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# Effects of Mathematical Modelling Instruction on Achievement in Matrices among Year Two Student-Teachers in Rwanda

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***Abstract:*** *Mathematical modelling has been widely recognized as a learner-centred instructional approach that promotes conceptual understanding and problem-solving in mathematics. However, limited empirical evidence exists on its effectiveness in improving student-teachers' achievement in matrices in Teacher Training Colleges (TTCs) in Rwanda. This study investigated the effect of mathematical modelling instruction on Year Two Science and Mathematics Education student-teachers' achievement in matrices in selected TTCs in Rwanda. A quasi-experimental pre-test–post-test control group design was employed. The experimental group was taught matrices using mathematical modelling activities grounded in real-life contexts, whereas the control group received conventional instruction over a three-week intervention period. Data were collected using a researcher-developed achievement test administered before and after the intervention. Descriptive statistics and independent- and paired-samples* t*-tests were used to analyse the data. The findings indicated no statistically significant difference between the groups at the pre-test stage, confirming comparable baseline achievement. Following the intervention, the experimental group achieved a significantly higher post-test mean score* ($M = 60.64, SD = 9.57$) *than the control group* ($M = 50.30, SD = 8.83$), $\mathrm{t}(101) = -5.70, \mathrm{p} < .001$. *The experimental group also demonstrated a significantly greater improvement between pre-test and post-test scores than the control group. The study concludes that mathematical modelling instruction significantly enhances student-teachers' achievement in matrices. It is recommended that mathematical modelling be integrated into mathematics instruction and teacher education programs to strengthen conceptual understanding and improve learning outcomes.*

***Keywords:*** *Mathematical modelling, Achievement, matrices, Student-teachers, Teacher Training Colleges, Mathematics education.*

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## 1. Introduction

Mathematics plays a vital role in developing logical reasoning, critical thinking, and problem-solving skills that are essential for academic success and everyday life (Carreira & Blum, 2021; Stillman et al., 2015). However, many learners continue to experience difficulties in understanding abstract mathematical concepts, particularly when instruction emphasizes procedural knowledge rather than conceptual understanding (Prabawanto et al., 2024).

Accordingly, there is an improving need for instructional approaches that actively engage students in meaningful learning experiences and improve the application of mathematical knowledge to real-world situations. Mathematical modelling has emerged as an effective learner-centred instructional approach that enables learners to connect abstract mathematical concepts with authentic real-life situations (Carreira & Blum, 2021; Stillman et al., 2015). Through mathematical modelling, learners formulate mathematical representations of practical problems, apply mathematical procedures, interpret solutions, and evaluate their appropriateness within the original context. This process promotes conceptual understanding, mathematical reasoning, and problem-solving skills, making mathematics more meaningful and relevant to learners' experiences (Freudenthal, 2002).

Several studies have reported positive effects of mathematical modelling on students' achievement in mathematics. Özer-Demir and Bukova-Güzel (2024) and Wang et al. (2023), found that learners exposed to modelling-based instruction achieved significantly higher academic performance and demonstrated stronger problem-solving abilities than those taught through conventional instructional approaches. Despite this evidence, limited empirical research has examined the effectiveness of mathematical modelling in Teacher Training Colleges in Rwanda, particularly in the teaching and learning of matrices.

Matrices constitute an important topic in mathematics education because they provide a foundation for solving systems of equations, data organization, transformations, and various real-life applications. However, student-teachers often encounter difficulties in understanding matrix concepts due to their abstract nature and the predominance of traditional teaching approaches. Given the role of Teacher Training Colleges in preparing future mathematics teachers, it is important to identify instructional approaches that can enhance student-teachers' achievement and conceptual understanding.

Therefore, this study investigated the effect of mathematical modelling instruction on Year Two Science and Mathematics Education student-teachers' achievement in matrices in selected Teacher Training Colleges in Rwanda. Specifically, the study compared the achievement of student-teachers taught through mathematical modelling instruction with those taught using conventional instructional approaches.

Mathematical modelling has gained increasing attention in mathematics education as an instructional approach that enables learners to connect mathematical concepts with real-world situations. Mathematical modelling involves identifying problems from authentic contexts, formulating mathematical representations, analyzing relationships, interpreting solutions, and validating results within the original context. Through this process, learners actively engage in problem-solving and develop conceptual understanding of mathematical ideas (Carreira & Blum, 2021). The approach aligns with contemporary learner-centred pedagogies that emphasize critical thinking, creativity, and the application of knowledge to practical situations.

The theoretical foundation of mathematical modelling can be explained through Realistic Mathematics Education (RME) and Constructivist Learning Theory. Realistic Mathematics Education, developed by Freudenthal (2002), posits that mathematics should be taught through meaningful contexts that enable learners to construct mathematical knowledge from realistic situations. According to this perspective, learners develop a deeper understanding when they engage in the process of mathematization, moving from real-life experiences to formal mathematical representations. Similarly, Constructivist Learning Theory suggests that knowledge is actively constructed through interaction, exploration, reflection, and collaboration rather than passively received from the teacher (Stillman et al., 2015). In mathematical modelling activities, learners are encouraged to investigate contextual problems, formulate mathematical models, test solutions, and evaluate outcomes, thereby promoting meaningful learning and conceptual understanding.

Empirical evidence indicates that mathematical modelling positively influences learners' achievement in mathematics. Özer-Demir and Bukova-Güzel (2024) found that students exposed to modelling-based instruction achieved significantly higher academic performance and mathematical literacy than those taught through conventional approaches. The study attributed these improvements to learners' active participation in authentic mathematical investigations that enhanced conceptual understanding. Similarly, Wang et al. (2023) reported that mathematical modelling instruction significantly improved students' problem-solving abilities, analytical thinking, and application of mathematical concepts in real-life contexts.

Other studies have produced comparable findings. Armutcu and Bal (2023) observed that integrating mathematical modelling into mathematics instruction enhanced learners' mathematical competencies, collaboration skills, and higher-order thinking abilities. Likewise, Patullayeva (2022) found that students who learned through modelling-oriented instruction demonstrated better mathematical reasoning and academic achievement than those taught using traditional approaches. These findings suggest that mathematical modelling promotes active engagement with mathematical concepts and supports deeper understanding than conventional teacher-centred methods.

Despite the growing body of evidence supporting mathematical modelling, most studies have been conducted in Europe, North America, and Asia. Empirical studies examining the effectiveness of mathematical modelling in African educational contexts remain relatively limited, particularly within teacher education institutions. In Rwanda, existing studies have largely focused on learner-centred pedagogy, implementation of the Competency-Based Curriculum, and general mathematics teaching practices, with limited attention given to the effectiveness of mathematical modelling in improving achievement in specific mathematical topics. Furthermore, little empirical evidence exists regarding the teaching and learning of matrices through mathematical modelling in Teacher Training Colleges.

The reviewed literature suggests that mathematical modelling has considerable potential to improve mathematics achievement by promoting conceptual understanding and problem-solving skills. However, the limited evidence from Rwandan Teacher Training Colleges, particularly in the teaching of matrices, reveals an important knowledge gap. This study therefore sought to determine the effect of mathematical modelling instruction on Year Two Science and Mathematics Education student-teachers' achievement in matrices in selected Teacher Training Colleges in Rwanda.

This study investigated the effects of mathematical modelling on Year Two student-teachers' achievement in matrices in Teacher Training Colleges (TTCs) in Rwanda's Southern Province. In Rwanda, where education is central to national development goals such as Vision 2050, improving mathematics performance remains a key priority, particularly in TTCs that prepare future educators.

Mathematical modelling involves representing real-world phenomena with mathematical concepts, analyzing them, and interpreting results, bridging the gap between abstract mathematics and practical applications (Carreira & Blum, 2021). Historically, (Freudenthal, 2002) emphasized that students learn mathematics effectively when they mathematize realistic contexts, forming the foundation of Realistic Mathematics Education. Research indicates that the success of modelling depends on teachers' pedagogical knowledge and skills, including their ability to design, implement, and scaffold modelling tasks (Barquero & Ferrando, 2024).

A growing body of empirical research has demonstrated the positive impact of mathematical modelling on mathematics achievement. The studies have shown that modelling-based instruction improves learners' conceptual understanding, mathematical literacy, problem-solving ability, creativity, and academic performance compared with conventional instructional approaches (Armutcu & Bal, 2023; Özer-Demir & Bukova-Güzel, 2024; Wang et al., 2023). By engaging learners in authentic tasks that require them to analyse, represent, solve, and interpret mathematical problems, modelling transforms mathematics from an abstract subject into a practical tool for addressing everyday challenges.

Although mathematical modelling has received considerable attention internationally, its implementation varies across educational contexts. European countries, particularly the Netherlands and Germany, have played a leading role in integrating modelling into mathematics education through Realistic Mathematics Education and related instructional frameworks (Carreira & Blum, 2021; Freudenthal, 2002). Similar efforts have been reported in several Asian countries, where modelling is incorporated into mathematics curricula to strengthen learners' problem-solving competencies and application of mathematical knowledge (Xu, 2016). In contrast, empirical evidence from African countries remains relatively limited, especially within teacher education institutions. Existing studies have largely focused on school mathematics and teacher preparation, leaving important gaps regarding the effectiveness of modelling instruction in preparing future mathematics teachers (Jacobs & Durandt, 2016; Jakobsen & Mhakure, 2024).

In Rwanda, the Competency-Based Curriculum advocates learner-centred pedagogies that encourage critical thinking, problem-solving, and the application of knowledge to real-life situations (REB, 2020). Despite these policy aspirations, mathematics instruction in many classrooms continues to rely predominantly on teacher-centred approaches that emphasize procedural knowledge rather than conceptual understanding (Hurrell, 2021). Therefore, student-teachers often experience difficulties in learning abstract mathematical topics, including matrices, which require learners to interpret symbolic representations, perform matrix operations, and apply these concepts to solve contextual problems (Munyaruhengeri et al., 2024). Such challenges may limit their achievement and their future capacity to teach mathematics effectively.

While previous international studies consistently report positive effects of mathematical modelling on mathematics learning, little empirical evidence exists regarding its effectiveness in Teacher Training Colleges in Rwanda, particularly in the teaching of matrices. No published study has specifically examined whether mathematical modelling instruction improves the achievement of Year Two Science and Mathematics Education student-teachers in matrices within Teacher Training Colleges in Rwanda's Southern Province. Addressing this gap is important because these institutions prepare future mathematics teachers whose instructional practices will influence mathematics learning in schools. Therefore, this study investigated the effect of mathematical modelling instruction on Year Two student-teachers' achievement in matrices in selected Teacher Training Colleges in Rwanda.

## 1.1 Problem Statement

Despite the emphasis of Rwanda's Competency-Based Curriculum on learner-centred and problem-solving approaches, the teaching of mathematics in many Teacher Training Colleges (TTCs) remains largely teacher-centred, with greater emphasis on procedural knowledge than on conceptual understanding (Chari, 2025). As a result, student-teachers continue to experience difficulties in learning abstract mathematical topics such as matrices, which require logical reasoning, symbolic manipulation, and the application of mathematical concepts to real-world situations. Previous studies have reported persistent challenges in mathematics achievement among Rwandan student-teachers and identified limitations in the implementation of innovative instructional approaches that promote meaningful learning (Habiyaremye et al., 2023).

Although mathematical modelling has been shown in several international studies to improve learners' conceptual understanding, problem-solving skills, and mathematics achievement, most of this evidence originates from Europe and Asia, with limited empirical research conducted in African teacher education contexts. Furthermore, no published study has specifically examined the effect of mathematical modelling instruction on Year Two Science and Mathematics Education student-teachers' achievement in matrices in Teacher Training Colleges in Rwanda. This knowledge gap limits evidence-based decisions regarding the adoption of modelling-based instruction in teacher education. Therefore, this study investigated the effect of mathematical modelling instruction on Year Two student-teachers' achievement in matrices in selected Teacher Training Colleges in Rwanda.

## 1.2 Research Objectives

The study generally aimed to determine the effect of mathematical modelling instruction on Year Two Science and Mathematics Education student-teachers' achievement in matrices in selected Teacher Training Colleges in Rwanda. Specifically, the study sought to:

1. Compare the pre-test achievement of student-teachers in matrices between the experimental and control groups before the intervention.
2. Compare the post-test achievement of student-teachers in matrices between those taught through mathematical modelling instruction and those taught using conventional instructional approaches.
3. Determine whether mathematical modelling instruction significantly improves student-teachers' achievement in matrices compared with conventional instructional approaches.

The study sought to answer the following research questions:

1. Is there a significant difference in the pre-test achievement of student-teachers in matrices between the experimental and control groups before the intervention?
2. Is there a significant difference in the post-test achievement of student-teachers in matrices between student-teachers taught through mathematical modelling instruction and those taught using conventional instructional approaches?
3. Does mathematical modelling instruction significantly improve student-teachers' achievement in matrices compared with conventional instructional approaches?

# 2. Literature Review

## 2.1 Theoretical Review

This study was guided by Realistic Mathematics Education (RME) and Constructivist Learning Theory, which together provide a theoretical basis for understanding how mathematical modelling instruction can enhance student-teachers' achievement in matrices.

Realistic Mathematics Education (RME), developed by (Freudenthal, 2002), posits that mathematics should be taught through meaningful real-life contexts that enable learners to construct mathematical ideas from authentic situations. Rather than viewing mathematics as a collection of abstract rules, RME encourages learners to engage in the process of mathematization by identifying problems, developing mathematical models, solving them, and interpreting the results within their original contexts. In the teaching of matrices, this perspective enables student-teachers to relate matrix concepts and operations to practical situations, thereby promoting conceptual understanding and improving problem-solving skills.

Constructivist Learning Theory complements RME by emphasizing that learners actively construct knowledge through exploration, interaction, reflection, and collaboration rather than passively receiving information (Stillman et al., 2015). Within mathematical modelling instruction, student-teachers collaboratively investigate contextual problems, formulate mathematical representations, test solution strategies, and evaluate the reasonableness of their results. Such learner-centred experiences foster deeper conceptual understanding, critical thinking, and meaningful learning, which are expected to enhance academic achievement.

The integration of RME and Constructivist Learning Theory provides a strong theoretical foundation for this study. While RME explains the importance of contextualizing mathematical ideas through modelling, Constructivist Learning Theory explains how active engagement in modelling activities promotes knowledge construction. Together, these theories support the proposition that mathematical modelling instruction is more likely to improve student-teachers' achievement in matrices than conventional teacher-centred instructional approaches.

## 2.2 Empirical Review

Empirical studies have consistently demonstrated that mathematical modelling is an effective instructional approach for improving learners' achievement in mathematics. Across different educational contexts, modelling-based instruction has been associated with enhanced conceptual understanding, mathematical reasoning, problem-solving skills, and the ability to apply mathematical knowledge to real-life situations.

Özer-Demir & Bukova-Güzel, (2024) found that students who learned through mathematical modelling achieved significantly higher academic performance and mathematical literacy than those taught using conventional instructional approaches. The study attributed these improvements to learners' active engagement in authentic mathematical investigations that promoted conceptual understanding. Similarly, (Wang et al., 2023) reported that mathematical modelling instruction significantly improved students' problem-solving ability, analytical thinking, creativity, and interpretation of mathematical solutions in real-world contexts. The authors argued that modelling enables learners to formulate mathematical representations of practical problems, solve them systematically, and evaluate the appropriateness of their solutions.

Comparable findings have been reported by (Armutcu & Bal, 2023), who observed that integrating mathematical modelling within STEM education enhanced students' mathematical competencies, collaboration, and higher-order thinking skills. Likewise, (Patullayeva, 2022) found that learners exposed to modelling-oriented instruction demonstrated significantly better mathematical reasoning and academic achievement than those taught through conventional methods. These improvements were attributed to the learner-centred nature of modelling activities, which encourage exploration, discussion, and reflective thinking.

Despite this growing body of evidence, most empirical studies have been conducted in Europe and Asia, with relatively few investigations undertaken in African educational contexts. In Rwanda, existing research has primarily examined the implementation of the Competency-Based Curriculum, teachers' pedagogical knowledge, and general mathematics teaching practices, with limited attention given to the effectiveness of mathematical modelling as an instructional approach in Teacher Training Colleges. Furthermore, little empirical evidence exists on the teaching and learning of matrices through mathematical modelling, despite matrices being a fundamental topic in teacher education that requires strong conceptual understanding and problem-solving skills. The reviewed studies collectively suggest that mathematical modelling has considerable potential to improve mathematics achievement. However, the limited evidence from Rwandan Teacher Training Colleges, particularly regarding the teaching of matrices, indicates an important knowledge gap. This study therefore sought to determine the effect of mathematical modelling instruction on Year Two Science and Mathematics Education student-teachers' achievement in matrices in selected Teacher Training Colleges in Rwanda.

# 3. Methodology

A quantitative research approach employing a quasi-experimental pre-test–post-test control group design was adopted to determine the effect of mathematical modelling instruction on Year Two Science and Mathematics Education (SME) student-teachers' achievement in matrices. The study was conducted in two selected Teacher Training Colleges (TTCs) in Rwanda's Southern Province, namely Muhanga and Cyahinda TTCs. The colleges were purposively selected because of their relatively low performance in mathematics. Intact Year Two SME classes were used, comprising a sample of 103 student-teachers, with 51 students in the experimental group and 52 students in the control group. The experimental group was taught matrices using mathematical modelling instruction, while the control group received conventional instructional approaches over a three-week intervention period. Ethical approval and permission to conduct the study were obtained from the University of Rwanda and districts in the southern province where the data were collected. Participation was voluntary, informed consent was obtained from all participants, and confidentiality and anonymity were maintained throughout the study. Data were collected using a researcher-developed Mathematics Achievement Test administered as both a pre-test and a post-test. The instrument was validated by experts in mathematics education. Quantitative data obtained from the pre-test and post-test achievement tests were entered into STATA MP/16 for analysis. Descriptive statistics, including means and standard deviations, were used to summarise student-teachers' achievement scores for the experimental and control groups. Inferential statistics, comprising independent samples *t*-tests and paired samples *t*-tests, were employed to determine whether there were statistically significant differences in achievement between and within the groups. Statistical significance was determined at the 0.05 level.

# 4. Results and Discussion

To compare the achievement of Year Two Science and Mathematics Education student-teachers in matrices taught through mathematical modelling instruction and those taught using conventional instructional approaches, the equivalence of the experimental and control groups was first established using pre-test scores. Descriptive statistics, including means and standard deviations, were computed to compare the achievement levels of the two groups before the intervention. The pre-test results are presented in Table 1.

**Table 1: Pre-Test Scores of Experimental and Control Groups**

| **Group** | N | Mean | **Standard Deviation** |
|---|---|---|---|
| Experimental group | 51 | 39.909 | 12.54 |
| Control group | 52 | 37.51 | 9.99 |

**Source:** Primary data, May 2026.

The findings in Table 1 show that the experimental group obtained a mean pre-test score of 39.91 (SD = 12.54), while the control group obtained a mean score of 37.51 (SD = 9.99). The difference between the two mean scores was relatively small, suggesting that the two groups had comparable levels of prior knowledge in matrices before the intervention. Both groups showed a moderate spread of scores, meaning students within each group did not all perform at the same level. Since they started roughly similarly, comparing the effects of mathematical modelling and conventional teaching on their matrix work is a fair comparison.

## 4.1 Effect of Mathematical Modelling Instruction on Student-Teachers' Achievement in Matrices

**Post-Test Mean Scores for Experimental and Control Groups**

Following the completion of the instructional intervention, the post-test was administered to both the experimental and control groups to assess students' achievement in matrices. The post-test means scores and standard deviations were computed to provide a descriptive comparison of the academic achievement of the two groups before conducting the independent samples *t*-test. The results are presented in Table 2.

**Table 2: Post-Test Scores of Experimental and Control Groups**

| **Group** | N | Mean | **Standard Deviation** |
|---|---|---|---|
| Experimental group | 51 | 60.64 | 9.57 |
| Control group | 52 | 50.30 | 8.83 |

Source**:** Primary data, May 2026.

Table 2 presents the post-test mean scores and standard deviations for students in the experimental and control groups after the instructional intervention. The results show that students in the experimental group achieved a higher mean score (M = 60.64, SD = 9.57) than those in the control group (M = 50.30, SD = 8.83).

The difference of 10.34 points between the two groups suggests that students who were taught using the mathematical modelling instructional approach performed better in matrices than those who were taught using the conventional teaching approach. This indicates that mathematical modelling may have enhanced students' understanding and application of matrix concepts.

Both groups had fairly similar standard deviations (9.57 versus 8.83), so scores were spread out to roughly the same degree in each. The experimental group also posted a higher mean, which hints that mathematical modelling may have helped students understand matrices better.

## 4.2 Independent samples t-Test for Post-Test Scores in two groups

In line with the first research objective, which sought to determine the effect of mathematical modelling instructional approaches on Year Two student-teachers' achievement in matrices, an independent-samples *t*-test was performed to compare the post-test mean scores of the experimental group named (1) and the control group named (0). The purpose of the analysis was to establish whether the observed difference in achievement between the two groups after the intervention was statistically significant. The results are presented in table 3.

**Table 3: Independent samples t-Test for Post-Test Scores in two groups**

*Two-sample t-test with equal variances*

| Group | Obs | Mean | Std. Err. | Std. Dev. | [95% Conf. Interval] | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| 0 (Control) | 52 | 50.30769 | 1.225218 | 8.835176 | 47.84796 | 52.76742 |
| 1 (Experimental) | 51 | 60.64706 | 1.340712 | 9.574599 | 57.95416 | 63.33996 |
| Combined | 103 | 55.42718 | 1.037889 | 10.53342 | 53.36854 | 57.48583 |
| Difference (0 – 1) | | -10.33937 | 1.814796 | | -13.93943 | -6.739299 |

diff = mean(0) – mean(1) t = -5.6973

Ho: diff = 0 degrees of freedom = 101

| Ha: diff < 0 | Ha: diff ≠ 0 | Ha: diff > 0 |
|---|---|---|
| Pr(T < t) = 0.0000 | Pr(\|T\| > \|t\|) = 0.0000 | Pr(T > t) = 1.0000 |

*Note*. Group 0 = Control group (Conventional instruction); Group 1 = Experimental group (Mathematical modelling instruction).

Table 3 shows the results of post-tests in both groups. An independent-samples $t$-test was conducted to determine whether there was a statistically significant difference in post-test achievement scores between Year Two student-teachers who were taught matrices using mathematical modelling instructional approaches (experimental group) and those who were taught using conventional instructional approaches (control group). As presented in table 3, the experimental group ($n = 51$) obtained a higher mean post-test score ($M = 60.65, SD = 9.57$) than the control group ($n = 52$), which recorded a mean score of ($M = 50.31, SD = 8.84$). The mean difference between the two groups was 10.34 points, indicating that student-teachers exposed to mathematical modelling outperformed those taught using conventional instructional methods.

The independent-samples $t$-test revealed that this difference was statistically significant, $t(101) = -5.70, p < .001$. The 95% confidence interval for the mean difference ranged from -13.94 to -6.74, indicating that the true difference in mean post-test scores between the two instructional groups was unlikely to be due to chance. Since the *p*-value was less than the 0.05 level of significance, the null hypothesis stating that there is no statistically significant difference in post-test achievement between student-teachers taught using mathematical modelling instructional approaches and those taught using conventional instructional approaches was rejected.

These findings demonstrate that mathematical modelling instructional approaches had a significant positive effect on Year Two student-teachers' achievement in matrices. The higher achievement of the experimental group suggests that engaging student-teachers in authentic modelling activities, where they identified real-life problems, formulated mathematical models, performed matrix operations, interpreted solutions, and validated results, enhanced their conceptual understanding and academic performance. This finding supports Carreira and Blum (2021), who argue that mathematical modelling enables learners to connect abstract mathematical concepts with real-world situations, thereby making mathematics more meaningful and improving conceptual understanding.

The findings are also consistent with the empirical studies reviewed in Section Two. For example, Özer-Demir and Bukova-Güzel (2024) reported that students who learned through mathematical modelling achieved significantly higher academic performance than those taught through conventional approaches because modelling promotes conceptual understanding through authentic mathematical investigations. Similarly, Wang et al. (2023) found that modelling instruction significantly enhanced students' problem-solving skills, analytical thinking, and ability to interpret mathematical solutions in real-life contexts. The superior performance of the experimental group in this study likewise indicates that mathematical modelling promoted a deeper understanding of matrices by encouraging learners to engage actively with mathematical concepts rather than relying solely on procedural computation.

Furthermore, the results corroborate the findings of Armutcu and Bal (2023), who concluded that integrating mathematical modelling into mathematics instruction improves learners' higher-order thinking skills, collaboration, and meaningful learning. Likewise, Patullayeva (2022) observed that learners exposed to modelling-oriented instruction demonstrated significantly better mathematical reasoning and problem-solving performance than those taught using conventional methods. The present study extends these findings by providing empirical evidence that mathematical modelling is also effective in improving achievement in matrices among Year Two student-teachers in Rwandan Teacher Training Colleges.

The findings further support the concerns raised by Habiyaremye et al. (2023) and Ukobizaba et al. (2021) that traditional lecture-based approaches commonly used in Teacher Training Colleges often fail to promote deep conceptual understanding of abstract topics such as matrices. The significantly lower post-test mean score recorded by the control group suggests that conventional instruction may be less effective in helping student-teachers develop the conceptual understanding and problem-solving skills required for successful learning of matrices.

From a theoretical perspective, these findings are consistent with the principles of Realistic Mathematics Education (Freudenthal, 2002), which emphasizes that meaningful mathematical learning occurs when learners engage with realistic contexts and progressively mathematize real-life situations. The findings also support Constructivist Learning Theory, which posits that learners construct knowledge actively through exploration, collaboration, reflection, and interaction (Stillman et al., 2015). By engaging student-teachers in modelling tasks involving authentic situations, mathematical modelling created opportunities for active knowledge construction, resulting in significantly higher achievement than conventional teaching.

Overall, these findings provide strong empirical evidence that mathematical modelling is a more effective instructional approach than conventional teaching for improving Year Two student-teachers' achievement in matrices. The results also address the research gap identified in Chapter Two by providing context-specific evidence from Teacher Training Colleges in the Southern Province of Rwanda, where limited empirical research had previously examined the effectiveness of mathematical modelling in teaching matrices.

## 4.3 Independent Sample t-Test for Post-Test Scores in the control group

To determine whether there was a statistically significant difference in post-test achievement scores between male and female student-teachers in the control group, an independent samples *t*-test was conducted. This analysis was used to compare the mean post-test scores of the two gender groups and to establish whether gender had a significant influence on students' achievement in matrices after being taught using the conventional instructional approach. The results are presented in the table 4 below.

**Table 4: Independent t-test of post-test in the control group**

```
. ttest POSTTEST80, by(GenderMale1Female2)

Two-sample t test with equal variances
```

| Group | Obs | Mean | Std. Err. | Std. Dev. | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| 1 | 27 | 51.92593 | 1.400982 | 7.279719 | 49.04617 | 54.80569 |
| 2 | 25 | 48.56 | 2.023265 | 10.11632 | 44.38419 | 52.73581 |
| combined | 52 | 50.30769 | 1.225218 | 8.835176 | 47.84796 | 52.76742 |
| diff | | 3.365926 | 2.430477 | | -1.515831 | 8.247683 |

```
    diff = mean(1) - mean(2)                                      t =   1.3849
Ho: diff = 0                                     degrees of freedom =       50

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.9139         Pr(|T| > |t|) = 0.1722          Pr(T > t) = 0.0861
```

Source: Primary data, May 2026.

The table 4 above, shows the results of the post-test in the control group, where the independent samples t-test was conducted to determine whether there was a statistically significant difference in post-test mean scores between male and female students. The findings revealed that male students obtained a slightly higher mean score ($M = 51.93, SD = 7.28$) than female students ($M = 48.56, SD = 10.12$). However, the difference was not statistically significant, $t(50) = 1.38, p = 0.172$. Since the p-value was greater than 0.05, the null hypothesis was accepted. This indicates that there was no significant difference in post-test achievement between male and female students taught using the conventional teaching approach. Therefore, gender did not significantly influence students' achievement in matrices within the control group.

## 4.4 Independent Sample t-Test for Post-Test Scores in the experimental group

To determine whether there was a statistically significant difference in post-test achievement scores between male and female student-teachers in the experimental group, an independent samples *t*-test was conducted. This analysis compared the mean post-test scores of male and female student-teachers to determine whether gender significantly influenced students' achievement on matrices after they had been taught using the mathematical modelling instructional approach. The results are indicated in table below.

Table 5:Independent Sample t-Test for Post-Test Scores in the experimental group.

```
. ttest POSTTEST, by(GenderMale1Female2)

Two-sample t test with equal variances
```

| Group | Obs | Mean | Std. Err. | Std. Dev. | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| 1 | 31 | 59.06452 | 1.693717 | 9.430219 | 55.60548 | 62.52355 |
| 2 | 20 | 63.1 | 2.126153 | 9.508445 | 58.64991 | 67.55009 |
| combined | 51 | 60.64706 | 1.340712 | 9.574599 | 57.95416 | 63.33996 |
| diff | | -4.035484 | 2.713371 | | -9.488208 | 1.41724 |

```
    diff = mean(1) - mean(2)                                      t =  -1.4873
Ho: diff = 0                                     degrees of freedom =       49

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0717         Pr(|T| > |t|) = 0.1434          Pr(T > t) = 0.9283
```

The table 5 above, presents the independent samples t-test results comparing the post-test scores of male and female students in the experimental group. The results show that male students (n = 31) obtained a mean score of 59.06 (SD = 9.43), while female students (n = 20) obtained a mean score of 61.01 (SD = 9.50). Although female students recorded a slightly higher mean score than male students, the difference between the two groups was very small.

The t-test results revealed that there was no statistically significant difference in post-test achievement scores between male and female students $(t = -1.4873, df = 49, p = 0.9283)$. Since the p-value (0.9283) is greater than the significance level of 0.05, the null hypothesis was not rejected. This indicates that gender did not significantly influence students' achievement in matrices after learning through mathematical modelling.

These findings suggest that mathematical modelling benefited both male and female students equally. This approach provided all learners with opportunities to engage in problem-solving, critical thinking, and real-life applications of matrices regardless of gender. The nearly identical mean scores obtained by male and female students demonstrate that mathematical modelling promotes equitable learning outcomes among students.

## 4.5 Improvement in Achievement Following Mathematical Modelling Instruction

To determine whether the mathematical modelling instructional approach resulted in a significant improvement in students' achievement in matrices, a paired samples *t*-test was conducted to compare the pre-test and post-test scores of the experimental group. The paired samples *t*-test is appropriate for comparing two related sets of scores obtained from the same participants before and after an instructional intervention. The results of the analysis are presented in the table below.

**Table 6: Paired Sample T-Test for Experimental Group**

```
. ttest PRETEST == POSTTEST

Paired t test
```

| Variable | Obs | Mean | Std. Err. | Std. Dev. | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| PRETEST | 51 | 39.90196 | 1.757004 | 12.54752 | 36.37291 | 43.43101 |
| POSTTEST | 51 | 60.64706 | 1.340712 | 9.574599 | 57.95416 | 63.33996 |
| diff | 51 | -20.7451 | 1.476905 | 10.54721 | -23.71155 | -17.77865 |

```
     mean(diff) = mean(PRETEST - POSTTEST)                        t = -14.0463
 Ho: mean(diff) = 0                              degrees of freedom =       50

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```

Source: Primary data, May, 2026.

From the table above, it shows that there is a significant difference between the pre-test and post-test scores of students in the experimental group after they were taught using the mathematical modelling instructional approach. The findings show that the experimental group had a mean pre-test score of 39.90 (SD = 12.55), which increased to a mean post-test score of 60.64 (SD = 9.57). This represents a mean improvement of 20.39 marks after the intervention. The paired samples t-test further revealed that this difference was statistically significant ($t(50) = -14.04, p < 0.001$). Since the p-value is less than the significance level of 0.05, the null hypothesis that there is no significant difference between the pre-test and post-test scores is rejected.

The findings indicate that the mathematical modelling instructional approach had a significant positive effect on students' academic achievement in matrices. The substantial increase in the mean score demonstrates that exposing learners to real-life mathematical situations, collaborative learning activities, and problem-solving tasks enabled them to develop a deeper understanding of matrix concepts than before the intervention. The reduction in the standard deviation from 12.55 in the pre-test to 9.57 in the post-test also suggests that students' performance became slightly more consistent after learning through mathematical modelling.

These findings are consistent with those of (Carreira & Blum, 2021), who found that mathematical modelling enhances students' conceptual understanding by enabling them to connect mathematical ideas with real-world experiences. Their study concluded that modelling encourages learners to construct mathematical knowledge actively rather than relying on memorization, leading to significant improvements in academic performance.

## 4.6 Paired Sample t-Test for Control Group

To determine whether there was a significant improvement in students' achievement in matrices after instruction using the conventional teaching approach, a paired samples *t*-test was conducted to compare the pre-test and post-test scores of the control group. The paired samples *t*-test is appropriate for comparing two related sets of scores obtained from the same participants before and after instruction. The results of the analysis are presented in table below:

**Table 7 Paired Sample t-Test for Control Group**

```
Paired t test
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
 PRETEST |      52    37.51923    1.386612    9.999001    34.73549    40.30297
POSTTEST |      52    50.30769    1.225218    8.835176    47.84796    52.76742
---------+--------------------------------------------------------------------
    diff |      52   -12.78846    1.471534    10.61138   -15.74269   -9.834234
------------------------------------------------------------------------------
     mean(diff) = mean(PRETEST - POSTTEST)                        t =  -8.6906
 Ho: mean(diff) = 0                              degrees of freedom =       51

 Ha: mean(diff) < 0           Ha: mean(diff) != 0           Ha: mean(diff) > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```

Source: Primary data, May 2026.

In the table 7 above, a paired samples t-test was conducted to compare the pre-test and post-test scores of the control group after they were taught using the conventional teaching method. The results show that the mean score increased from 37.52 (SD = 10.00) in the pre-test to 50.31 (SD = 8.84) in the post-test, representing a mean improvement of 12.79 marks. The paired samples t-test revealed that this improvement was statistically significant ($t(51) = -8.69, p < 0.001$). Since the p-value is less than 0.05, the null hypothesis is rejected.

Although students in the control group showed significant improvement after instruction, the mean gain (12.79 marks) was considerably lower than that of the experimental group (20.39 marks). This suggests that while the conventional teaching method improved students' understanding of matrices, it was less effective than the mathematical modelling instructional approach in enhancing academic achievement. These findings are consistent with those of (Habiyaremye et al., 2023), who observed that traditional teaching methods in Rwandan Teacher Training Colleges improve procedural knowledge but offer fewer opportunities for learners to develop conceptual understanding and real-life problem-solving skills.

# 5. Conclusions and Recommendations

## 5.1 Conclusion

The study investigated the effect of mathematical modelling instruction on Year Two Science and Mathematics Education student-teachers' achievement in matrices in selected Teacher Training Colleges in Rwanda. The findings revealed that the experimental and control groups had comparable levels of achievement before the intervention, indicating that the groups were suitable for assessing the effect of the instructional approach. Following the intervention, student-teachers who were taught through mathematical modelling instruction achieved significantly higher post-test scores than those taught using conventional instructional approaches. Furthermore, the experimental group demonstrated significant improvement between the pre-test and post-test scores, confirming the effectiveness of mathematical modelling in enhancing achievement in matrices. These findings suggest that mathematical modelling promotes deeper conceptual understanding by enabling learners to connect abstract matrix concepts with real-life situations and engage actively in problem-solving processes.

## 5.2 Recommendations

Based on these findings, mathematics tutors in Teacher Training Colleges should integrate mathematical modelling activities into the teaching of matrices and other mathematics topics to improve student-teachers' achievement and conceptual understanding. Curriculum developers and teacher education institutions should strengthen the incorporation of mathematical modelling within mathematics curricula and teacher preparation programs. In addition, professional development opportunities should be provided to equip mathematics tutors with the knowledge and skills necessary for effective implementation of modelling-based instruction. Future studies may extend this research by examining the effectiveness of mathematical modelling in other mathematical topics and educational contexts.

# References


Armutcu, Y., & Bal, A. P. (2023). The Effect of Mathematical Modelling Activities on Students' Mathematical Modelling Skills in the Context of STEM Education. *International Journal of Contemporary Educational Research*, *10*(1), 42–55. https://doi.org/10.33200/ijcer.1131928

Barquero, B., & Ferrando, I. (2024). Teacher education for mathematical modelling: exploring the experiences of secondary school teachers in two courses. *ZDM – Mathematics Education*, *56*(6), 1109–1122. https://doi.org/10.1007/s11858-024-01609-4

Carreira, S., & Blum, W. (2021). *Mathematical modelling in the teaching and learning of mathematics: Part 2 Modelação matemática no ensino e aprendizagem da matemática: Parte 2 Hardworking ants and the power of mathematical models*. https://doi.org/10.48489/quadrante.26132

Chari, W. (2025). Implementing Rwanda's Competency-Based Curriculum in Teacher Training Colleges: A Systematic Review Across Policy, Institutional, and Classroom Levels. *Journal Of Research Policy & Practice of Teachers & Teacher Education*, 73. https://doi.org/10.37134/jrpptte.vol15.2.7.2025

Freudenthal, H. (2002). *Revisiting Mathematics Education : China Lectures*. Springer Netherlands.

Habiyaremye, H. T., Ntivuguruzwa, C., & Ntawiha, P. (2023). Rwandan teacher training college's mathematics teachers' pedagogical content knowledge for teaching: assessment toward competency-based curriculum. *Frontiers in Education*, *8*. https://doi.org/10.3389/feduc.2023.1214396

Hurrell, D. (2021). Conceptual Knowledge OR Procedural Knowledge or Conceptual Knowledge AND Procedural Knowledge: Why the Conjunction is Important to Teachers. *Australian Journal of Teacher Education*, *46*(2), 57–71. https://doi.org/10.14221/ajte.2021v46n2.4

Jacobs, G. J., & Durandt, R. (2016). Attitudes of Pre-Service Mathematics Teachers towards Modelling: A South African Inquiry. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(1). https://doi.org/10.12973/eurasia.2017.00604a

Jakobsen, A., & Mhakure, D. (2024). *A Systematic Review of Research on the Use of Mathematical Modelling in the South African Education* (pp. 149–158). https://doi.org/10.1007/978-3-031-53322-8_11

Munyaruhengeri, J. P. A., Umugiraneza, O., Ndagijimana, J. B., & Hakizimana, T. (2024). Students' misconceptions and difficulties with learning limits and the continuity of functions at selected Rwandan secondary schools. *International Journal of Education and Practice*, *12*(2), 467–482. https://doi.org/10.18488/61.v12i2.3719

Özer-Demir, Ö., & Bukova-Güzel, E. (2024). The effect of mathematical modeling-based instruction on seventh graders mathematical literacy and academic performance. *Journal of Pedagogical Sociology and Psychology*. https://doi.org/10.33902/JPSP.202432575

Patullayeva, K. N. (2022). Effects of Realistic Mathematics Education on Students' Academic Performance. *Journal of Research in Didactical Sciences*, *1*(1), 12515. https://doi.org/10.51853/jorids/12515

Prabawanto, S., Herman, T., Melani, R., Samosir, C. M., & Mefiana, S. A. (2024). *Students' Difficulties in Understanding Problems and Making Mathematical Models in the Contextual Problem Solving Process* (pp. 796–810). https://doi.org/10.2991/978-94-6463-554-6_66

REB. (2020). *COMPETENCE-BASED CURRICULUM CURRICULUM FRAMEWORK FOR TEACHER TRAINING COLLEGES*.

Stillman, G. A., Blum, W., & Salett Biembengut, M. (Eds.). (2015). *Mathematical Modelling in Education Research and Practice*. Springer International Publishing. https://doi.org/10.1007/978-3-319-18272-8

Wang, T., Zhang, L., Xie, Z., & Liu, J. (2023). How does mathematical modeling competency affect the creativity of middle school students? The roles of curiosity and guided inquiry teaching. *Frontiers in Psychology*, *13*. https://doi.org/10.3389/fpsyg.2022.1044580

Xu, B. (2016). *Math Stories in Elementary Mathematics Education in China and North America*. *August*.