Pre-Service Mathematics Teachers' Instructional Practices and Students' Conceptual Understanding in Algebra and Geometry: Implementation of the Mathematical Modelling Framework for Ghana (MMF-Gh)

Joseph Amoah [1], Ebenezer Bonyah[2], Joseph Frank Gorden[3]

[1]Department of Mathematics Education, University of Skills Training and Entrepreneurial, Development, Kumasi, Ghana

[2]Department of Mathematics Education, University of Skills Training and Entrepreneurial Development, Kumasi, Ghana

[3]Department of Mathematics Education, University of Skills Training and Entrepreneurial Development, Kumasi, Ghana

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ABSTRACT

This study examined pre-service mathematics teachers' perceptions of mathematical modelling, changes in their instructional practices, and differences in students' conceptual understanding scores following the implementation of the Mathematical Modelling Framework for Ghana (MMF-Gh). The quantitative component employed a one-group pre-test–post-test design involving 60 pre-service mathematics teachers from two selected Colleges of Education and 400 Junior High School students. Two mathematics education experts contributed to the review and refinement of the framework. Data were collected using a structured questionnaire, lesson-plan evaluation rubrics, classroom observation instruments, and pre- and post-tests. Descriptive statistics and paired-samples t-tests were used for analysis. Before implementation, 85.0% of participating pre-service teachers agreed or strongly agreed that mathematical modelling was important in mathematics teaching. Post-intervention lesson-plan scores were significantly higher across all assessed criteria ($p < .01$). Observed instructional time allocated to teacher-led exposition decreased from 85.0% to 40.0%, while student-centred activities increased from 15.0% to 60.0%. Students' post-test scores were significantly higher in algebraic reasoning, geometric visualization, problem-solving skills, and mathematical communication ($p < .01$), with mean differences ranging from 23.0 to 30.0 percentage points. The findings document favourable initial perceptions and subsequent differences in instructional practices and student scores within the participating settings.

Keywords: Mathematical modelling; pre-service mathematics teachers; instructional practices; algebra; geometry; conceptual understanding; Ghana.

1. INTRODUCTION

Mathematics education provides opportunities for learners to interpret relationships, reason with representations, and solve contextual problems (Boadu & Boateng, 2024; Boadu et al., 2026). In Ghana, the Mathematics Common Core Programme for JHS 1–3 emphasises competencies including critical thinking and problem-solving, communication, and collaboration (NaCCA, 2020). These expectations make instructional approaches that connect mathematical content with learners' experiences relevant to teacher preparation. Algebra and geometry require learners to explain relationships and connect different representations. Preparing prospective teachers for these demands involves attention to task selection, mathematical explanations, students' reasoning, and assessment. In Ghanaian SHS, Kumazah and Agyei (2025) examined inquiry-based geometry teaching. Although their setting differs from the JHS setting of this study, their work provides a relevant point of comparison for examining student-centred mathematics instruction. Mathematical modelling involves connecting real-world situations with mathematical representations, mathematical work, interpretation, and

validation. It can function as an instructional approach as well as an object of learning (Erbas et al., 2014). The cycle described by Blum and Leiss (2007) offers a basis for considering how learners move between contextual situations and mathematical solutions. Designing a modelling task requires more than placing a conventional exercise within a short story. Guerrero-Ortiz and Borromeo Ferri (2022) identified a tendency for pre-service teachers without modelling training to construct word problems when attempting to design modelling tasks. Their findings highlight the importance of distinguishing modelling activities from conventional contextual exercises. Technology also requires instructional judgement. Agyei et al. (2024) reported relatively limited transformative uses of digital technologies among Ghanaian senior high school mathematics teachers. This finding supports attention to the mathematical purpose of technology use rather than its presence alone. For modelling instruction, digital tools may support exploration and representation, but teachers still need to guide interpretation and validation.

This study examines the Mathematical Modelling Framework for Ghana (MMF-Gh), which combines locally relevant situations with structured modelling activities for algebra and geometry. This study, address teachers' initial perceptions, changes in planned and observed instruction, and differences in students' conceptual understanding scores. The contribution is context-specific evidence concerning implementation in two selected colleges of education and associated teaching-practice settings. The international modelling literature provides a foundation for situating MMF-Gh in mathematics education. Blum and Niss (1991) discuss the purposes and challenges of incorporating applications and modelling into mathematics instruction, while Kaiser and Sriraman (2006) describe different perspectives on modelling and its educational objectives. Galbraith (2007) highlights continuing challenges in translating modelling principles into classroom practice. Together, these contributions inform the development and interpretation of MMF-Gh as a context-sensitive instructional framework for algebra and geometry in Ghanaian teacher education. Its contribution lies in contextual adaptation rather than the establishment of a new theory of mathematical modelling.

1.1 Research Questions

1. What are participating pre-service mathematics teachers' perceptions of the importance of mathematical modelling before the implementation of MMF-Gh?
2. What changes are observed in participating pre-service mathematics teachers' instructional practices in algebra and geometry following the implementation of MMF-Gh?
3. What differences are observed between students' conceptual understanding scores in algebra and geometry before and after the implementation of MMF-Gh?

2. LITERATURE REVIEW

2.1 Theoretical Framework

This study draws on constructivist learning theory, social constructivist theory, and experiential learning theory. Constructivism emphasises learners' active construction of knowledge through exploration and reflection. Mathematical modelling aligns with this perspective by providing opportunities to analyse real-world situations, develop mathematical representations, interpret results, and reconsider solutions. This perspective informs the examination of pre-service teachers' perceptions of modelling and their provision of opportunities for conceptual reasoning. Social constructivism highlights the role of interaction, language, and instructional guidance in learning (Vygotsky, 1978). During modelling activities, learners discuss assumptions, explain their reasoning, compare approaches, and evaluate solutions collaboratively. These practices are relevant to the modelling literature reviewed by Brown et al. (2024) and provide a basis for examining classroom discussion and collaborative problem-solving.

Experiential learning theory connects concrete experience, reflective observation, abstract conceptualisation, and active experimentation (Kolb, 2015). Modelling activities reflect these processes through engagement with practical situations, consideration of mathematical relationships, and testing of solutions against the original context. These perspectives inform the Mathematical Modelling Framework for Ghana (MMF-Gh), adapted from the modelling cycle described by Blum and Leiss (2007). They guide the examination of teachers'

perceptions, changes in instructional practices, and differences in students' conceptual-understanding scores. Their alignment provides a theoretical rationale for the framework without establishing its effectiveness.

2.2 Conceptual Framework

The study's conceptual framework is anchored in the modelling cycle described by Blum and Leiss (2007), which presents mathematical modelling as an iterative process connecting real-world situations with mathematical representations, solutions, interpretation, and validation. Consistent with constructivist principles, the framework emphasises learners' engagement with practical problems, reflection, and collaborative reasoning. The study adapted and implemented the Mathematical Modelling Framework for Ghana (MMF-Gh) within pre-service mathematics teacher education, with attention to local contexts and available instructional resources. MMF-Gh comprises five interrelated components.

Technology as Foundation (T) concerns the use of digital tools, such as GeoGebra and Desmos, for visualization, calculation, and experimentation. Although presented first, technology supports activities across the framework rather than functioning solely as a completed initial step. Problem Formulation (P) involves identifying a locally relevant situation, clarifying the problem, and considering relevant information and assumptions. Mathematical Abstraction (M) concerns translating the situation into mathematical relationships or representations and working mathematically towards a solution. Validation and Iteration (V) involves interpreting results within the original context, examining their plausibility, and revising assumptions or representations where necessary. Generalization and Transfer (G) provides opportunities to consider how mathematical relationships and solution approaches apply to other situations. The framework is non-linear, allowing learners to revisit components as their understanding of the problem develops. These components provide an instructional structure for planning and facilitating modelling activities in algebra and geometry. Within this study, the framework guides the examination of pre-service teachers' perceptions, changes in instructional practices, and differences in students' conceptual-understanding scores. Its proposed relationships express instructional intentions rather than established causal outcomes.

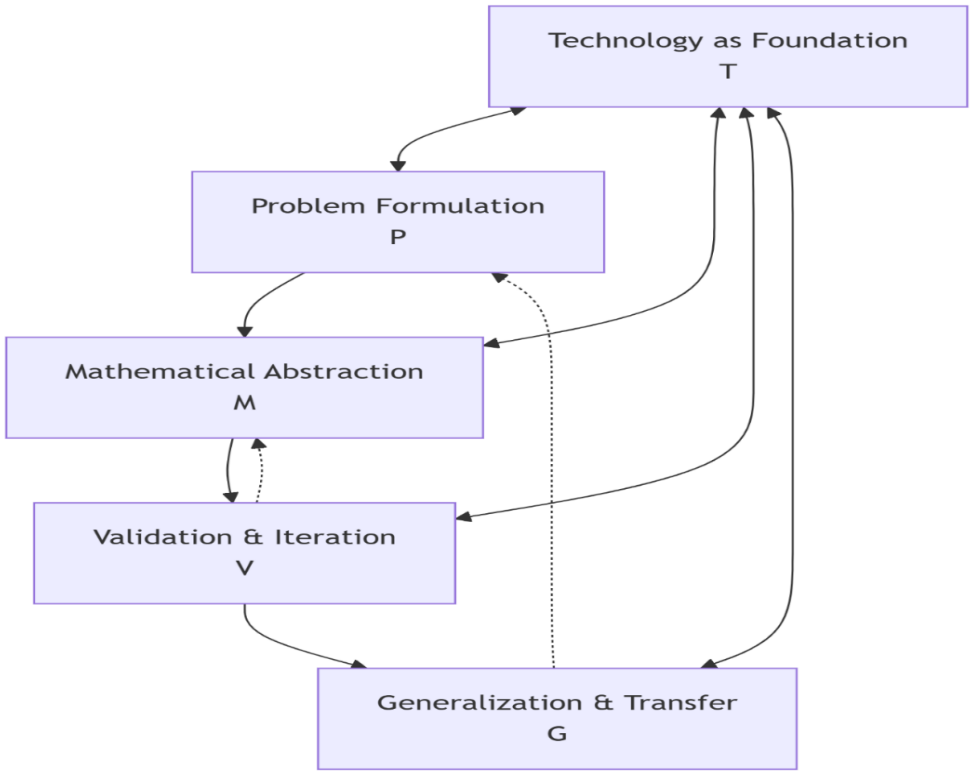


Figure 1: The MMF-Gh Model.

Source: Adapted from Blum and Leiss Modelling Cycle (Blum & Leiss, 2007).

3. MATERIALS AND METHODS

3.1 Research Paradigm and Research Design

The study was guided by pragmatism. A one-group pre-test–post-test design was used to examine differences in participating pre-service mathematics teachers' instructional practices and students' conceptual understanding scores in algebra and geometry before and after the implementation of the Mathematical Modelling Framework for Ghana (MMF-Gh). A pre-intervention questionnaire examined teachers' perceptions of the importance of mathematical modelling. Lesson-plan evaluations generated numerical ratings of planned instruction, classroom observations recorded instructional time allocation, and student tests measured performance in the assessed mathematical domains. Data were analysed using descriptive statistics and paired-samples t-tests, as appropriate. The same participating groups were assessed before and after implementation, without a separate comparison group.

3.2 Population, Sample, and Sampling Techniques

The **population** of a study refers to the complete set of individuals, events, or elements that possess specific characteristics relevant to the research problem (Arthur et al., 2022; Boadu et al., 2023). The accessible population comprised 600 pre-service mathematics teachers and 12 lecturers from two selected Colleges of Education in Ghana, together with 1,000 Junior High School students in the associated teaching-practice settings. A **sample** is a subset of the population selected to participate in the study, representing the larger group while making data collection feasible and manageable (Boadu et al., 2026). The study involved 60 pre-service mathematics teachers and 400 Junior High School students. Two mathematics education lecturers also participated in the expert review and refinement of the Mathematical Modelling Framework for Ghana (MMF-Gh).

Sampling techniques are the strategies or methods used to select participants from the population. They ensure that the sample adequately represents the population and that the study findings are valid and reliable (Arthur et al., 2022; Bannor et al., 2023). Stratified sampling was used to select pre-service mathematics teachers across Levels 100, 200, and 300. The sample comprised 20 first-year students, 25 second-year students, and 15 third-year students, with 30 participants from each college. The 60 participants constituted 10.0% of the accessible pre-service mathematics teacher population. Two lecturers were purposively selected based on their expertise and experience in mathematics education. Their role concerned the review and refinement of MMF-Gh rather than participation in the pre-test–post-test evaluation.

Simple random sampling was used to select 400 Junior High School students from schools where the participating pre-service teachers undertook their teaching practice. The sample comprised 120 students in JHS 1, 140 in JHS 2, and 140 in JHS 3, representing 40.0% of the accessible student population. The sampling procedures included participants from both colleges and the specified academic levels. The findings are interpreted within the participating institutions and teaching-practice settings.

3.3 Data Collection Instruments

The quantitative data were obtained using a structured pre-service teacher questionnaire, classroom observation checklists, lesson-plan evaluation rubrics, and student pre- and post-tests. The questionnaire examined pre-service mathematics teachers' perceptions of the importance of mathematical modelling in mathematics teaching. Responses were recorded using five categories ranging from strongly disagree to strongly agree. Classroom observation checklists documented instructional activities. The reported observation data concerned the proportion of instructional time allocated to teacher-led exposition and student-centred activities before and after the implementation of MMF-Gh.

Lesson-plan evaluation rubrics generated numerical scores for the inclusion of real-world problems, implementation of the modelling cycle, technology integration, variety of assessment strategies, and overall lesson-plan quality. The student pre- and post-tests assessed curriculum-related algebra and geometry content across JHS 1–3. The assessed dimensions comprised algebraic reasoning, geometric visualization, problem-solving skills, and mathematical communication. Test tasks required students to explain their reasoning, use

mathematical representations, and interpret contextual problems. Responses were scored numerically to permit comparison of students' performance before and after implementation.

Table 1: Student-Test Structure, Scoring, and Quality Evidence

Question	Topic	Algebraic reasoning	Geometric visualization	Problem-solving	Mathematical communication	Total
Q1	Taxi-fare linear relationship	4	0	1	1	6
Q2	Interpreting a distance–time graph	3	0	1	2	6
Q3	Simultaneous equations in context	3	0	2	1	6
Q4	Rectangle dimensions and Factorisation	4	0	1	1	6
Q5	Matchstick patterns	2	0	3	1	6
Q6	Triangular plot	0	3	2	1	6
Q7	Symmetry and construction	0	4	1	1	6
Q8	Reflection of a triangle	0	4	1	1	6
Q9	Cylindrical tank and cost	0	2	3	1	6
Q10	Ladder problem	0	3	1	2	6
Total		**16**	**16**	**16**	**12**	**60**

The marking scheme in Table 1 allocates 60 marks across 10 main questions, with six marks assigned to each question. Algebraic reasoning, geometric visualization, and problem-solving each carry 16 marks, while mathematical communication carries 12 marks. Questions 1-5 address algebra content, and Questions 6-10 address geometry content. Problem-solving and mathematical communication are assessed across both sections. Marks are allocated to distinct features of students' responses. Algebraic reasoning assesses the formulation and manipulation of mathematical expressions and relationships. Geometric visualization assesses diagrams, constructions, transformations, and spatial relationships. Problem-solving assesses strategy selection, application of procedures, and interpretation of solutions. Mathematical communication assesses explanations, notation, labelled representations, units, and contextual conclusions. Each dimension score is converted to a percentage by dividing the marks obtained by the maximum available marks for that dimension and multiplying by 100.

3.4 Validity and Reliability of the Instruments

The quality of the instruments was considered in relation to content validity, student-test reliability, and consistency between assessors. Content validity requires evidence that the test items adequately represent the intended mathematical content and skills, while pilot reliability requires analysis of students' item scores. Inter-rater agreement concerns the consistency of independent ratings of the same classroom observations and lesson plans. Table 2 illustrates how percentage agreement is calculated for these two instruments.

Table 2: Illustrative Inter-Rater Percentage Agreement

Instrument	Material independently assessed	Raters	Lessons/plans double-rated	Paired decisions	Matching decisions	Percentage agreement
Classroom observation instrument	Ten common intervals per lesson, classified by instructional activity	2	12 lessons	120	108	90.00%
Lesson-plan evaluation rubric	Five criteria per lesson plan	2	12 plans	60	51	85.00%

Inter-rater reliability concerns the consistency of independent assessments of the same material. Percentage agreement is calculated by dividing the number of matching decisions by the total number of paired decisions and multiplying by 100. Table 2 presents an illustrative calculation for classroom observations and lesson-plan evaluations. For classroom observations, two assessors independently classified ten common intervals in each of 12 lessons. Their classifications matched on 108 of 120 paired decisions, yielding 90.0% agreement. For lesson-plan evaluations, two assessors independently scored 12 plans against five criteria. Their ratings matched on 51 of 60 paired decisions, yielding 85.0% agreement.

4. DATA ANALYSIS, RESULTS, AND FINDINGS

Quantitative data were analysed using the Statistical Package for the Social Sciences (SPSS). Frequencies and

percentages summarised participants' demographic characteristics and questionnaire responses. Means summarised pre- and post-intervention lesson-plan scores and students' scores in algebraic reasoning, geometric visualization, problem-solving skills, and mathematical communication. Paired-samples t-tests examined differences between corresponding pre- and post-intervention scores.

Classroom observation data were analysed descriptively to compare the proportions of instructional time allocated to teacher-led exposition and student-centred activities. Changes in these proportions were expressed in percentage points. The analyses addressed the three research questions by describing teachers' initial perceptions, changes in instructional practices, and differences in students' conceptual understanding scores following the implementation of MMF-Gh.

Table 3: Pre-Service Mathematics Teachers (N=60)

Characteristic	Category	Frequency (f)	Percentage (%)
Gender	Male	28	46.7
	Female	32	53.3
Age	18–20	15	25
	21–23	35	58.3
	24–26	10	16.7
Year of Study	1st Year	20	33.3
	2nd Year	25	41.7
	3rd Year	15	25
College Affiliation	College A	30	50
	College B	30	50

The participants in Table 3 comprised 60 pre-service mathematics teachers selected equally from two Colleges of Education in Ghana. The gender distribution was relatively balanced, with 32 female participants (53.3%) and 28 male participants (46.7%). Most participants were aged 21–23 years (58.3%), while 25.0% were aged 18–20 years and 16.7% were aged 24–26 years. Regarding year of study, 41.7% were second-year students, 33.3% were first-year students, and 25.0% were third-year students. College A and College B each contributed 30 participants (50.0%), providing equal representation from the two participating institutions.

Table 4: Demographics of Expert Participants (N=2)

Characteristic	Category	Frequency (f)	Percentage (%)
Gender	Male	1	50
	Female	1	50
Highest Qualification	MPhil	2	100
Years of Teaching Experience	5+ years	2	100

Two mathematics education experts in Table 4 participated in the validation and refinement of the MMF-Gh. Both experts held Master of Philosophy (MPhil) degrees and had at least five years of teaching experience. Their qualifications and professional experience informed their assessment of the framework and their recommendations for its refinement. The expert panel comprised one male and one female participant.

Table 5: Demographics of Junior High School Students (N=400)

Characteristic	Category	Frequency (f)	Percentage (%)
Gender	Male	208	52
	Female	192	48
Age	14–15	120	30
	16–17	200	50
	18–19	80	20
Grade Level	JHS 1	120	30
	JHS 2	140	35
	JHS 3	140	35

A total of 400 Junior High School students in Table 5 participated in the classroom-based interventions used to evaluate the implementation of the MMF-Gh. The gender distribution was nearly balanced, with male students constituting 52.0% of the sample and female students accounting for 48.0%. Most participants were aged 16–17 years (50.0%), followed by those aged 14–15 years (30.0%) and 18–19 years (20.0%). Regarding grade level, 30.0% were in JHS 1, while JHS 2 and JHS 3 each accounted for 35.0%. This distribution provided representation across all three Junior High School grade levels in the evaluation of the framework.

4.1 Pre-Service Mathematics Teachers' Perceptions of Mathematical Modelling Before the Implementation of MMF-Gh

A pre-intervention needs assessment survey examined participating pre-service mathematics teachers' perceptions of the importance of mathematical modelling in mathematics teaching. Responses were recorded using five categories ranging from strongly disagree to strongly agree. Table 5 presents the response distribution.

Table 6: Pre-Service Mathematics Teachers' Perceptions of Mathematical Modelling Before the Implementation of MMF-Gh (N = 60)

Assessment Area	Response Category	Percentage	Frequency
Perceptions	Strongly Agree	45%	27
	Agree	40%	24
	Neutral	10%	6
	Disagree	5%	3
	Strongly Disagree	0%	0

A needs assessment survey examined participating pre-service mathematics teachers' perceptions of mathematical modelling before the implementation of MMF-Gh. Table 6 presents their responses concerning the importance of mathematical modelling in mathematics teaching. Of the 60 participants, 27 (45.0%) strongly agreed and 24 (40.0%) agreed, giving a combined proportion of 85.0%. Six participants (10.0%) expressed a neutral position, while three (5.0%) disagreed. None of the participants strongly disagreed. These findings indicate that most participating pre-service mathematics teachers perceived mathematical modelling as important in mathematics teaching before the implementation of MMF-Gh. Although a small proportion expressed neutrality or disagreement, the overall response pattern was favourable. This finding concerns participants'

perceptions of the importance of mathematical modelling, confidence in applying and to incorporate them into classroom instruction.

4.2 Changes in Pre-Service Mathematics Teachers' Instructional Practices in Algebra and Geometry Following the Implementation of MMF-Gh

Changes in participating pre-service mathematics teachers' instructional practices in algebra and geometry were examined through lesson-plan evaluations and classroom observations before and after the implementation of MMF-Gh. Lesson-plan evaluations assessed changes in planned instruction, while classroom observations examined the allocation of instructional time to teacher-led exposition and student-centred activities.

Table 7: Paired-Samples t-Tests Comparing Pre- and Post-Intervention Lesson-Plan Scores (N = 60)

Assessment criterion	Pre-intervention mean	Post-intervention mean	Mean difference	t-value	p-value
Inclusion of real-world problems	1.2	4.1	2.9	8.75	< .01
Implementation of the modelling cycle	1.4	3.9	2.5	9.32	< .01
Technology integration	1.5	4.3	2.8	7.89	< .01
Variety of assessment strategies	1.8	3.7	1.9	6.45	< .01
Overall lesson-plan quality	1.3	4.0	2.7	10.45	< .01

Table 7 shows that post-intervention mean scores were higher than pre-intervention mean scores across all assessed criteria. The reported paired-samples t-tests indicated statistically significant differences in each comparison ($p < 0.01$). Inclusion of real-world problems increased from a mean of 1.2 to 4.1, representing the largest mean difference of 2.9. Implementation of the modelling cycle increased from 1.4 to 3.9, a mean difference of 2.5. Technology integration increased from a mean of 1.5 to 4.3, while the variety of assessment strategies increased from 1.8 to 3.7. Overall lesson-plan quality increased from 1.3 to 4.0, representing a mean difference of 2.7. These findings indicate that post-intervention lesson plans received higher ratings for incorporating real-world problems, implementing the modelling cycle, integrating technology, and including varied assessment strategies.

Table 8: Effect Sizes and Confidence Intervals from Lesson-Plan Results

Assessment criterion	95% CI for mean difference	Cohen's d_z	95% CI for d_z
Inclusion of real-world problems	2.24–3.56	1.130	0.802–1.451
Implementation of the modelling cycle	1.96–3.04	1.203	0.867–1.533
Technology integration	2.09–3.51	1.019	0.703–1.328
Variety of assessment strategies	1.31–2.49	0.833	0.536–1.124
Overall lesson-plan quality	2.18–3.22	1.349	0.995–1.697

Table 8 presents the magnitude and precision of the reported differences in lesson-plan scores. Overall lesson-plan quality recorded the largest calculated standardized difference ($d_z = 1.349$, 95% CI [0.995, 1.697]), followed by implementation of the modelling cycle ($d_z = 1.203$, 95% CI [0.867, 1.533]). Inclusion of real-world problems and technology integration recorded effect sizes of 1.130 and 1.019, respectively.

Variety of assessment strategies had the smallest calculated effect size ($d_z = 0.833$, 95% CI [0.536, 1.124]). All calculated confidence intervals for the mean differences were above zero, indicating positive estimated pre-post differences across all assessed criteria (Lakens, 2013).

Table 9: Pre- and Post-Intervention Distribution of Observed Instructional Time

Instructional activity	Pre-intervention (%)	Post-intervention (%)	Change (Percentage points)
Teacher-led exposition	85.0	40.0	−45.0
Student-centred activities	15.0	60.0	+45.0

Table 9 shows a change in the allocation of observed instructional time. Teacher-led exposition decreased from 85.0% before implementation to 40.0% afterwards, a reduction of 45.0 percentage points. Student-centred activities increased from 15.0% to 60.0%, an increase of 45.0 percentage points. Before implementation, observed instruction was predominantly teacher-led; following implementation, a larger proportion of instructional time was allocated to student-centred activities. The findings address Research question 2 by documenting changes in instructional planning and observed classroom practices following the implementation of MMF-Gh. Lesson-plan scores were higher across all assessed criteria, and classroom observations showed increased time allocated to student-centred activities. These findings demonstrate pre-post differences without establishing that MMF-Gh alone caused the changes.

4.3 Differences in Students' Conceptual Understanding Scores in Algebra and Geometry Before and After the Implementation of MMF-Gh

Students' conceptual understanding in algebra and geometry was assessed before and after the implementation of MMF-Gh. The assessment covered algebraic reasoning, geometric visualization, problem-solving skills, and mathematical communication. Table 7 presents the pre- and post-test mean scores and the reported paired-samples t-test results.

Table 10: Pre- and Post-Test Scores on Assessed Dimensions of Students' Conceptual Understanding (N = 400)

Assessment area	Pre-test mean (%)	Post-test mean (%)	Mean difference (percentage points)	t-value	p-value
Algebraic reasoning	48.0	72.0	24.0	7.85	< .01
Geometric visualization	45.0	70.0	25.0	8.15	< .01
Problem-solving skills	38.0	68.0	30.0	9.02	< .01
Mathematical communication	42.0	65.0	23.0	6.95	< .01

As presented in Table 10, post-test mean scores were higher than pre-test mean scores across all four assessed areas. Algebraic reasoning increased from 48.0% to 72.0%, representing a difference of 24.0 percentage points ($t = 7.85$, $p < 0$ .01). Geometric visualization increased from 45.0% to 70.0%, a difference of 25.0 percentage points ($t = 8.15$, $p < 0.01$). Problem-solving skills recorded the largest mean difference, increasing from 38.0% to 68.0%, a difference of 30.0 percentage points ($t = 9.02$, $p < 0.01$). Mathematical communication increased from 42.0% to 65.0%, representing a difference of 23.0 percentage points ($t = 6.95$, $p < 0.01$). The reported paired-samples t-tests indicated statistically significant differences between pre- and post-test scores in each assessed area. These findings indicate that participating students obtained higher scores on the assessed dimensions of conceptual understanding following the implementation of MMF-Gh.

Table 11: Conditional Effect-Size and Confidence-Interval Calculations from the Student-Test Results

Assessment area	95% CI for mean difference	Cohen's d^z	95% CI for d^z
Algebraic reasoning	17.99–30.01	0.393	0.291–0.494

Geometric visualization	18.97–31.03	0.408	0.305–0.509
Problem-solving skills	23.46–36.54	0.451	0.348–0.554
Mathematical communication	16.49–29.51	0.348	0.246–0.448

Table 11 presents the magnitude and precision of the reported differences in student-test scores. Problem-solving skills recorded the largest calculated standardized difference ($d^z = 0.451$, 95% CI [0.348, 0.554]), followed by geometric visualization ($d^z = 0.408$, 95% CI [0.305, 0.509]) and algebraic reasoning ($d^z = 0.393$, 95% CI [0.291, 0.494]). Mathematical communication recorded the smallest calculated effect size ($d^z = 0.348$, 95% CI [0.246, 0.448]). All calculated confidence intervals for the mean differences were above zero, indicating positive estimated pre–post differences across the four assessed areas.

5. DISCUSSION

This study examined participating pre-service mathematics teachers' perceptions of mathematical modelling, changes in their instructional practices, and differences in students' conceptual-understanding scores following the implementation of MMF-Gh. The reported findings concern perceived importance, planned instruction, observed instructional time, and student performance within the participating settings.

Regarding Research question 1, 85.0% of participating pre-service teachers agreed or strongly agreed that mathematical modelling was important in mathematics teaching. This indicates favourable initial perceptions of its instructional relevance. However, recognizing its importance does not establish competence in designing or facilitating modelling activities. Guerrero-Ortiz and Borromeo Ferri (2022) found that pre-service teachers without modelling training tended to construct conventional word problems when attempting to develop modelling tasks. Their findings highlight the distinction between valuing modelling and understanding its instructional requirements. Accordingly, the present perception results support conclusions about perceived importance rather than confidence, familiarity, or preparedness.

For Research question 2, post-intervention lesson-plan scores were significantly higher across all assessed criteria ($p < .01$). Inclusion of real-world problems increased from 1.2 to 4.1, modelling-cycle implementation from 1.4 to 3.9, technology integration from 1.5 to 4.3, assessment variety from 1.8 to 3.7, and overall lesson-plan quality from 1.3 to 4.0. These differences indicate stronger representation of the assessed instructional features in post-intervention plans.

The calculated paired-samples effect sizes provide additional information about the magnitude of these differences. Overall lesson-plan quality had the largest standardized difference, $d^z = 1.349$, 95% CI [0.995, 1.697], followed by modelling-cycle implementation, $d^z = 1.203$, 95% CI [0.867, 1.533]. The corresponding values were 1.130 for real-world problem inclusion, 1.019 for technology integration, and 0.833 for assessment variety. These estimates describe differences relative to the variability of participants' change scores; they do not establish that MMF-Gh caused the differences. Their interpretation also depends on the consistency and validity of the lesson-plan scoring. The lesson-plan findings relate to the distinction identified by Erbas et al. (2014) between modelling as an instructional approach and modelling as an instructional objective.

Greater inclusion of modelling features in plans does not independently establish teachers' mastery of modelling. Similarly, the technology findings can be considered alongside Agyei et al. (2024), who reported limited transformative uses of digital technologies among Ghanaian senior high school mathematics teachers. Higher technology-integration ratings in the present study indicate stronger inclusion in planned instruction, but do not establish the quality of classroom use. Classroom observations provided complementary descriptive evidence. Teacher-led exposition decreased from 85.0% to 40.0% of observed instructional time, while student-centred activities increased from 15.0% to 60.0%. This represents a 45.0-percentage-point shift towards student-centred activities. However, time allocation alone does not establish the quality of participation, equitable involvement, or the extent to which activities involved mathematical modelling.

Regarding Research question 3, reported post-test scores were significantly higher across all four assessed dimensions ($p < 0.01$). Algebraic reasoning increased from 48.0% to 72.0%, geometric visualization from 45.0% to 70.0%, problem-solving from 38.0% to 68.0%, and mathematical communication from 42.0% to 65.0%. The mean differences ranged from 23.0 to 30.0 percentage points. The conditional standardized differences ranged from $d^z = 0.348$ to 0.451. Problem-solving recorded the largest estimate, $d^z = 0.451$, 95% CI [0.348, 0.554], followed by geometric visualization, $d^z = 0.408$, 95% CI [0.305, 0.509], and algebraic reasoning, $d^z = 0.393$, 95% CI [0.291, 0.494]. Mathematical communication had the smallest estimate, $d^z = 0.348$, 95% CI [0.246, 0.448]. These estimates describe within-student differences. The overlapping confidence intervals do not establish statistically significant differences between the four effect sizes.

The geometry findings provide a point of comparison with Kumazah and Agyei (2025), who reported favourable geometry outcomes following inquiry-based instruction in Ghanaian senior high schools. However, differences in instructional approaches, educational levels, research designs, and assessments limit direct comparison. The reported patterns are consistent with the study's constructivist emphasis on active engagement, representation, interpretation, and reflection. These theoretical connections offer possible interpretations rather than tested explanations of the score differences. The one-group pre-test–post-test design cannot separate MMF-Gh implementation from other explanations, including ordinary instruction, maturation, and familiarity with assessment tasks. Students' grouping within classes and schools also requires consideration when assessing statistical precision.

6. CONCLUSION

Most participating pre-service mathematics teachers perceived mathematical modelling as important before the implementation of MMF-Gh. Following implementation, lesson-plan scores were higher for real-world problem inclusion, modelling-cycle implementation, technology integration, assessment variety, and overall quality. Classroom observations also showed a greater proportion of instructional time allocated to student-centred activities. Students' post-test scores were significantly higher than their pre-test scores in algebraic reasoning, geometric visualization, problem-solving, and mathematical communication. These findings document changes in instructional practices and differences in student performance within the participating settings. The findings provide context-specific evidence for MMF-Gh.

7. RECOMMENDATIONS

1. Mathematics education lecturers in the participating colleges should incorporate guided modelling tasks into algebra and geometry teaching-methods courses. Lesson planning, microteaching, and feedback should address problem formulation, representation, validation, technology use, and assessment.
2. Mathematics education lecturers and teaching-practice supervisors should evaluate planned and observed instruction using explicit scoring criteria. Feedback should examine the quality of mathematical reasoning and participation alongside instructional time allocation.
3. Curriculum developers and mathematics teacher educators should develop locally relevant modelling tasks and exemplar lesson plans, with attention to learners' educational levels and available resources.
4. Mathematics teacher educators and JHS teachers should use clearly defined assessment criteria for algebraic reasoning, geometric visualization, problem-solving, and mathematical communication.

8. FUTURE RESEARCH DIRECTIONS

1. Future studies should use comparison-group designs and account for students' grouping within classes and schools.
2. Longitudinal research should examine whether differences in instructional practices and student performance persist.
3. Further research should examine how pre-service teachers interpret and implement individual MMF-Gh components.

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