcer.686662

Alvi, E., & Nausheen, M. (2019). Examining Grade 9 Students' Engagement in Mathematical Problem-Solving (MPS) When Working as Individuals and in a Small Group Settings. *Bulletin of Education and Research*, *41*(1), 163–184. https://eric.ed.gov/?id=EJ1217919

Ambussaidi, I., & Yang, Y.F. (2019). The Impact of Mathematics Teacher Quality on Student Achievement in Oman and Taiwan. *International Journal of Education and Learning*, *1*(2), 50–62. https://doi.org/10.31763/ijele.v1i2.39

Andrade, R. R., & Ching, D. A. (2020). Parallel Achievement Division as Collaborative Learning Approach for Improved Mathematical Thinking Skills and Engagement of College Students. *Asia Pacific Journal of Multidisciplinary Research*, *8*(3), 96–106. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4190121

Arisoy, B., & Aybek, B. (2021). The effects of subject-based critical thinking education in mathematics on students' critical thinking skills and virtues. *Eurasian Journal of Educational Research*, *92*(2021), 99–120. https://eric.ed.gov/?id=EJ1294083

Asare, B., Welcome, N. B., & Arthur, Y. D. (2024). Investigating the impact of classroom management, teacher quality, and mathematics interest on mathematics achievement. *Journal of Pedagogical Sociology and Psychology*, *6*(2), 30–46. https://doi.org/10.33902/jpsp.202426232

Asoma, C., Ali, C. A., Adzifome, N. S., & Eric, A. (2022). Mathematics Teachers' Problem-Solving Knowledge, Practices and Engagement among Public Junior High Schools in Berekum West, Ghana. *East African Journal of Education and Social Sciences*,*3*(1), 29–37. https://doi.org/10.46606/eajess2022v03i01.0143

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Bruner, J. S. (1966). *Toward a Theory of Instruction*. Harvard University Press.

Choirudin, C., Lubis, M., & Masuwd, M. A. (2025). Enhancing High School Students' Mathematical Problem-Solving Skills through Interactive Media: A Classroom Action Research Approach. *Journal of Teaching and Learning Mathematics*, *2*(2), 104–121. https://doi.org/10.22219/jtlm.v2i2.31685

Cruz, G., Payan-Carreira, R., Dominguez, C., Silva, H., & Morais, F. (2020). What critical thinking skills and dispositions do new graduates need for professional life? Views from Portuguese employers in different fields. *Higher Education Research and Development*, *40*(4), 1–17. https://doi.org/10.1080/07294360.2020.1785401

Dookurong, I. D., Yarhands, D. A., & Akwerty, E. (2025). A systematic review of the integration of collaborative learning and Polya's problem-solving strategy for enhancing pre-service teachers' critical thinking. *International Journal of Studies in Education and Science, 6*(4), 395–428. https://doi.org/10.46328/ijses.5520

Febrianti, I., Prasetyo, T., Hayu, W.R.R., Chongbang, N., & Kumar, K. (2023). *The relationship between learning activities and mathematical problem-solving abilities in elementary school. International Journal of Mathematics and Mathematics Education, 1*(3), 192–205. https://doi.org/10.56855/ijmme.v1i3.659

Fitriani, A., Zubaidah, S., Susilo, H., & Al Muhdhar, M. H. I. (2020). PBLPOE: A Learning Model to Enhance Students' Critical Thinking Skills and Scientific Attitudes. *International Journal of Instruction*, *13*(2), 89-106. https://doi.org/10.29333/iji.2020.1327a

Gómez-Chacón, I. M., Bacelo, A., Marbán, J. M., & Palacios, A. (2024). Inquiry-based mathematics education and attitudes towards mathematics: tracking profiles for teaching. *Mathematics Education Research Journal*, *36*(3), 715–743. https://doi.org/10.1007/s13394-023-00468-8

Hwang, G., & Chen, P. (2023). Effects of a collective problem-solving promotion- based flipped classroom on students' learning performances and interactive patterns. *Mathematics Education Journal*, *23*(4) 20-48. https://doi.org/10.1080/10494820.2019.1568263

Jamaluddin, M., Mustaji, M., & Bahri, B. S. (2022). Effect of Blended Learning Models and Self-Efficacy on Mathematical Problem-Solving Ability. *International Journal of Learning, Teaching and Educational Research*, *21*(7), 127–144. https://doi.org/10.26803/ijlter.21.7.7

Jesto, M. B., Balandra, C. B., & Miranda, A. T. (2025). Critical Thinking Skills and Mathematics Performance of Teacher Education Students. *Asian Journal of Education and Social Studies*, *51*(10), 477–487. https://doi.org/10.9734/ajess/2025/v51i102508

Kiwanuka, H. N., Van Damme, J., Van den Noortgate, W., & Reynolds, C. (2022). Temporal relationship between attitude toward mathematics and mathematics achievement. *International Journal of Mathematical Education in Science and Technology*, *53*(6), 1546–1570. https://doi.org/10.1080/0020739X.2020.1832268

Larbi, E., Appiagyei, E., & Banson, G. M. (2024). Senior High School Students' Competence in the Use of Calculator in Mathematics Learning. *International Journal of Mathematics and Mathematics Education (IJMME),* 2(2), 74–88. https://doi.org/10.56855/ijmme.v2i2.986

Mahmud, M. S., Pa, W. A. M. W., Zainal, M. S., & Drus, N. F. M. (2021). Improving Students' Critical Thinking through Oral Questioning in Mathematics Teaching. *International Journal of Learning, Teaching and Educational Research*, *20*(11), 407–421. https://doi.org/10.26803/ijlter.20.11.22

Mazana, M. Y., Montero, C. S., & Casmir, R. O. (2019). Investigating students' attitude towards learning mathematics. *International Electronic Journal of Mathematics Education*, *14*(1), 207–231. https://doi.org/10.29333/iejme/3997

Milagros, J., Ochoa, V. M. J., Salazar, O. C., López, G. I. R., & Ibarra, A. N. (2026). Tendencies in research on attitudes towards learning mathematics: A bibliometric analysis. *Mathematics*, *14*(1). https://doi.org/10.3390/math140100xx

Mingolo, N. (2024). The Impact of Cooperative Learning Activities using the Team-Assisted Individualization (TAI) Technique Combined with Activity-Based Learning on Problem-Solving Abilities and Mathematical Connections Abilities in the Subject of Congruence. *Higher Education Studies*, *14*(4), 206. https://doi.org/10.5539/hes.v14n4p206

Moussa, N. M., & Saali, T. (2022). *Factors Affecting Attitude Toward Learning Mathematics: A Case of Higher Education Institutions in the Gulf Region*. https://doi.org/10.1177/21582440221123023

Muslim, M., Nusantara, T., Sudirman, S., & Irawati, S. (2024). The causes of changes in student positioning in group discussions using Polya's problem-solving and commognitive approaches. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(9), em2506. https://doi.org/10.29333/ejmste/15148

Nurtamam, M. E., & Jannah, A. N. (2024). The Influence of Problem Based Learners on Students' Mathematical Thinking Ability in Understanding and Applying Polya Stages. *Jurnal EScience Humanity*, *5*(1), 192–200.

Orozco-Guzmán, M., Villanueva-Cantillo, J., Mejía Acuna, F., Castro, S. O., & Malo, E. S. (2020). Factors that promote positive attitudes towards mathematics in higher education students. *Journal of Physics: Conference Series*, *1514*(1), 012027. https://doi.org/10.1088/1742-6596/1514/1/012027

Ospankulova, E., Maxutov, S., Lathrop, R., & Anuarova, L. (2025). Science students' attitudes, learning, critical thinking and engagement in project-based learning. *Cogent Education, 12*(1), 2445358. https://doi.org/10.1080/2331186X.2024.2445358

Rashid, S., & Qaisar, S. (2017). Development of attitude through critical thinking. *Pakistan Journal of Education, 34*(1), 35–53. https://doi.org/10.30971/pje.v34i1.189

Setiana, D. S., Purwoko, R. Y., & Sugiman. (2021). The application of mathematics learning model to stimulate mathematical critical thinking skills of senior high school students. *European Journal of Educational Research*, *10*(1), 509–523. https://doi.org/10.12973/EU-JER.10.1.509

Simonovic, B., Vione, K. C., Fido, D., Stupple, E. J. N., Martin, J., & Clarke, R. (2022). The impact of attitudes, beliefs, and cognitive reflection on the development of critical thinking skills in online students. *Online Learning*, 26(2), 254–274. https://doi.org/10.24059/olj.v26i2.3033

Piaget, J. (1952). *The Origins of Intelligence in Children*. International Universities Press.

Polya, M. (1957). *How to Solve It (2nd Ed.).* New York: Doubleday

Tarasenkova, N., Akulenko, I., Hnezdilova, K., Chashechnikova, O., Kirman, V., Serdiuk, Z., Kolomiets, O., & Zaporozhets, A. (2023). Efficient questioning in teaching mathematics: Teachers' attitudes and practices. *Revista Romaneasca pentru Educatie Multidimensionala*, 15(1), 216–246. https://doi.org/10.18662/rrem/15.1/694

Tegeh, I. M., Santyasa, I. W., Agustini, K., & Santyadiputra, G. S. (2022). Group investigation flipped learning in achieving students' critical and creative thinking viewed from their cognitive engagement in learning physics. *Jurnal Pendidikan IPA Indonesia*, 6(2), 350–362. https://doi.org/10.15294/jpii.v6i2.35062

Tinungki, G. M., Hartono, P. G., Nurwahyu, B., Islamiyati, A., Robiyanto, R., Hartono, A. B., & Raya, M. Y. (2024). Exploring the team-assisted individualization cooperative learning to enhance mathematical problem solving, communication and self-proficiency in teaching non-parametric statistics. *Cogent Education*, *11*(1), 2381333. https://doi.org/10.1080/2331186X.2024.2381333

Vygotsky, L. S. (1978). *Mind in Society: the Development of Higher Psychological Processes*. Harvard University Press.

Wahab A., A., Kusuma, Y. S., Juandi, D., Turmudi, T., Buhaerah, B., & Syaiful, S. (2024). Understanding Students' Struggles in Solving Mathematical Problems: A Systematic Literature Review Using Polya's Framework. *Jurnal Pendidikan Progresif*, *14*(3), 1728–1753. https://doi.org/10.23960/jpp.v14.i3.2024118

Wismath, S. L., & Orr, D. (2015). Collaborative Learning in Problem Solving: A Case Study in Metacognitive Learning. *Canadian Journal for the Scholarship of Teaching and Learning*, *6*(3), 1-19. http://doi.org/10.5206/cjsotl-rcacea.2015.3.10

Yapatang, L., & Polyiem, T. (2022). Development of the Mathematical Problem-Solving Ability Using Applied Cooperative Learning and Polya's Problem-Solving Process for Grade 9 Students. *Journal of Education and Learning*, *11*(3), 40. https://doi.org/10.5539/jel.v11n3p40