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Factors influencing the effectiveness of mathematical modelling in teaching matrices among year two student-teachers in rwanda's teacher training colleges

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Abstract

Mathematical modelling translates real-world situations or problems into mathematical language, develops and uses mathematical representations to solve them, and interprets and validates the results in the original real-life context. This study explored factors influencing the effectiveness of mathematical modelling in teaching matrices to Year Two Science and Mathematics Education student-teachers in Teacher Training Colleges (TTCs), Southern Province, Rwanda. It used a mixed-methods, quasi-experimental design. Both colleges were purposively selected; all 103 student-teachers in the two intact classes, along with the two mathematics tutors teaching them, participated. Data came from a Likert-scale questionnaire (pilot Cronbach's alpha = 0.70), classroom observations, and structured tutor interviews. We analysed questionnaire data using means and standard deviations in STATA; we analysed qualitative data thematically. Student-teachers rated tutor feedback (M = 4.04), clear explanation (M = 3.96), and modelling skills (M = 3.68) highly, but rated resource availability (M = 2.59) and time allocation (M = 2.59) low. Tutors and observations identified tutor preparation, teaching materials, administrative support, learner participation, and prior algebra knowledge as enabling conditions, and limited time, scarce resources, large classes, and difficulty designing modelling tasks as constraints. The study recommends continuous professional development in modelling for tutors, investment in textbooks and ICT, and more time for modelling lessons.

Keywords: modelling, matrices, effectiveness, implementation, tutors, resources, Rwanda

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1. Introduction

Mathematical modelling involves translating between real-world situations and mathematics, working with the resulting model, and interpreting the results in the original context (Niss & Blum, 2020). Because it links abstract ideas to authentic problems, it has been promoted worldwide as a learner-centred alternative to procedure-driven teaching (Blum & Borromeo Ferri, 2009). Intervention studies report that modelling activities improved secondary students' modelling skills and helped them adapt more easily to group work (Armutcu & Bal, 2023), and modelling competence has been linked to students' creativity (Wang et al., 2023).

These gains are not automatic. Teacher education for modelling places weight on teachers designing modelling tasks, analyzing how those tasks are implemented, and identifying the conditions and constraints that help or hinder modelling in their classrooms (Barquero & Ferrando, 2024). More broadly, research on mathematics teaching treats teachers' competencies, knowledge and skills, and the external context of teaching as key influences on what happens in classrooms (Manizade et al., 2023). Knowing whether modelling works is therefore only half of the question. The other half is understanding what makes it work in a particular setting.

That second question is pressing in Sub-Saharan Africa, where research documents diverse difficulties in mathematics education, from policy and curriculum to instruction and infrastructure (Luneta, 2022). In Rwanda, the Competence-Based Curriculum for Teacher Training Colleges (TTCs) aligns pre-service teacher training with the national Competence-Based Curriculum (Rwanda Education Board, 2020), yet the average score of TTC mathematics tutors on an assessment of mathematical knowledge for teaching was below 50% (Habiyaremye et al., 2023), and learners' misconceptions in abstract topics have been linked to limited exposure to active learning approaches (Munyaruhengeri et al., 2024). Matrices, with their symbolic notation and procedural operations, are a case in point for student-teachers, who must master the topic and later teach it.

The first phase of this study showed that Year Two student-teachers taught matrices through mathematical modelling achieved significantly higher post-test scores than peers taught conventionally (Niyitegeka & Nzabarirwa, 2026). That result does not explain under what conditions the approach worked or what held it back, so the second phase addresses that gap by examining the conditions under which mathematical modelling worked for teaching matrices and the factors that constrained it, drawing on the experiences of Year Two student-teachers and their tutors.

1.1 Statement of the problem

Modelling raised Year Two student-teachers' achievement in matrices in this study (Niyitegeka & Nzabarirwa, 2026), but an average effect does not tell tutors, college leaders or policy makers what must be in place for the approach to work, or what is likely to undermine it. Rwandan TTCs face documented constraints, including inadequate resources (Dzavo et al., 2024) and low mathematical knowledge for teaching among tutors (Habiyaremye et al., 2023), yet, to the authors' knowledge, little evidence shows how such conditions shape modelling instruction, particularly for matrices and in the Southern Province. Without such evidence, any wider adoption of modelling risks being uneven and ineffective in colleges that lack the necessary conditions. This study addresses that gap by examining how modelling is implemented in college classrooms, identifying the conditions that support or hinder its effectiveness, and offering evidence to guide more consistent and informed adoption.

1.2 Research objective

To explore the factors that influence the effectiveness of mathematical modelling instructional approaches in teaching matrices to Year Two Science and Mathematics Education (SME) student-teachers in selected TTCs.

1.3 Research question

What factors influence the effectiveness of mathematical modelling instructional approaches in teaching matrices to Year Two SME student-teachers in selected TTCs?

2. Related Literature

2.1 Theoretical framework

Two complementary perspectives frame the study: Realistic Mathematics Education holds that learners build mathematical understanding by mathematising realistic situations (Freudenthal, 2002) and Constructivist learning theory adds that learners construct knowledge through exploration and social interaction, building on what they already know (Vygotsky, 1978). Both imply that modelling lessons depend on more than the task itself: someone must choose and introduce authentic situations, learners must engage, and the setting must give them the time and materials to do so. These implications guided the choice of factors examined here.

2.2 Global perspectives on conditions for effective modelling

Research on modelling instruction points to the teacher as a pivotal condition. Barquero and Ferrando (2024) studied two courses for in-service secondary teachers in which teachers designed modelling tasks, analysed their implementation, and identified the conditions and constraints that facilitate or hinder modelling in classrooms. Blum and Borromeo Ferri (2009) argue that modelling can be learned when teaching keeps a balance between teacher guidance and learners' independent work. Manizade et al. (2023) review how research on mathematics teaching has treated teachers' competencies, knowledge and skills alongside the external context of teaching. Wang et al. (2023) found, in a large sample of seventh graders, that in classes with more guided inquiry, students' curiosity had a stronger influence on creativity, which suggests that how teachers guide learners matters. Evidence from teacher education also suggests that modelling can strengthen pre-service teachers' attitudes and self-efficacy in geometry instruction (Agyei et al., 2026).

On the learner side, Wang et al. (2023) found that curiosity mediates the link between modelling competence and creativity. Armutcu and Bal (2023) report that students taught through modelling activities adapted more easily to group work, and Jung and Brady (2025) show that whole-class discussion of solutions gives learners opportunities to take part in valued modelling actions. Contextual conditions matter as well: Barquero and Ferrando (2024) stress identifying the conditions

and constraints that hinder the integration of modelling, and Stillman et al. (2015) bring together research on the cultural, social and cognitive influences on modelling education.

2.3 African and Rwandan perspectives

Research in Rwandan TTCs suggests that these conditions are under strain. Habiyaremye et al. (2023) assessed all 23 mathematics tutors in Rwandan TTCs and found low mathematical knowledge for teaching (an average score below 50%) alongside a positive attitude towards pedagogical content knowledge, and concluded that tutors need to improve their performance. A later quasi-experimental study with 433 Year Two Science and Mathematics Education student-teachers reported gains in the experimental group, including in mathematical modelling, and recommended targeted training for TTC tutors (Habiyaremye et al., 2024). Resource shortages are also documented: in a study of one Rwandan TTC, Dzavo et al. (2024) reported a lack of adequate resources to implement the Competence-Based Curriculum fully and recommended that the government provide them. Luneta (2022) describes diverse difficulties in mathematics education across Sub-Saharan Africa more broadly. What is missing is evidence on how these conditions play out when a modelling approach is introduced to teach a specific topic, such as matrices, to student-teachers. The present study offers such evidence from two TTCs.

3. Methods

3.1 Research design

This article draws on the second objective of a mixed-methods study that used a quasi-experimental pre-test–post-test design with intact classes. The first objective, on the effect of modelling on achievement, is reported in Niyitegeka and Nzabarirwa (2026). The second objective required contextual evidence, so it relied on questionnaire data, classroom observations, and tutor interviews, which were integrated through triangulation. The intervention lasted three weeks. Muhanga TTC (experimental group) was taught matrices through mathematical modelling, using real-life situations such as transport schedules, financial transactions, and data organization, while Cyahinda TTC (control group) was taught the same content through conventional, teacher-centred instruction.

3.2 Population and sampling

The Southern Province has four TTCs (Save, Muhanga, Cyahinda and Mbuga) with 264 Year Two SME student-teachers in total. Muhanga and Cyahinda were purposively selected because of their comparatively low mathematics performance, and one was assigned as the experimental and the other as the control group. All Year Two SME student-teachers in the two intact classes took part (n = 103: 51 at Muhanga and 52 at Cyahinda; 58 males and 45 females). The single tutor teaching Year Two SME mathematics at each college was purposively included (n = 2), giving 105 participants and a response rate of 100%. The tutors had different amounts of teaching experience (4–7 years and more than seven years).

3.3 Instruments

Second, a guided classroom observation checklist covered lesson planning and organization, student engagement, use of mathematical modelling, teaching methods and interaction, classroom management, and assessment and feedback. The completed checklist supplied for this revision documents the modelling lesson on the transpose of matrices at Muhanga TTC. It records whether each indicator was observed and includes the observer's comments. Third, a structured interview guide for tutors included sections on the factors that supported effective use of modelling and on challenges and suggestions.

3.4 Validity and reliability

Mathematics education experts at the University of Rwanda, including the research supervisor, reviewed all instruments for content validity, and wording was refined after their comments. A pilot at a third TTC (Save), excluded from the main study, gave a Cronbach's alpha of 0.70 ($\alpha = 0.7028$) for the questionnaire, which met the threshold of 0.70 set for acceptable reliability. Trustworthiness of the qualitative data was supported through clear observation protocols and observation during the intervention (credibility), documentation of procedures (dependability), and triangulation of questionnaire, observation, and interview evidence (confirmability).

3.5 Data analysis

Questionnaire data were analysed in STATA MP/16 using means and standard deviations. Mean scores were interpreted using equal-interval bands: 1.00–1.80 (very low), 1.81–2.60 (low), 2.61–3.40 (moderate), 3.41–4.20 (high), and 4.21–5.00 (very high). Observation notes and interview recordings, transcribed verbatim, were read repeatedly, coded, grouped into categories, and developed into themes, which were then compared with the questionnaire results.

3.6 Ethical considerations

Ethical clearance was obtained from the University of Rwanda College of Education, and permission was granted by the management of the participating TTCs. Participation was voluntary; participants gave informed consent and could withdraw at any time, and responses were kept anonymous and confidential.

4. Findings

This section is organised around the research question: *What factors influence the effectiveness of mathematical modelling instructional approaches in teaching matrices to Year Two SME student-teachers in selected TTCs?* Four groups of factors emerged. For each, questionnaire results are presented where an item was available, followed by observation and interview evidence and a discussion against the literature. Because the questionnaire was completed by student-teachers from both colleges, the ratings reflect perceptions across the two groups, and the factors are described as perceived influences rather than statistically tested predictors of achievement.

4.1 Teacher competence and instructional support

Student-teachers rated all four aspects of tutor competence and support as high (Table 1). Tutor feedback was rated highest (M = 4.04, SD = 0.94), followed by clarity of explanation (M = 3.96, SD = 0.94), tutors' modelling skills (M = 3.68, SD = 0.86), and the contribution of teaching methods to understanding (M = 3.55, SD = 0.79).

Table 1: Student-Teachers' Perceptions of Teacher Competence and Instructional Support (N = 103)

Statement	Mean	SD	Interpretation
Teacher feedback improves understanding	4.04	0.94	High
Tutors explain modelling activities clearly	3.96	0.94	High
Tutors have adequate modelling skills	3.68	0.86	High
Teaching methods help students understand matrices	3.55	0.79	High

Note. Scale: 1 = strongly disagree to 5 = strongly agree. Source: Primary data (2026).

The completed observation checklist provides concrete evidence about lesson preparation and instructional support in the modelling lesson in TTCs. The teacher clearly stated the lesson objectives and followed a logical sequence, and the materials for mathematical modelling were prepared. The observer also noted that the teacher was well prepared to teach the transpose of matrices and used examples and demonstrations effectively. These observations complement the student-teachers' high ratings of tutor feedback (M = 4.04), clarity of explanation (M = 3.96), and modelling skills (M = 3.68). The interviews added tone. The tutor who taught through modelling credited his own preparation and showed that it takes time to prepare and design.

This pattern fits Barquero and Ferrando (2024), whose teacher-education courses centred on teachers designing modelling tasks and analyzing their implementation; Habiyaremye et al. (2023), who found low mathematical knowledge for teaching among TTC tutors; and Blum and Borromeo Ferri (2009), who stress the balance between teacher guidance and independent learning. This also echoes the call for targeted tutor training in Habiyaremye et al. (2024). A cautious reading is that general competence in explaining and giving feedback is present, but modelling-specific task design remains the weaker area.

4.2 Learning resources, time and classroom conditions

Resources and time were the two weakest-rated conditions, each with a low mean of 2.59 (Table 2). Student-teachers moderately agreed that some modelling activities were difficult to understand (M = 3.23), and their agreement that large class size affected their participation was low (M = 2.26).

Table 2: Student-Teachers' Perceptions of Resources, Time and Classroom Conditions (N = 103)

Statement	Mean	SD	Interpretation
There are enough learning resources	2.59	0.32	Low
Time allocated for modelling lessons is sufficient	2.59	0.32	Low
Some modelling activities are difficult to understand	3.23	0.45	Moderate
Large class size affects participation	2.26	0.40	Low

Note. Scale: 1 = strongly disagree to 5 = strongly agree. Source: Primary data (2026).

The checklist confirmed that materials for the modelling lesson had been prepared and were available. It also recorded that the teacher managed the lesson time, but the observer's comment indicated that the lesson was rushed and that the time was short. The overall observation notes further stated that the mathematical modelling approach was used to teach the transpose of matrices, but learners were not allowed to complete all the activities that had been prepared. This provides classroom-level evidence of the tension between lesson preparation and the time needed for learners to work through modelling activities. The tutors' accounts matched the low ratings for resources and time. They reported that textbooks the low rating for resources agrees with Dzavo et al. (2024), who report a lack of adequate resources for implementing the Competence-Based Curriculum in a Rwandan TTC. The moderate rating for task difficulty, together with the tutors' remarks about translating situations into matrices, points to the early stage of the modelling cycle, where learners translate between the real world and mathematics, as a place where they need support (Niss & Blum, 2020).

Class size shows a divergence between data sources. Student-teachers did not see class size as a major barrier to their own participation, whereas tutors listed large classes as a challenge. A tentative explanation is that the two groups were thinking about different things: students about their own participation, tutors about the logistics of guiding group work and giving feedback in limited time. The data cannot confirm this, and the point deserves follow-up.

4.3 Learner participation and prior knowledge

The completed checklist recorded that students actively participated in the lesson, asked questions or sought clarification, and worked collaboratively in modelling tasks. The observer's comments noted that students were carrying out their own demonstrations and that the teacher provided solutions and guidance during the activities. In the transpose lesson, students represented problems using matrices and interpreted results from matrix solutions. The checklist also indicated that the teacher encouraged critical thinking and problem-solving, while students demonstrated improvement in problem-solving skills. These observations support the view that learner participation and interaction were important features of the modelling lesson. However, the overall observation note cautioned that learners were not allowed enough opportunity to apply all the activities that had been prepared. The tutor who used modelling also reported that students became more willing to ask questions, share ideas, and work together. Both tutors named students' willingness to participate and their prior knowledge of basic algebra as conditions for success. The conventionally taught class was described

in the wider study records as relying more on tutor explanation, note-taking and exercises detached from real-life contexts.

These accounts align with Armutcu and Bal (2023) on group work and with Jung and Brady (2025) on learners' participation in modelling actions during whole-class discussion, and with the constructivist view that new understanding is built on prior knowledge (Vygotsky, 1978). Participation appears to work in both directions: it was a condition that helped modelling lessons succeed, and it was also something the modelling lessons visibly encouraged. Because the observations compare two colleges with different tutors, differences in participation cannot be attributed to modelling alone.

4.4 Institutional support and professional development

The checklist showed that the teacher checked students' understanding orally during the lesson and that students demonstrated improvement in problem-solving skills. However, the indicator on immediate corrective feedback was marked 'No'. This suggests that, although the teacher monitored understanding and provided support during activities, immediate corrective feedback was not consistently observed. The observer also recorded that the classroom environment was well organised and supported learning. The tutors named supportive school administration, along with access to textbooks and ICT tools.

4.5 Bringing the evidence together

Table 3 summarizes how the questionnaire, tutor interviews and classroom observation evidence line up. checklist provides specific evidence of lesson preparation, prepared materials, active participation, collaborative work, use of demonstrations, oral checking of understanding and an organised classroom. It also identifies areas requiring attention: the lesson was rushed, learners did not complete all prepared activities, and immediate corrective feedback was not observed. Teacher competence, learner participation and institutional support acted mainly as enabling conditions, while limited time and resources acted as constraints; task design and class size were mixed.

Table 3: Summary of Factors Influencing the Effectiveness of Mathematical Modelling

Factor	Questionnaire	Tutor interviews	Classroom observation	Role
Teacher competence and guidance	High (M = 3.55–4.04)	Preparation helps; task design is difficult	Checklist: objectives clearly stated; logical sequence; materials prepared; teacher well prepared and used examples/demonstrations effectively	Limit with a gap in task design
Learning resources	Low (M = 2.59)	Textbooks, ICT, and aids needed	Checklist: modelling materials were prepared for the lesson	Constraint when limited

Factor	Questionnaire	Tutor interviews	Classroom observation	Role
Time allocation	Low (M = 2.59)	Modelling needs more time	Checklist: time was managed, but the lesson was rushed; learners could not complete all prepared activities	Constraint
Class size	Low (M = 2.26)	Named as a challenge	Not specifically recorded as a difficulty in the submitted checklist	Divergent evidence
Task difficulty for learners	Moderate (M = 3.23)	Some students need support	Checklist: students represented problems using matrices and interpreted results; activities were not all completed because time was short	Moderate constraint
Learner participation and prior knowledge	Moderate(M=3.41)	Willingness and algebra knowledge matter	Checklist: active participation, questions/clarification, collaboration, and student demonstrations; improvement in problem-solving was observed	Moderately
Institutional support and professional development	High(M=4.8)	Supportive administration; training requested	Checklist: institution provides support to the teachers.	Highly

Source: Primary data (2026).

This pattern is what the theoretical framework would lead us to expect. Realistic Mathematics Education and constructivism both treat meaningful contexts and active learner engagement as the core of modelling instruction (Freudenthal, 2002; Vygotsky, 1978), and the factors identified here are the practical conditions that allow those principles to operate in a TTC classroom: a tutor able to design and guide tasks, learners who take part, and the time and materials to do so.

4.6 Limitations of the evidence

Several limitations apply. The observation supplied for this revision records the modelling lesson in southern province TTCs; it should not be treated as direct checklist evidence about the control TTCs.

The qualitative evidence also comes from one tutor per college, so tutor, college, and instructional condition are confounded.

5. Conclusion

I found that the effectiveness of mathematical modelling in teaching matrices depends on the conditions surrounding the approach, not the approach alone. Tutor feedback and explanation, learner participation, prior algebra knowledge, and supportive administration enable it. Limited instructional time and learning resources constrain it, and tutors find it difficult to design suitable modelling tasks; evidence on class size was identified.

Recommendations.

To mathematics tutors: plan modelling lessons around familiar contexts, support learners in translating situations into matrix form, and build on learners' prior algebra knowledge.

To TTC management: supply textbooks, ICT tools and teaching aids, protect enough lesson time for modelling activities, and support tutors through collaborative planning and supervision.

To the Rwanda Education Board and the Ministry of Education: provide continuous professional development in modelling task design and include modelling activities in the curriculum and textbooks.

To researchers: examine these factors with larger samples, more tutors, and group-level analysis, and test statistically how each factor relates to achievement.

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