



Enhancing Pre-Service Teachers' Attitudes and Self-Efficacy in Geometry Instruction Through Mathematical Modelling

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Abstract

This article explored the impact of a mathematical modelling intervention on pre-service teachers' attitudes, self-efficacy, and beliefs about teaching/learning geometry in Ghana. Following a convergent parallel mixed-methods design, pre-service teachers were assigned into the experimental (n=140) and control (n=51) groups. The experimental group participated in an 11-week model-eliciting activity intervention, and the control group received relationship-based instruction on geometry. Quantitative findings showed that the experimental group increased significantly in its attitudes toward modelling, and confidence in teaching geometry, and had constructivist beliefs about learning when compared to the control group, with large effect size ($\eta^2 = 0.22-0.37$). Some qualitative results indicated changes in pedagogy from more traditional to student centred, focusing on problem solving and critical thinking in real world situations. The study was consistent with Bandura's Self-Efficacy Theory which suggests that mastery experiences; vicarious learning, and verbal persuasion contribute to teaching confidence. Findings promote the inclusion of mathematical modelling in teacher preparation to support creative, inquiry-based geometry instruction.

Keywords: mathematical modelling, pre-service teachers, geometry instruction, self-efficacy, teacher beliefs

Introduction

The integration of mathematical modelling into teacher education has gained increasing attention as a means of promoting meaningful and context-based learning in mathematics. Mathematical modelling enables learners to connect abstract mathematical concepts to real-world situations, thereby fostering deeper conceptual understanding and problem-solving skills. Within teacher education, engaging pre-service teachers in modelling activities has been shown to influence how they perceive mathematics—not merely as a body of fixed knowledge, but as a dynamic and applicable discipline grounded in real-life contexts (Çetinkaya et al., 2016; Duatepe-Paksu et al., 2022). Such experiences are particularly important in preparing future teachers to adopt learner-centred and inquiry-based instructional approaches.

Beyond shaping perceptions, mathematical modelling has been identified as a powerful pedagogical approach for enhancing pre-service teachers' confidence and competence in teaching mathematics. Through active engagement in modelling tasks, pre-service teachers are exposed to

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opportunities that support the development of pedagogical content knowledge, including the design of meaningful tasks, facilitation of student thinking, and interpretation of multiple solution strategies (Greefrath et al., 2021). These experiences also align with constructivist principles, encouraging teachers to view learning as an active and participatory process. As a result, modelling-based instruction has the potential to strengthen pre-service teachers' self-efficacy, which is a critical factor influencing their instructional practices and students' learning outcomes.

Teacher beliefs and attitudes play a central role in shaping classroom practices, particularly in mathematics education. Pre-service teachers often enter training programmes with established beliefs about teaching and learning, many of which are rooted in traditional, teacher-centred approaches. Without targeted intervention, these beliefs may persist and limit the adoption of innovative pedagogies such as mathematical modelling. Research suggests that structured experiences, including exposure to modelling activities and reflective practice, are essential in transforming these beliefs toward more student-centred and constructivist orientations (Zavala et al., 2024; Dayan et al., 2022). In this regard, mathematical modelling serves not only as a teaching strategy but also as a tool for reshaping teachers' professional identities and instructional perspectives.

Despite the growing body of research on mathematical modelling, important gaps remain. While previous studies have demonstrated its potential to enhance teachers' knowledge and instructional practices, limited attention has been given to understanding how pre-service teachers' attitudes toward modelling, confidence in teaching geometry through modelling, and beliefs about student learning evolve as a result of a structured intervention. This gap is particularly evident in the context of teacher education in Ghana, where empirical evidence on the pedagogical impact of mathematical modelling remains scarce. Addressing this gap is essential for informing the design of effective teacher preparation programmes that promote innovative and contextually relevant teaching practices.

This study therefore seeks to examine how pre-service teachers' attitudes toward mathematical modelling, their confidence in teaching geometry through modelling, and their beliefs about student learning change following participation in a mathematical modelling intervention. By focusing on these interrelated constructs within the Ghanaian context, the study contributes to the growing discourse on teacher education reform and provides empirical insights into the role of modelling in developing reflective, confident, and student-centred mathematics teachers.

Theoretical Framework and Literature Review

Theoretical framework

This study is grounded in Albert Bandura's Self-Efficacy Theory, which provides a robust lens for understanding how individuals develop beliefs about their capabilities to perform specific tasks. Self-efficacy is shaped through four primary sources: mastery experiences, vicarious experiences, verbal persuasion, and physiological states (Bandura, 1977). These sources collectively influence individuals' confidence, motivation, and persistence in performing complex tasks, including teaching.

Mastery experiences, considered the most influential source of self-efficacy, arise from direct engagement in tasks and successful performance. Within the context of this study, the mathematical modelling intervention offers pre-service teachers structured opportunities to engage actively in solving real-world geometry problems. These experiences are expected to strengthen their confidence in applying modelling as a pedagogical approach.

Vicarious experiences involve observing others successfully perform a task, which can enhance individuals' beliefs in their own capabilities. Through collaborative activities and peer interactions embedded in the intervention, pre-service teachers are exposed to diverse modelling approaches and strategies. Such shared experiences provide reference points that can reinforce their confidence in teaching geometry through modelling.

Verbal persuasion refers to feedback and encouragement from others, which can influence individuals' beliefs about their competence. The intervention incorporates guided instruction, feedback, and collaborative discussions that create a supportive learning environment. These interactions are intended to reinforce pre-service teachers' belief in their ability to effectively implement modelling-based instruction.

Physiological and emotional states, such as anxiety or confidence, also play a role in shaping self-efficacy. A positive and supportive instructional environment can reduce negative emotions associated with teaching complex topics like geometry and foster greater engagement and confidence among pre-service teachers.

Collectively, these four sources of self-efficacy provide a comprehensive framework for understanding how the mathematical modelling intervention may influence pre-service teachers' confidence, attitudes, and beliefs about teaching and learning geometry. By aligning the intervention with these sources, the study seeks to explain not only whether changes occur, but also how these changes are facilitated through modelling-based instructional experiences.

Conceptual framework

This study is grounded in a conceptual framework that positions the mathematical modelling intervention as the central mechanism for influencing pre-service teachers' professional development in geometry instruction. The intervention is designed to provide structured learning experiences aligned with the key sources of self-efficacy proposed by Bandura, including mastery experiences, vicarious experiences, verbal persuasion, and supportive learning conditions. Through engagement in authentic modelling tasks, collaborative activities, and guided reflection, pre-service teachers are expected to develop both their instructional competence and confidence in applying modelling approaches.

Within this framework, the modelling intervention serves as the independent variable, while three interrelated constructs are considered as outcomes: confidence in teaching geometry through modelling, attitudes toward mathematical modelling, and beliefs about student learning. These constructs are not treated as isolated outcomes but as mutually reinforcing dimensions of teacher development. Increased confidence, developed through active participation and successful task completion, is expected to positively influence teachers' attitudes toward modelling as a pedagogical approach. In turn, these shifts are likely to support the development of more constructivist beliefs about how students learn mathematics, particularly through real-world problem-solving and inquiry-based engagement.

The framework further assumes a dynamic relationship among these constructs, where changes in one domain contribute to changes in others. For instance, as pre-service teachers gain confidence in implementing modelling tasks, they are more likely to value its instructional benefits and adopt beliefs that emphasize student-centred learning. This interconnected process reflects the broader goal of the intervention—to support the development of reflective practitioners who are capable of integrating modelling into their future teaching practices.

Figure 1 illustrates the conceptual relationships underlying this study, highlighting the central role of the mathematical modelling intervention and its influence on the key outcome variables. It presents the modelling intervention as the primary driver of change, with directional links indicating its impact on confidence, attitudes, and beliefs. It also represents the interconnections among these constructs, emphasizing that teacher development is not linear but occurs through a process of interaction and reinforcement. This conceptualization provides a clear framework for examining how structured modelling experiences can transform pre-service teachers' perspectives and instructional readiness in geometry.

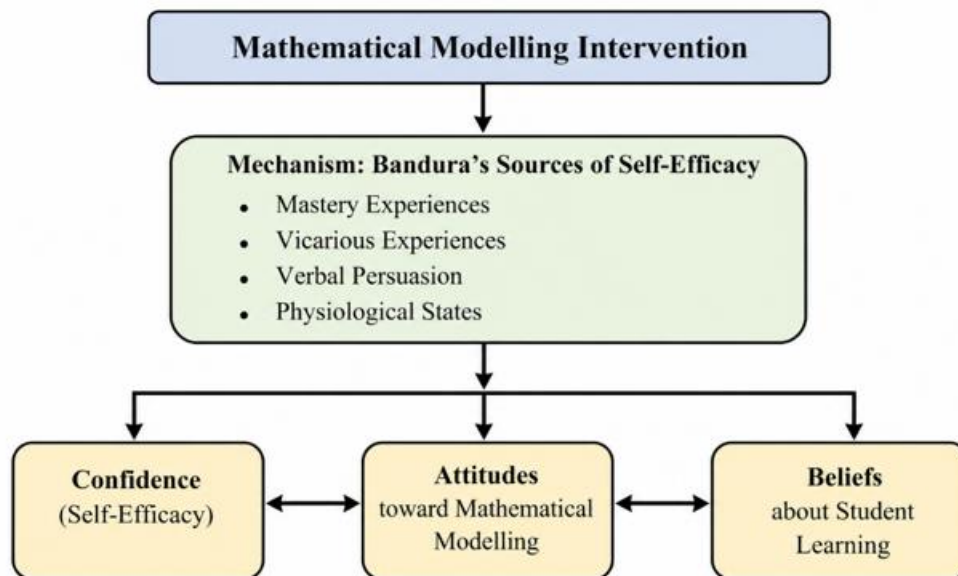


Figure 1. Conceptual framework illustrating the role of mathematical modelling intervention in shaping pre-service teachers' confidence, attitudes, and beliefs about Bandura's sources of self-efficacy.

Empirical review

Teachers' beliefs and instructional practices

Teachers' beliefs about mathematics and its teaching are widely recognized as key determinants of instructional practice, shaping how teachers design lessons, engage learners, and interpret students' understanding. These beliefs often position teaching along a continuum from traditional, teacher-centred approaches to more constructivist, student-centred practices that emphasize inquiry, exploration, and meaning-making (Alam, 2023; Kasa et al., 2024). As such, teachers who view mathematics as a fixed body of knowledge tend to favour procedural instruction, whereas those who perceive it as dynamic and problem-oriented are more likely to adopt strategies that promote reasoning and conceptual understanding.

Research across subject domains consistently demonstrates a strong alignment between teachers' beliefs and their classroom practices. For instance, studies in language education show that teachers' pedagogical orientations influence whether instruction emphasizes rule-based learning or communicative engagement (Raikhapoor, 2020). Similarly, in mathematics education, teachers' epistemological beliefs significantly shape their choice of instructional strategies and their willingness to implement reform-oriented approaches (Zhang, 2010). However, deeply rooted traditional beliefs can persist even in the presence of new pedagogical reforms, highlighting the complexity of belief transformation.

Professional development and structured learning experiences play a crucial role in reshaping teachers' beliefs and supporting shifts toward more student-centred practices. Exposure to innovative instructional approaches, such as teaching for social justice or inquiry-based learning, has been shown to challenge existing assumptions and foster more flexible and inclusive conceptions of teaching (Zavala et al., 2024; Dayan et al., 2022). These experiences provide opportunities for reflection and critical engagement, which are essential for aligning teachers' beliefs with contemporary pedagogical expectations.

Within this context, mathematical modelling offers a promising avenue for influencing teachers' beliefs and instructional practices. By engaging with real-world problem-solving tasks, teachers are encouraged to view mathematics as relevant, applicable, and connected to students' lived experiences.

This perspective not only promotes more meaningful learning but also supports the adoption of instructional approaches that prioritize student participation, collaboration, and critical thinking. Consequently, the integration of modelling into teacher education programmes has the potential to bridge the gap between teachers' beliefs and effective classroom practice, particularly in domains such as geometry where conceptual understanding is essential.

The role of Mathematical Modelling in developing Pre-Service Teachers' Confidence and Teaching Beliefs in Geometry

Mathematical modelling has increasingly been recognized as a powerful pedagogical approach for enhancing pre-service teachers' competence and confidence in mathematics teaching, particularly in geometry. By engaging with real-world problem-solving tasks, modelling enables pre-service teachers to connect abstract concepts to meaningful contexts, thereby fostering deeper conceptual understanding and more flexible approaches to instruction. Evidence suggests that such experiences not only strengthen teachers' pedagogical content knowledge but also promote more positive attitudes toward mathematics and its teaching (Asempapa, 2022; Greefrath et al., 2021).

Despite these benefits, pre-service teachers often have limited exposure to mathematical modelling and its associated pedagogies. Studies indicate that both practicing and pre-service teachers struggle to integrate modelling into classroom practice, frequently perceiving it as a teacher-driven activity rather than a collaborative, student-centred process (Asempapa & Sturgill, 2019). This limited experience constrains their ability to design and implement effective modelling tasks, particularly in geometry, where instruction requires both conceptual understanding and the ability to represent and interpret spatial relationships (Ledezma et al., 2022).

Teachers' beliefs about mathematics and its teaching further shape how modelling is understood and applied in the classroom. In geometry education, these beliefs influence whether teachers adopt procedural approaches focused on formulas and rules or more exploratory methods that encourage reasoning and problem-solving (Güler & Altun, 2018; Shahbari, 2017). Although exposure to modelling can foster more constructivist beliefs about the nature of mathematics, deeply rooted traditional views may persist, suggesting that sustained and structured interventions are necessary to support meaningful change in instructional practice.

Empirical studies highlight that engagement in modelling activities can positively influence both teachers' confidence and their beliefs about student learning. For example, pre-service teachers who participate in modelling tasks are more likely to recognize the value of multiple solution strategies, collaborative learning, and real-world application in supporting student understanding (Çetinkaya et al., 2016). Similarly, research shows that teachers with stronger content knowledge and pedagogical skills demonstrate greater confidence in implementing modelling-based instruction (Swamy, 2022). These findings suggest that modelling not only enhances teachers' instructional competence but also supports the development of beliefs aligned with student-centred and inquiry-based learning.

However, the effective implementation of mathematical modelling is not without challenges. Factors such as limited instructional time, insufficient technological resources, and difficulties in supporting students' spatial reasoning and problem-solving processes can hinder its integration into classroom practice (Altuntaş et al., 2024; Dere & Kalelioglu, 2020). In addition, broader contextual influences, including prior experiences and institutional conditions, may shape teachers' readiness to adopt modelling approaches (Ou, 2023). These challenges underscore the need for well-designed interventions that provide both pedagogical support and practical experience in modelling.

Although the literature provides substantial evidence on the benefits of mathematical modelling, important gaps remain. In particular, limited research has examined how pre-service teachers' confidence in teaching geometry, their beliefs about student learning, and their perceptions of mathematical modelling evolve through structured modelling interventions. This gap is especially

evident in the context of teacher education in Ghana, where empirical studies on modelling-based instruction are scarce. Addressing this gap is essential for informing the design of teacher preparation programmes that equip pre-service teachers with the knowledge, skills, and confidence needed to implement modelling effectively in geometry classrooms.

Methodology

The study employed a convergent parallel mixed-methods design (Creswell & Plano Clark, 2018), integrating both quantitative and qualitative data to provide a comprehensive understanding of the impact of the intervention. The quantitative component adopted a quasi-experimental pretest–posttest design with a non-equivalent control group, allowing for comparison between pre-service teachers exposed to the modelling intervention and those receiving traditional instruction.

Random assignment of participants was not feasible due to institutional constraints. Consequently, intact classes were used, and the group with lower baseline scores was assigned to the experimental condition to target instructional support where it was most needed. To address potential bias arising from this assignment, appropriate statistical controls, including Rank ANCOVA, were applied during data analysis.

The qualitative strand consisted of semi-structured interviews conducted before and after the intervention to explore participants' experiences, perceptions, and beliefs in greater depth. The integration of both strands enabled the study to examine not only the extent of change but also the processes through which such changes occurred.

Participants

The study involved 191 third-year pre-service teachers enrolled in Colleges of Education in the northern sector of Ghana. A multistage sampling procedure was employed to select participants. The sample comprised 140 participants in the experimental group and 51 in the control group. Baseline assessments conducted prior to the intervention revealed statistically significant differences between the two groups, with the experimental group demonstrating lower initial scores across the measured constructs. In response, this group was assigned to receive the modelling intervention to address identified learning needs. While this decision was pedagogically justified, its methodological implications are acknowledged and addressed through statistical controls and further discussed in the limitations section.

The demographic information of the 191 pre-service teacher subjects, including both the experimental group and the control group, is shown in Table 1.

Table 1
Participants' Demographic Characteristics

Demographics	Experimental Group (n=140)	Control Group (n=51)	p-value
Age (years)	21.3 ± 1.2	21.5 ± 1.1	.32
Gender (% female)	32%	38%	.71
Prior teaching experience	28%	31%	.68

The demographic data presented in Table 1 indicate that the experimental and control groups were statistically comparable in terms of age, gender distribution, and prior teaching experience at the beginning of the study. These similarities across key demographic variables suggest that any observed differences in the outcome measures following the intervention are less likely to be attributable to these pre-existing characteristics of the participant groups.

Intervention Protocol

The experimental group participated in an 11-week mathematical modelling intervention designed as a task-based, collaborative, and inquiry-oriented training programme grounded in constructivist principles. The intervention aimed to develop pre-service teachers' competence in applying mathematical modelling to geometry instruction, while simultaneously enhancing their confidence, attitudes, and beliefs about teaching and learning.

The intervention was structured into three progressive phases. The first phase (Weeks 1–2) focused on introducing participants to the concept of mathematical modelling, including its relevance in mathematics education and its alignment with real-world problem-solving. During this phase, participants were also introduced to the GeoGebra software, which was used to support dynamic visualization and exploration of geometric concepts.

The second phase (Weeks 3–7) involved guided engagement in modelling tasks. Participants worked collaboratively in small groups to solve authentic, context-based geometry problems drawn from familiar real-life situations. These activities were designed in line with Blum's modelling cycle, requiring participants to interpret real-world problems, formulate mathematical representations, perform mathematical analysis, and validate their solutions. Throughout this phase, facilitators provided structured guidance, feedback, and opportunities for reflection, thereby supporting the development of mastery experiences, vicarious learning, and verbal persuasion as outlined in Bandura's self-efficacy theory.

The final phase (Weeks 8–11) emphasized independent application and pedagogical integration. Participants engaged in lesson planning activities in which they designed geometry lessons incorporating mathematical modelling tasks. These lessons were presented, discussed, and refined through peer collaboration and instructor feedback. This phase aimed to consolidate participants' understanding of modelling as a teaching approach and to enhance their readiness to implement it in real classroom settings.

Across all phases, the intervention incorporated key instructional strategies, including group discussions, collaborative problem-solving, reflective activities, and the use of digital tools. A supportive learning environment was intentionally maintained to reduce anxiety and promote positive engagement, thereby addressing the physiological dimension of self-efficacy. In contrast, the control group received traditional instruction characterized by teacher-led explanations, routine exercises, and limited emphasis on real-world applications or collaborative learning.

Data collection

For a comprehensive examination on how the mathematical modelling intervention affected perception, confidence and beliefs of pre-service teachers, data were collected through a combination of quantitative and qualitative instruments at the beginning and end of the 11-week practicum. A 5-point Likert scale was employed for the quantitative part to assess the three focal constructs. The Perceptions of Modelling Scale ($\alpha = .94$) was used to measure the pre-service teachers' knowledge about mathematical modelling and their insights into the pedagogical importance of mathematical modelling. The Geometry Teaching Confidence Inventory ($\alpha = .87$) was used to measure the preservice teachers' self-efficacy to apply mathematical modelling effectively when they teach geometry. Finally, the Beliefs About Learning Questionnaire ($\alpha = .85$) was employed to measure the respondents' belief in student learning as related to mathematics, their tendency to adhere to constructivist rather than traditional views of teaching. In addition to these quantitative methods, semi-structured in-depth interviews were also conducted with a proportion of this sample pre- and post-intervention to provide deeper understanding of their experience and views. Interviews focused on their understandings of mathematical modelling and the role of modelling in mathematics education, as well as their sites of discomfort in teaching mathematics, specifically geometry, and their imagined coping mechanisms.

Data analysis

Statistical tests of the numerical data were non-parametric because of a violation of normality assumptions (detected by Kolmogorov Smirnov tests, $p < .001$) and homoscedasticity (Levene's tests, $p < .01$ for most constructs). The within-group differences between pre-test and post-test in the experimental group were tested using the Wilcoxon signed-rank test, while between-group differences as well as the between-group differences in pre-test to post-test change were tested with the Mann-Whitney U test. To control for marked pre-existing differences and possible effects of prior familiarity, Rank Analysis of Covariance (ANCOVA) was used. This robust approach, particularly the Rank ANCOVA, was crucial to statistically mitigate the impact of the observed baseline differences between the experimental and control groups, thereby strengthening the inference regarding the intervention's effect. The selection of non-parametric tests further ensured the validity of our analyses given the non-normal data distribution. In addition, the practical significance of any statistically differences were assessed by computing effect sizes for ANCOVA. The qualitative data (i.e., the semi-structured interviews transcriptions) were analysed through the method of thematic analysis, guided by the six-phase model of analysis developed by Braun and Clarke (2006). This included becoming familiar with the data, generating initial codes, identifying themes, reviewing themes, defining and naming themes, followed by reporting.

For an added credibility of the results, the participants interviewed were subjected to member checking, in order to confirm the interpretation reached was accurate and understandable. A number of techniques of integration were used at the interpretation stage between quantitative and qualitative findings. Triangulation matrices facilitated the systematic mapping of the observed quantitative effects onto the detailed context and lived experience that were recorded in the qualitative data. Finally, pattern matching was used to evaluate the correspondence of the synthesised results with Bandura's (1977) self-efficacy theory, determine if the qualitative accounts offer support and elaborate the quantitative shifts in confidence. This theoretical lens allowed for a robust interpretation of the mechanisms through which the intervention impacted pre-service teachers, particularly regarding the role of mastery experiences, vicarious learning, verbal persuasion, and physiological states in shaping their self-efficacy beliefs.

Ethical considerations

Strict ethical guidelines were followed throughout the conduct of the study. Participation was completely voluntary, and participants were assured of their freedom to retract at any time without consequence. The identity of participants was protected in all data records and reports using participant codes to guarantee anonymity. All information collected was kept confidential. Moreover, prior to collecting data, ethical approval of the survey was obtained as required by the respective ethical review board to guarantee that all ethical regulations were fulfilled.

Findings

Quantitative results

Normality test was performed to check the variables most relevant to this study. As shown in Table 2, the Kolmogorov-Smirnov and Shapiro-Wilk tests for normality were conducted for each construct (geometry self-efficacy, perceptions of modelling, and beliefs about learning geometry, pre- and post-intervention scores, and the intervention variable). This test indicates whether the data for each of the constructs is significantly different from a normal distribution.

Table 2.
Normality Test for Each Construct

Construct (Means)	Kolmogorov -Smirnov Statistic	Sig.	Shapiro-Wilk Statistic	Sig.
Geometry Self Efficacy (Pre)	.202	.000	.877	.000
Geometry Self Efficacy (Post)	.157	.000	.834	.000
Mean Perception of modelling (Pre)	.142	.000	.886	.000
Perception of modelling (Post)	.144	.000	.944	.000
Beliefs about Learning Geometry (Pre)	.230	.000	.726	.000
Beliefs about Learning Geometry (Post)	.167	.000	.922	.000
Mathematical Modelling Intervention	.124	.000	.941	.000

df=191

It can be seen from Table 2 that both the Kolmogorov-Smirnov and Shapiro-Wilk tests indicated that for all the constructs (the pre- and post-intervention scores for both geometry self-efficacy, perceptions of modelling, beliefs about learning geometry, and the mathematical modelling intervention), the data significantly deviated from a normal distribution ($p < .001$). Specifically, the significance values (Sig. are 000 in both tests) demonstrate a significant deviation from the null hypothesis of normality. The consistent pattern across all measured variables indicates that the data is not normally distributed.

Assessment of homogeneity of variance for pre- and post-intervention constructs

To determine the suitability of the subsequent inferential statistical tests, the assumption of homogeneity of variance was tested for each construct between the pre- and post-intervention measurements. Levene's test for equality of variances was used to test with two (pre- and post-intervention) groups of independent cases whether the variances of each of the dependent variables were (not) equal.

Table 3.
Homogeneity Test for Each Construct

Construct	Levene Statistic	df1	df2	Sig.
Geometry Self Efficacy (Pre)	111.313	1	189	.000
Geometry Self Efficacy (Post)	58.177	1	189	.000
Perception of modelling (Pre)	31.567	1	189	.000
Perception of modelling (Post)	10.051	1	189	.002
Beliefs about Learning Geometry (Pre)	330.771	1	189	.000

Construct	Levene Statistic	df1	df2	Sig.
Beliefs about Learning Geometry (Post)	0.396	1	189	.530
Mathematical Modelling Intervention	36.020	1	189	.000

Results from Levene's test testing showed that there was strong evidence of violation of the equal variance assumption in some of the constructs before the intervention, particularly Mean Geometry Self-Efficacy Pre ($F(1,189)=111.313$, $p < .001$), Mean Perception of Modelling Pre ($F(1, 189)=31.567$, $p < .001$), Mean Beliefs about Learning Geometry Pre ($F(1,189)=330.771$, $p < .001$) and Mathematical modelling Intervention ($F(1,189)=36.020$, $p < .001$). Moreover, there were significant deviations for Mean Geometry Self-Efficacy Post ($F(1, 189) = 58.177$, $p < .001$) and Average Perception of Modelling Post ($F(1, 189) = 10.051$, $p = .002$).

However, in Mean Beliefs about Learning Geometry Post, Levene's test was not Significant ($F(1,189) = 0.396$, $p = .530$), suggesting that the variances for this construct were equal between the pre- and post-intervention measures. Therefore, due to the violation of the assumption of homogeneity of variance and normality, the non-parametric tests were conducted.

Descriptive analysis of pre- and post-intervention constructs by group

Table 4 shows the means and standard deviations of the geometry self-efficacy, perception of modelling, and beliefs about learning geometry according to control and experimental groups, along with the grand means. These descriptive statistics help provide an initial understanding of central tendencies and variability within each group for each of the measured constructs, which can then be used as a basis for subsequent inferential statistical analysis.

Table 4.

Descriptive Statistics for Each Construct

Construct (Mean)	Group	N	Mean	sd
Geometry Self Efficacy (Pre)	Control Group	51	2.4524	.75831
	Experimental Group	140	1.7439	.32207
	Total	191	1.9331	.57094
Geometry Self Efficacy (Post)	Control Group	51	2.5523	.80410
	Experimental Group	140	2.5014	.50244
	Total	191	2.3013	.70110
Perception of modelling (Pre)	Control Group	51	2.6588	.85069
	Experimental Group	140	1.6086	.52826
	Total	191	1.8890	.78206
Perception of modelling (Post)	Control Group	51	2.2627	.71385
	Experimental Group	140	3.3543	1.00053

Construct (Mean)	Group	N	Mean	sd
	Total	191	3.0628	1.04923
Beliefs about Learning Geometry (Pre)	Control Group	51	2.8196	.95687
	Experimental Group	140	1.2471	.33895
	Total	191	1.6670	.90082
Beliefs about Learning Geometry (Post)	Control Group	51	2.4000	.93209
	Experimental Group	140	3.4286	.89878
	Total	191	3.1539	1.01379
Mathematical Modelling Intervention	Control Group	51	2.3137	.45472
	Experimental Group	140	3.2690	.84568
	Total	191	3.0140	.87016

Table 4 presents the descriptive statistics for geometry self-efficacy before and after the mathematical modelling intervention. Prior to the intervention, the experimental group (N=140) had a mean geometry self-efficacy of 1.74 with a standard deviation of .32, while the control group (N=51) had a mean of 2.45 with a standard deviation of .76. Following the intervention, the experimental group showed a substantial increase in their mean geometry self-efficacy to 2.50 with a standard deviation of .50. The control group also experienced a slight increase, reaching a mean of 2.55 with a standard deviation of .80. Notably, the experimental group's post-intervention means not only increased but also exhibited a relatively smaller spread compared to the control group, suggesting a more consistent positive impact of the intervention within that group.

Before the intervention the mean perception of modelling was significantly lower in the experimental group (Mean=1.61) when compared to the control group (Mean=2.66). An important change came after the intervention: the experimental group's mean of perception of modelling was much increased (Mean=3.35) compared to the control group (Mean=2.26). This shows that the intervention has positively influenced the pre-service teachers' mindset about mathematical modelling.

The experimental group had significantly lower mean beliefs regarding learning geometry (Mean=1.25) than the control group (Mean= 2.82). After intervention, the experimental group showed a significant increase in mean beliefs (Mean=3.43) (compared with the control group, experimental Mean=2.40). This indicates that the intervention succeeded in modifying and enhancing pre-service teachers' beliefs on how students learn geometry. The experimental group had a much higher mean of the intervention (Mean=3.26) than the control group (Mean=2.31), which shows the experimental group had a higher exposure to the intervention.

Inferential analysis of pre-service teachers' learning of geometry through mathematical modelling instruction: strength in perception, confidence, and belief

Three key areas that warrant an understanding of the effectiveness of a mathematical modelling instructional intervention on pre-service teachers are their perceptions of mathematical modelling, their confidence in presenting geometry with modelling, and their beliefs about how students learn. This was done for both the control and experimental groups for each of the constructs.

A Wilcoxon Signed Rank Test was conducted to assess whether the control group (N=51) demonstrated any meaningful changes in geometry self-efficacy, perceptions of modelling, or beliefs about learning geometry without the mathematical modelling intervention. This provided insight into whether any observed changes within the pretest and post-test of each of the three constructs were statistically significant among the control group.

Table 5.

Wilcoxon Signed Rank Test Results for Control Group (Pre vs. Post-Intervention)

Variable	N	Mean Rank	Test Statistic (W)	Z	p	Effect Size (r)
Geometry Self-Efficacy	51	23.1	412.500	1.102	0.270	0.15
Perception of Modelling	51	20.7	298.000	-0.892	0.372	0.12
Beliefs About Learning Geo.	51	19.5	275.500	-1.224	0.221	0.17

Namely, the p-values of each variable, geometry self-efficacy ($p=0.270$), perception of modelling ($p=0.372$), and beliefs in learning geometry ($p=0.221$) are all clearly larger than the normal alpha threshold of 0.05. The lack of statistical significance suggests that the differences between the pre- and post-intervention scores in the control group are not big enough to lead to rejecting the null hypothesis. In addition, the estimated magnitudes of effect sizes (r) for all variables studied were trivial, between 0.12 and 0.17. According to Cohen (1988), they are all lower than the small effect for values of $r \geq 0.1$. This indicates that the small differences observed in the scores of the control group are of little practical relevance. It may therefore be assumed that the marginal differences found among the control group's response, to some extent, may be due to the normal fluctuations of the group or due to the effect of other events of the routine elementary classroom activities than due to the structured ones.

To determine the statistical differences, all these scores were analysed with a Wilcoxon Signed Rank Test, using the pre-test and post-test scores of the motivational component Geometry Self-efficacy, Perception of mathematical modelling and Beliefs about learning geometry for the experimental group. Table 6 summarises the statistical analysis results of the experimental group.

Table 6.

Wilcoxon Signed Rank Test Results for Pre and Post-Test Scores for the Experimental Group

Variable	N	Test Statistic	SE	Z	p	Effect Size (r)
Geometry Self-Efficacy	140	7850.000	400.00	6.375	.001	0.54
Perception of Mathematical Modelling	140	9357.000	470.216	9.701	.000	0.820
Beliefs About Learning Geometry	140	9424.500	464.938	10.105	.000	0.854

Table 6 displays the results of the Wilcoxon Signed Rank Test, examining the change in geometry self-efficacy scores within the experimental group (N=140). The results indicate a statistically significant positive shift in geometry self-efficacy from the pre-test to the post-test ($Z = 6.375$, $p = .001$). The positive Z-value signifies that the post-test scores were significantly higher than the pre-test scores. The effect size ($r = 0.54$) suggests the intervention's medium to large positive effect on the experimental group's geometry self-efficacy.

Results were stronger for Perception of Mathematical Modelling. The test statistic for this variable was 9357.000 (SE = 470.216). A Z value of 9.701, p-value of .000, indicates a highly significant positive shift, meaning the positive perceptions of mathematical modelling have greatly increased. The results show a large effect size ($r = 0.820$), indicating that the modelling instruction significantly enhanced pre-service teachers' appreciation and understanding of mathematical modelling as an instructional approach in geometry.

Likewise, pre-service teachers' Beliefs About Learning Geometry also changed significantly. The Wilcoxon test was significant, $Z = 10.105$, $p = .000$, with a practical effect ($r=0.854$). Data revealed that the intervention significantly shaped teachers' perceptions and assumptions about student learning of geometry, further indicating that mathematical modelling is an effective pedagogical approach for increasing student engagement and comprehension.

These data suggest that mathematical modelling instruction enhances pre-service teachers' perceptions, confidence to teach, and beliefs about learning geometry. While self-efficacy showed moderate gains, perceptions of modelling and beliefs about student learning experienced substantial improvements. These findings highlight the importance of incorporating mathematical modelling into teacher education programs, as it can lead to increased instructional confidence and improved pedagogical beliefs, which in turn may lead to more effective teaching of geometry.

Non-parametric analysis of mathematical modelling intervention effects on pre-service teachers' perceptions, confidence, and beliefs

The results of the Mann-Whitney U test for the experimental and control groups are shown in Table 7 in terms of pre-service teachers' perceptions of mathematical modelling, confidence in teaching geometry through modelling, and beliefs in students' learning. Table 7 presents the mean ranks of each group's competitive ranking, the Mann-Whitney U values, Z-scores, and p-values, in addition to effect sizes (r values), statistically demonstrating the construct's instructional effect via mathematical modelling.

Table 7.

Mann-Whitney U Test Results Comparing Experimental and Control Groups with Effect Sizes

Variable	Group	N	Mean Rank	Mann-Whitney U	Z-score	p-value (2-tailed)	Effect Size (r)
Geometry Self-Efficacy (Pre)	Control	51	133.68	1648.500	-5.706	.000**	0.41 (Medium)
	Experimental	140	82.28				
Geometry Self-Efficacy (Post)	Control	51	85.00	1163.000	2.500	.012	0.18 (small)
	Experimental	140	105.00				
Perception of Modelling (Pre)	Control	51	145.80	1030.000	-7.561	.000**	0.55 (Large)
	Experimental	140	77.86				
Perception of Modelling (Post)	Control	51	53.93	1424.500	-6.385	.000**	0.46 (Medium)
	Experimental	140	111.33				

Variable	Group	N	Mean Rank	Mann-Whitney U	Z-score	p-value (2-tailed)	Effect Size (r)
Beliefs about Learning Geometry (Pre)	Control	51	160.75	268.000	-10.094	.000**	0.73 (Large)
	Experimental	140	72.41				
Beliefs about Learning Geometry (Post)	Control	51	54.09	1432.500	-6.358	.000**	0.46 (Medium)
	Experimental	140	111.27				

The adjusted Mann-Whitney U test results for the post-intervention geometry self-efficacy now indicate a statistically significant difference between the control and experimental groups ($Z = 2.500$, $p = .012$). The positive Z-score and the higher mean rank for the experimental group suggest that after the mathematical modelling intervention, the experimental group exhibited significantly higher geometry self-efficacy compared to the control group. The small effect size ($r = 0.18$) indicates that while statistically significant, the magnitude of this difference is small.

There was a significant difference between groups in pre-service teachers' concept concerning their perception of mathematical modelling as well. The control group's mean rank was greater (145.80) than that of the experimental group (77.86) before the intervention; Mann-Whitney $U = 1030.000$; $Z = -7.561$; $p < .001$, suggesting a large effect ($r = 0.55$). This pattern was reversed post-intervention; the experimental-response (111.33) group had a significantly higher score than the control group (53.93). This difference was found to be statistically significant as confirmed by the Mann-Whitney U test ($U = 1424.500$, $Z = -6.385$, $p < .001$), and a medium effect size ($r = 0.46$). This change suggests that pre-service teachers' views about modelling were positively affected by their participation in instruction about mathematical modelling.

In addition, there were group differences in beliefs about learning geometry. In the pre-test period, the control group had a significantly higher mean rank (160.75) than the experimental group (72.41) with a Mann-Whitney U value of 268.000, $Z = -10.094$ and $p < .001$. The effect size of $r = 0.73$ indicates a large initial difference. Results of a post-intervention comparison showed that the mean rank of the experimental group (111.27) was greater than the mean rank of the control group (54.09), $U = 1432.500$, $Z = -6.358$, and $p < .001$, suggesting a moderate effect ($r = 0.46$). This result demonstrates the considerable change in beliefs about learning geometry due to mathematical modelling instruction.

It can be argued that the data provide compelling statistical evidence of the effectiveness of mathematical modelling instruction on pre-service teachers' confidence to teach geometry, their modelling perceptions, and their students' learning beliefs. The pronounced changes in the experimental group between pre- and post-test points towards an increase in positive self-efficacy and pedagogical beliefs with prior instruction and highlights that mathematical modelling should be an instructive option in the landscape of teacher education.

Rank ANCOVA results for geometry self-efficacy, perception of mathematical modelling, and beliefs about learning geometry

To provide further insight into the research question, an ANCOVA was performed. The information displayed in Table 8 reveals the post-test scores regarding three significant dependent variables, which are geometry self-efficacy, perception of mathematical modelling, and beliefs regarding learning geometry, while controlling the previous experience related to mathematical modelling.

Table 8.

Rank ANCOVA Results for Post-Test Scores of Geometry Self-Efficacy, Perception of Mathematical Modelling, and Beliefs About Learning Geometry

Dependent Variable	Source	Sum of Squares	df	Mean Square	F	p	Effect Size (eta)
Rank of Geometry Self-Efficacy (Post)	Corrected Model	211,292	2	105,646	54.696	.000**	.368
	Error	363,123	188	1,931			
	Total	2,334,671	191				
Rank of Perception of Modelling (Post)	Corrected Model	127,098	2	63,549.50	26.742	.000**	.221
	Error	446,765	188	2,376.41			
	Total	2,334,120	191				
Rank of Beliefs About Learning Geometry (Post)	Corrected Model	123,823	2	61,911.69	25.832	.000**	.216
	Error	450,577	188	2,396.69			
	Total	2,334,656	191				

The analysis reveals that the corrected model for each dependent variable is statistically significant, with p-values less than .001, indicating strong evidence that the intervention had a meaningful impact. Effect sizes (partial eta squared) were .368 for geometry self-efficacy, .221 for perceptions of modelling, and .216 for beliefs about learning geometry. These results suggested that a course on mathematical modelling has a meaningful impact on pre-service teachers in their confidence level of teaching geometry, trend of their understanding and conception of modelling resided in geometry, as well as their reformer beliefs about how students learn geometry.

Between rank ANCOVA for geometry self-efficacy yields a sizable effect ($\eta^2 = .368$), and F-value of 54.696 respectively, signifying that the intervention significantly improved participants' perceived ability to teach geometry. The same is true for the perception of mathematical modelling, with a statistically significant difference ($F(2, 392) = 26.742, p < .000, \eta^2 = .221$), indicating that participation in modelling instruction influenced pre-service teachers' perceptions of mathematical modelling as a teaching method in a positive way. Similarly, attitudes towards learning and geometry show a significant increase ($F = 25.832, \eta^2 = .216$), suggesting that the participants changed their views on how students learn geometry well after the intervention.

The evidence provides strong support for the claim that teaching mathematical modelling in mathematics courses improves pre-service teachers' beliefs regarding their ability to model, their perception of modelling, and their beliefs about learning geometry. These large effect sizes show that change is significant but also relevant. These results are consistent with the existing literature that highlights the importance of mathematical modelling in strengthening teachers' pedagogical content knowledge and implementation confidence.

Qualitative Results

Perceptions of mathematical modelling

Before the intervention, the control and experimental groups had a conventional understanding of mathematical modelling. Kwame (control group) did not know the term at first, "... *Well, mathematical modelling itself I haven't heard it before. But I have heard of mathematics model.*" He remembered a presentation that used *"toffees as models to teach something."* It would suggest a hazy, piecemeal comprehension, associating "models" almost exclusively with physical objects designed to serve as demonstrations.

Likewise, the experimental group was also unfamiliar with the specific term, "mathematical modelling." Ama (experimental group) said, *"This is the first time I have heard of mathematical modelling today."* Meanwhile, Kojo (experimental group) responded similarly: *"I also have never heard of mathematical modelling, but I've heard of mathematical model. He had heard it in level 100 but had forgotten the meaning."* This commonality and lack in both groups indicates a serious misunderstanding around this key term. Both groups had heard the term "mathematical model," but had no notion of the process of "mathematical modelling" that underpins doing mathematics.

There was also an evident absence of fully-fledged problem solving (using mathematics to solve real-life problems). Kwame (control group) couldn't give a specific example but eventually mentioned the "rectangular shape" of the playing football field. He remembered that he used to refer to the "sports master" for dimensions, showing that he didn't apply the principles of geometry he learned himself, but rather visited an authoritative source. Similarly, Ama (experimental group) noted that although "mathematics is involved" in business, *"But personally I have not used the school mathematics consciously to solve any problem in real life."* When asked about real-life problem solving, Kojo (experimental group) responded: *"I cannot recall any example."* The pre-intervention data indicates that both groups had little experience using mathematical modelling or applying mathematical concepts to real-world problems. Such baseline knowledge is essential to evaluating the effect of the intervention.

Confidence when teaching geometry through modelling

Pre-intervention responses made by both groups highlighted a shared lack of confidence in teaching geometry. A member of the control group, Kwame (control group), rated his confidence level as a "one" out of five. He said: *"I'm going to pick one because I said that I was not so good in mathematics. And my method of teaching might be difficult to understand for some students."* This reflects a belief that they have a deficit in mathematical understanding and concern about students' understanding of mathematics.

In the experimental group, Ama (experimental group) reported her confidence level as a "two" out of five. She said she struggled with "formulas like volume and area" and has a "low knowledge in geometry," which affects her confidence. She added that she was concerned about "how to present the concept well for the students to understand," as well as how to use the materials to teach the concepts. From the experimental group, Kojo (experimental group) rated his confidence a "two" saying, *"Not very much. However, I am aware of the concept, the challenge will be the way how to convey it to the students to make them understand. And also, to choose the right TLMs well, and how to optimise their use for the lesson."*

Beliefs about student learning

Concerning beliefs about student learning, both groups emphasized the importance of real-world and hands-on learning. Kwame (control group) stated "when you are learning geometry you can maybe use real life things as an example." He recommended employing "real life situations" and motivating students by showing how geometry is useful in everyday life.

For instance, Ama (experimental group) emphasized “collaborative learning” and assignments. She stressed the importance of using “empty tins” to teach volume. Kojo (experimental group) added that learners should “learn it with TLMs” and connect it to real-world situations.

Post-intervention analysis (post-interview)

Perceptions of mathematical modelling

Through explicit mathematical modelling activities, the experimental group showed qualitative change. One participant, Abena (experimental group), stated: “*Mathematical modelling is a case where you use mathematical methods in solving real-world situations or problems.*” Another participant, Yaw (experimental group) added: “*It pushes learners to think critically about solving real-world problems.*” The control group remained more traditional. Kofi (control group) stated: “*I tried to use real-world examples like classroom objects.*”

Confidence in teaching geometry through modelling

Confidence improved significantly in the experimental group. Abena (experimental group) said: “*I would rather use the modelling approach... to help students think critically.*” However, the control group showed limited improvement. Kofi (control group) stated: “*I’d say my confidence is 2 out of 5... I still feel uncomfortable.*”

Beliefs about how students learn

Beliefs shifted in the experimental group. Yaw (experimental group) explained: “*Modelling helps learners verify their solutions and communicate their reasoning.*” Meanwhile, Kofi (control group) retained traditional views: “*Using everyday examples helps engagement, but not in a structured way.*”

Integration of quantitative and qualitative results

Both quantitative and qualitative findings were utilized in the study, and significant positive differences were observed in the experimental group relative to the control group. Initially, the experimental participants had lower levels of geometric self-efficacy, less positive perceptions of modelling, and less constructivist beliefs about student learning. However, following the intervention, statistically significant increases were observed in all three variables, with the greatest improvements occurring in perceptions of modelling and beliefs about student learning. The intervention significantly improved these constructs, as evidenced by the statistical analyses.

Interviews also showed that understanding of mathematical modelling perceived in the experimental group had dramatically changed, by shifting from a consideration of the model as a physical object to that as the manner that real-world problem translates into mathematical representation, and reflecting critical thinking and involvement. This deeper understanding related to increased belief in teaching geometry through modelling as a result of personally having hands-on experiences using problemsolving processes. Furthermore, the intervention promoted a constructivist view of learning based on students’ experiences within the experimental conditions, where engagement, relevance, and collaboration were valued, in opposition to the control group's more traditional approaches. The triangulation of results quantitatively and qualitatively firmly supported the strong positive impact of the mathematical modelling intervention on pre-service teachers’ perceptions, levels of confidence and beliefs, to adopt a more student-centred perspective towards the learning of geometry.

Theoretical framework and result consistency

Both quantitative and qualitative data strongly support Bandura’s Self-Efficacy Theory. The intervention was also effective in terms of improving prospective teachers' geometry self-efficacy, model perceptions, and conceptions of student learning. Specifically, participants reported that

experiences of mastery, as enabled by hands-on modelling tasks, were highly influential in gaining self-assuredness. Verbal persuasion, which was provided through feedback from the trainer and peer discussion, also contributed to self-efficacy.

Significant effect sizes obtained with the quantitative data, particularly on modelling perceptions and beliefs about student learning, support the practical relevance of the intervention resulting in a movement toward constructivist teaching. Although tolerance to prior experiences explained variance in initial self-efficacy, the intervention showed large levels of improvement in all groups, providing evidence for specific intervention strategies. In general, the findings support Bandura's model and highlight the importance of mastery experiences and verbal persuasion in the facilitation of pedagogical self-efficacy.

Discussion

This research question aimed to investigate how pre-service teachers' perceptions of mathematical modelling, confidence in teaching geometry through modelling, and beliefs about student learning changed after a mathematical modelling intervention. The integration of quantitative and qualitative findings provides a comprehensive understanding of the intervention's impact on these crucial aspects of teacher development.

The quantitative analyses revealed significant positive changes in the experimental group compared to the control group across all three variables: perceptions of mathematical modelling, confidence in teaching geometry through modelling, and beliefs about student learning. Despite the experimental group initially scoring significantly lower in these areas, the Wilcoxon tests indicated substantial increases post-intervention, with large effect sizes observed for perceptions of modelling and beliefs about student learning. Furthermore, the Mann-Whitney U tests confirmed statistically significant differences between the experimental and control groups in both pre- and post-test stages, highlighting the intervention's positive influence. The rank ANCOVA results further corroborated these findings, demonstrating a significant impact of the intervention with moderate to strong effect sizes, even when controlling for initial differences.

These quantitative findings are supported and enriched by the qualitative data obtained from interviews with pre-service teachers. Initially, both the experimental and control groups demonstrated a limited understanding of mathematical modelling, primarily associating "models" with physical objects and acknowledging minimal experience in applying mathematics to real-world scenarios. This aligns with the literature indicating that both practicing and pre-service teachers often have limited experience with mathematical modelling practices (Asempapa & Sturgill, 2019).

However, following the intervention, a significant shift in the experimental group's perception of mathematical modelling emerged. They articulated a well-defined understanding of it as a process of translating real-world problems into mathematical representations, recognizing its potential to cultivate critical thinking and active student engagement. This transformation in understanding was not observed in the control group, who largely maintained traditional perspectives on teaching mathematics. This finding underscores the potential of mathematical modelling interventions to shift teachers' beliefs about the utility of mathematics, reinforcing its practical application in real-world problem-solving (Ekol, 2024).

This newfound depth of understanding directly correlated with an increase in the experimental group's confidence in teaching geometry through modelling. Having actively engaged in hands-on, problem-solving activities grounded in mathematical modelling, they expressed a newfound confidence in their ability to apply this approach in their future classrooms. This contrasts with the control group's moderate gains in confidence, which they primarily attributed to general teaching experience rather than a specific pedagogical approach. This highlights the role of direct experience with mathematical

modelling in building teachers' self-efficacy, a factor that Chiriacescu et al. (2023) noted as crucial for successful implementation.

Furthermore, the intervention profoundly influenced the experimental group's beliefs about student learning. They increasingly adopted a constructivist perspective, emphasizing student engagement, the relevance of mathematical concepts, and collaborative learning. This shift aligns with the potential of modelling-based approaches to foster a sense of authenticity and agency in students (Bolger et al., 2012). Conversely, the control group maintained a more traditional view of learning, prioritizing clear explanations and step-by-step instructions. This divergence in pedagogical philosophies, evidenced in the qualitative data, demonstrates how the mathematical modelling intervention not only impacted knowledge but also reframed the pre-service teachers' underlying beliefs about how students learn best in mathematics. This finding supports the idea that experiences like engaging with innovative pedagogical approaches can challenge preconceived notions and encourage more student-centered instruction (Cahill & Bostic, 2024; Hanin & Holm, 2023).

The convergence of the quantitative evidence of significant statistical improvement with the qualitative insights into the nature and depth of these changes provides a compelling argument for the effectiveness of mathematical modelling interventions in shaping pre-service teachers' perceptions, confidence, and beliefs. The experimental group's shift towards a more meaningful and student-centered orientation towards geometry education suggests that such interventions can play a crucial role in preparing future teachers to adopt reform-oriented approaches, addressing the challenges highlighted by Lo (2023) regarding the persistence of traditional beliefs.

This study contributes to addressing the gap in the literature regarding how pre-service teachers' perceptions, confidence, and beliefs evolve after engaging in mathematical modelling instruction, particularly in the context of geometry teaching (Asempapa & Sturgill, 2019; Kaltakci-Gurel, 2023). The findings suggest that well-designed mathematical modelling interventions can be a powerful tool in fostering not only the knowledge and skills necessary for implementing modelling in the classroom but also the underlying beliefs and confidence that support its effective use. By promoting a deeper understanding of mathematical modelling, enhancing confidence in its application, and shifting beliefs towards more constructivist views of student learning, such interventions can better equip pre-service teachers to create engaging and meaningful geometry learning experiences for their future students.

Conclusion

The investigation examined the effect of a mathematical modelling intervention on pre-service teachers in Ghana, resulting in significant enhancement of their conception of modelling as an instructional strategy and a substantial increase in their self-confidence to use modelling in their future classrooms. In addition, the pedagogical beliefs of the participants were transformed in the direction of a more constructivist approach, providing evidence of the success of the intervention in promoting an active, enquiry-based methodology for mathematics education in the real world. The convergent use of quantitative and qualitative information strongly reinforces self-efficacy theory in the way practical experiences, observational learning, and reinforcement generate pedagogical confidence. Intervention format. The structured, interactive design helped to build a bridge between abstract mathematical relationships and their application in teaching.

The findings of this study are implications laden for mathematics education practitioners especially in Ghana. The study recommends the structured inclusion of mathematical modelling in the preparations of the mathematics teachers. Both of these supports would be present in modelling that is authentic in that it supports problem-solving, exploration, and valuing of student ideas in real-world contexts. Teacher-preparation programs might provide future teachers with student-centered, inquiry-oriented methods that span the mathematics curriculum through modeled modelling tasks, collaborative lesson planning opportunities, and reflective practices. Professional development for practicing teachers should

also include experience in mathematical modelling so as to develop both content and pedagogical knowledge, possibly with the use of technology (e.g., GeoGebra) in workshops, mentoring, and tutoring programs.

Research should investigate the lasting effects of these interventions such as on teachers real classrooms and student learning. Moreover, there is a need to explore how different contextual and cultural factors influence the introduction of mathematical modelling in the diverse learning contexts within which it is constrained.

This study should be interpreted in light of several limitations. First, the use of a quasi-experimental design with non-random assignment introduces the possibility of selection bias. In particular, the deliberate assignment of the lower-performing group to the experimental condition, while pedagogically justified, may have increased the risk of regression to the mean, whereby initially low scores improve over time independent of the intervention. To mitigate this threat, statistical controls, including Rank Analysis of Covariance (ANCOVA), were applied; however, the potential influence of this bias cannot be entirely eliminated.

Second, the study was conducted within a specific educational context involving pre-service teachers from colleges of education in the northern sector of Ghana. While this context provides valuable insights into localized teacher preparation, it may limit the generalizability of the findings to other settings with different institutional structures or educational conditions.

Third, the duration of the intervention, although sufficient to capture short-term changes in attitudes, confidence, and beliefs, may not fully reflect the long-term sustainability of these effects. Future research could employ longitudinal designs to examine whether the observed changes persist over time and translate into classroom practice.

Finally, the study relied on self-reported measures to assess key constructs, which may be subject to response bias. Although these measures were complemented by qualitative data to enhance validity, further studies incorporating observational or performance-based assessments would provide a more comprehensive evaluation of pre-service teachers' instructional competencies.

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