Classroom Practices Mirroring Mathematical Knowledge for Teaching in Rwandan Teacher-Training Colleges: TPACK-Informed Lesson Planning.

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Abstract: Persistent challenges in effectively integrating technology, pedagogy, and content knowledge into mathematics instruction in Rwandan Teacher Training Colleges highlight the need for targeted professional development. This study employed a quasi-experimental design to address this gap by enhancing teaching practices by integrating Technological Pedagogical Content Knowledge into lesson planning. Six tutors from randomly selected schools participated, with half assigned to an experimental group receiving training, while the control group received no specific instruction. The six-month intervention aimed to enhance tutors' mathematical knowledge for teaching through lesson planning that explicitly integrated technological, pedagogical, and content knowledge components. The data collection utilized a customized Lesson Observational Analysis Protocol to assess classroom dynamics. Findings revealed notable shifts in tutors' practices post-intervention. The experimental group shifted away from predominantly using closed-ended questions, favoring more open-ended 'why' questions that promote deeper student reasoning. Additional changes were observed in how tutors confirmed understanding, structured group activities, and student justifications. The study contributes valuable insights into the impact of TPACK-informed training on teaching practices in Rwandan TTCs, offering a foundation for refining instructional strategies and improving mathematics education. The study was limited to tutors' practices and called for future direction in diving into students' practices.

Keywords: Technological Pedagogical Content Knowledge (TPACK), Mathematical Knowledge for Teaching (MKT), Teacher Professional Development, Lesson Observation Analysis Protocol (LOAP), Quasi-Experimental Design, Rwandan Teacher Training Colleges, Mathematics Instructional Practices

INTRODUCTION

Rwanda experienced a curriculum transformation from knowledge-based to competency-based in 2016. Implementing a competency-based curriculum (CBC) and a national continuous professional development (CPD) framework for teachers involves a significant shift in teaching fundamental concepts (REB, 2020; Habiyaremye et al., 2023). However, mathematics tutors in Rwandan Teacher Training Colleges (TTCs) continue to rely on traditional teaching practices, with limited evidence of practical shifts in line with CBC expectations. The gap between intended curriculum reform and real instructional change presents a critical issue that this study addresses. Educators are charged under CBC with transferring knowledge and abilities and assisting students in their learning journey to gain practical knowledge and skills indicated in the new curriculum. Furthermore, given the goals of the National Teacher CPD Framework, it is critical to construct and communicate a description of teaching excellence that is both evidence-based and context-sensitive at all levels (REB, 2019). Effective teaching of mathematics necessitates a firm understanding of key concepts, astute pedagogical abilities, and the incorporation of Information and Communication Technology (ICT) tools to enhance learning experiences and create a better comprehension of mathematical principles (Serin, 2023). The curriculum in Rwandan mathematical instruction requires the participation of teachers. Their job is critical in supporting students in grasping mathematical concepts, allowing them to properly apply and integrate these principles into a variety of areas such as science, mathematics, and technology (REB, 2020). The goal is to improve knowledge and abilities by fostering critical thinking and problem-solving skills, while promoting methodical, creative, and independent learning..

Taking a global perspective on mathematics education, scholars have developed a variety of frameworks for measuring teachers' mathematical knowledge for teaching (MKT) (Hill et al., 2008). These frameworks consider including knowledge in both subject content knowledge (SCK) and pedagogical content knowledge (PCK). Krauss et al. (2008) used this paradigm to investigate knowledge of mathematical tasks as instructional tools, interpretation of students' thinking, familiarity with different representations, and explanations of mathematical difficulties. Integrating Technological Pedagogical Content Knowledge (TPACK) into these frameworks enhances the understanding of how technology can effectively support teaching and learning in mathematics (Habiyaremye et al., 2022b). The findings confirmed two key issues in the context of mathematics education: the challenge of designing items that target PCK alone, as Specialized Content Knowledge often serves as a foundation for PCK; and the identification of teachers who lack sufficient SCK, thereby impeding the development of a robust TPACK framework. This updated TPACK framework includes an additional component known as "horizon knowledge," which builds upon subject-specific content knowledge by offering insights into curricular progression and the sequencing of concepts across grade levels (Jacinto & Jakobsen, 2020).

While the MKT model appears to demonstrate only minor differences between domains, it has the ability to display the complete range of interactions between MKT domains (Koponen et al., 2019). As specified in the Official Gazette (2020), teachers in Rwanda are required to improve their skills and knowledge through capacity-building programs. This policy emphasizes the importance of teachers honing their skills, particularly in mathematics instruction, by tailoring instruction to learners' levels, incorporating creativity and innovation, connecting mathematics with other subjects and real-life situations, and possessing a comprehensive mastery of mathematical content (Habiyaremye et al., 2023; REB, 2020). Despite the requirement, obstacles remain in delivering traditional knowledge and skills in Rwandan schools (Habiyaremye et al., 2022a, 2023). Traditional knowledge transmission faces challenges that must be addressed. These obstacles may impede the optimal transfer of critical cultural and practical knowledge. Addressing these difficulties is critical to improving Rwanda's overall educational experience (Tabaro, 2018).

Despite implementing a CBC, Rwanda lacks a mathematical knowledge framework for assessing teachers' proficiency in teaching mathematics (Sugawara & Nikaido, 2014). The implementation of CBC anticipates teachers not only imparting knowledge and skills, but also facilitating students' learning processes for developing practical knowledge and abilities. However, it is unclear whether teachers' teaching approaches have changed post-shift. While existing research highlights the theoretical potential of TPACK to enhance instruction [7], [18], few empirical studies have investigated its practical impact on observable teaching behaviors in African teacher-training contexts. The National Teacher CPD Framework attempts to provide evidence-based descriptions of high-quality teaching at various levels within the Rwandan context. Despite this emphasis, there are still issues in providing instructors with the requisite information for teaching skills in Rwandan schools (Dorimana et al., 2022; Habiyaremye et al., 2022a), as traditional teaching techniques fall short of building a profound comprehension of academic subject directed toward societal applications. Due to the emphasis on the notion of MKT in the CBC, Rwanda has begun measuring teachers' proficiency in teaching mathematics. As Mathematics specialists on the JICA Project, we noted a recurring issue among educators in interpreting the knowledge and abilities indicated in the new curriculum (JICA, 2020). Despite meeting with instructors regularly, it became clear that many failed to understand the mathematical ideas stated in CBC while aiding students in building the necessary competencies.

The literature review indicates various interpretations of MKT and differing perspectives on mathematics teachers' responsibilities in education. There are numerous opinions on how educators understand and express mathematical topics, reflecting the complexities of their teaching responsibilities (Scheiner et al., 2023). This investigation emphasizes the importance of a comprehensive understanding of the teacher's role in conveying mathematical knowledge. The many interpretations in the literature necessitate a more in-depth assessment of effective teaching tactics and pedagogical approaches in mathematics education. In the same vein, Rwandan mathematics teachers have difficulty understanding their students' thinking processes across a range of mathematical topics (Dorimana et al., 2022). These challenges underscore the need for additional study to bridge the gap between teachers' expertise and effective classroom instruction, emphasizing the importance of aligning instructional techniques with the intricacies of mathematics learning (Habiyaremye et al., 2023). The present assessment system for mathematics tutors in Rwandan teacher-training colleges stresses their ability to perform pedagogical activities connected to the subject knowledge required for mathematics instruction. However, there is a need for a more complete examination of the junction of educators' subject matter competence and their ability to implement successful teaching approaches. To address these challenges, this study explores the effectiveness of TPACK-guided lesson planning training to improve tutors' classroom practices that reflect MKT mastery. By integrating technology with pedagogical and content knowledge, the intervention is designed to help tutors plan and deliver mathematics lessons that convey subject matter and support active learning, conceptual understanding, and student engagement—core aspects of MKT. By focusing on the specific instructional challenges within mathematics education in Rwanda, this research offers insights that can inform the refinement of teacher training programs, particularly in countries with similar educational reforms, curriculum structures, or resource constraints..

This extensive investigation has major implications for improving mathematics instruction in Rwanda. The study provides actionable recommendations to better teacher training programs by identifying the strengths and areas for growth in mathematics tutors' performance. Addressing specific pedagogical issues in mathematics instruction should contribute to developing more effective teaching methodologies. Finally, this study's findings can potentially promote a more robust and impactful mathematics education system in Rwanda, aligning with broader aims of educational excellence and equipping students for success in an increasingly complicated terrain of mathematical knowledge.

Theoretical Framework

Classroom observation stands as a valuable and dynamic tool for assessing the effectiveness of teachers' instructional practices. By systematically documenting classroom activities, observers can gain insights into the nuances of teaching, providing a comprehensive view of pedagogical strategies, student-teacher interactions, and the overall learning environment (Nkundabakura et al., 2023). This firsthand approach offers a real-time perspective on implementing instructional methods, allowing evaluators to gauge the alignment between planned curriculum and actual classroom delivery. The effectiveness of classroom observation lies in its ability to capture the richness of teaching practices, including the utilization of diverse teaching aids, classroom management techniques, and responsiveness to students' individual needs (Delgado-Rebolledo & Zakaryan, 2020). Moreover, this method fosters a reflective and collaborative culture among educators, as feedback derived from observations can inform professional development initiatives and contribute to continuous improvement in teaching methodologies (Bognar et al., 2024).

The study used the TPACK paradigm as its guiding framework to assess tutors' ability to smoothly integrate technology, pedagogy, and subject matter knowledge into their teaching approaches (Nzaramyimana & Umugiraneza, 2023). The TPACK model provides a complete evaluation of the teachers' competency in navigating the intricate junction of technology tools, pedagogical tactics, and mathematical topic understanding (Adipat, 2021; Uwurukundo & Tusiime, 2022). This analytical technique is expected to give useful insights into the overall effectiveness of mathematics teaching within Rwandan teacher-training institutions, perhaps informing adjustments and upgrades in pedagogical practices and instructional strategies. The TPACK model, established as a theoretical framework, enables a nuanced assessment of the delicate interplay of technological, pedagogical, and content knowledge in the context of mathematics education (Schmidt et al., 2014). It provides a systematic lens through which to evaluate how teachers use their expertise across different domains to improve their students' learning experiences (Santos & Castro, 2021). The researchers' goal in using the TPACK model in this study is not only to assess the current state of mathematics education in Rwandan teacher-training colleges but also to contribute to the broader discourse on effective pedagogical approaches and strategies for teaching mathematics, with an emphasis on the integration of technology and pedagogy to optimize the conveyance of mathematical concepts.

Research Questions

Two research questions have guided this study:

(1) How did tutors' practices evolve following TPACK-informed training, comparing the period before and after the intervention?

(2) Which specific aspects of tutors' practices were significantly affected by TPACK-informed lesson planning, as observed in the changes before and after the training?

METHODS

Research Design

Using a quasi-experimental research design, the research intervention improved Rwandan Teacher Training Colleges' (TTCs) tutors' MKT through progressive lesson plan guidance incorporating TPACK elements. A quasi-experimental design was appropriate for this study due to practical limitations in random assignment and the need to maintain authentic school settings. This approach is commonly used in education research to assess interventions under naturalistic conditions (Cresswell, 2014). Six teachers from 6 out of 16 schools were chosen at random for the study. The participants were divided into two groups: the experimental group received training based on the TPACK paradigm, whereas the control group received no specific instruction. The first author worked hand in hand with tutors (teachers in the context of TTC) in an experimental group to improve their lesson planning by incorporating technology, pedagogy, and content aspects. A classroom observation tool was used to capture pertinent data from both groups. This method allowed for a thorough analysis of many elements in tutors' instructional methods, ensuring an objective and measurable assessment of their capacity to blend pedagogical tactics with mathematical subject mastery. The use of a quantitative observational methodology in this study improved the rigor and precision of the evaluation, giving a solid quantitative foundation for drawing conclusions about the quality of mathematics instruction in the selected teacher-training institutes.

Intervention Delivered

The intervention took a dual strategy, integrating TPACK in lesson planning and evaluating tutors' practices in delivering a lesson plan. As a guide, the researchers created an extensive training program for instructors to boost their effectiveness in teaching mathematics. The participants were divided into two groups: the experimental group received training based on the TPACK paradigm, whereas the control group received no specific instruction. This setting allowed for a controlled assessment of the impact of the intervention versus its absence. An observation checklist was used to evaluate the intervention's effectiveness. This checklist methodically collected data throughout classroom sessions, allowing for a detailed analysis of numerous factors in the teachers' educational approaches. This technique ensured a full and objective evaluation of their abilities to mix educational tactics with a strong comprehension of mathematical subjects. The study aimed to improve the precision and rigor of the evaluation by employing a quantitative observational design. This quantitative foundation offered a solid foundation for making conclusions about the overall quality of mathematics education in the TTC, providing useful insights for refining teaching approaches and improving the training of future mathematics educators.

Data Collection Procedures

Before embarking on data collection, ethical permission was obtained from the Unit of Research and Innovation at the University of Rwanda College of Education, and ethical clearance was obtained from the Directorate of Science, Technology, and Research at the Ministry of Education. This clearance was presented to TTC's head teachers. Reaching the classroom, we clearly explained the study's purpose and ensured that both tutors and students were voluntarily willing to participate. We used the S-T graph Lesson Observational Analysis Protocol (LOAP) tool to collect data during classroom observations (Habiyaremye et al., 2025). Developed through an iterative process grounded in instructional design principles and educator feedback, LOAP aligns with Rwanda's Competence-Based Curriculum (CBC) by emphasizing clearly defined objectives, teacher-student interaction, and structured lesson phases. The tool includes six key icons: Start (real-time activity tracking), Log (organized data storage), Analysis (timing summaries), S-T Graph (teacher-student talk ratio), Activity (frequency and duration of actions), and Observation (structured lesson flow, currently under development). These features were refined over multiple trials to ensure clarity, usability, and validity.

We used LOAP to observe tutors in both control and experimental groups. We observed one classroom for 80 minutes with each tutor before intervention. Three tutors in the experimental group were guided to prepare an effective lesson plan (Ndihokubwayo et al., 2022) over a period of six months or two semesters (January to July 2023), while those in the control group continued their usual routine. Throughout this period, we observed each tutor in the experimental group four times, served a post-intervention (we call this after intervention), and observed each tutor in the control group at the end of this period. Therefore, we recorded 21 lessons (we call this a classroom observation), including six lessons in control and 15 in the experimental group.

Data Analysis Procedures

We evaluated 14 activities:

(1) While closed questions can serve a purpose in certain contexts, they tend to elicit specific answers and may not inherently promote deep critical thinking. This activity can lean towards a more teacher-centered approach.
(2) Forming groups for a specific purpose promotes collaborative learning, teamwork, and the exchange of ideas among students. It is aligned with active learning.
(3) Modifying tasks based on difficulty levels allows for differentiation, catering to individual student needs. It supports effective teaching practices.
(4) Drawing attention to important details is a good teaching practice that helps students focus on critical aspects of the content. It supports effective teaching practices.
(5) Connecting a topic to prior knowledge enhances understanding and helps students build on what they already know. It supports effective teaching practices.
(6) Addressing students' claims or concerns fosters a supportive learning environment and ensures that individual needs are acknowledged. It supports effective teaching practices.
(7) Providing encouragement is a positive teaching practice that motivates students and contributes to a positive learning atmosphere. It supports effective teaching practices.
(8) Using examples to illustrate a concept provides concrete instances for understanding abstract ideas. It supports effective teaching practices.
(9) Asking and Responding to 'Why' Questions: This activity encourages critical thinking and deeper understanding by prompting students to explore the reasons behind concepts or solutions. It is aligned with active learning.

(10) Make Groups for a Specific Purpose: Forming groups for a specific purpose promotes collaborative learning, teamwork, and the exchange of ideas among students. It is aligned with active learning.
(11) Confirming understanding is a good practice to ensure that students comprehend the material, providing an opportunity for clarification and reinforcement. It supports effective teaching practices.
(12) Allowing students to justify their ideas promotes active participation, communication, and reasoning skills development. It is aligned with active learning.
(13) Demonstrate a Task (Teacher-led): Teacher-led demonstrations involve the instructor showcasing a task to the students. While valuable, this can be more teacher-centered, especially if students are passive observers rather than actively participating.
(14) Demonstrate a Task (Student-led): Student-led demonstrations encourage peer learning, collaboration, and a hands-on approach to understanding tasks or concepts. It is aligned with active learning.

The selection of the 14 evaluated teaching activities was grounded in established instructional and theoretical frameworks, particularly those underpinning MKT [5], TPACK [21], and principles of active learning and formative assessment [27]. These activities were chosen to reflect observable behaviors that align with core components of pedagogical content knowledge (e.g., using representations, checking understanding), cognitive engagement (e.g., asking "why" questions, justifying ideas), and instructional differentiation (e.g., modifying task difficulty). Together, they form a structured lens through which teaching effectiveness can be evaluated in accordance with competency-based education principles.

The recorded data obtained at preset intervals (in seconds) was thoroughly analyzed using Excel, ensuring a full assessment of quantitative and visual aspects. The obtained data was then effectively displayed through clear and informative graphs for both the control and experimental groups. This visual depiction made the findings more understandable and allowed for a more detailed assessment of performance trends over time. This analytical method improved the interpretation of data in the context of the mathematics classroom, providing useful insights into the success of the intervention in enhancing teaching techniques.

We used a confidence interval to compute statistical significance between groups on specific tutor practice. We followed these general steps to compute confidence intervals for our data: We calculated the mean and standard deviation for each group (Experimental and Control) and measurement (Before and After). These descriptive statistics were used to estimate the center and spread of the data. We chose 95% as the confidence level for our interval. We computed Standard Error [Standard Deviation/sqrt (sample size)]; our sample size was 3 for the control before and after intervention because we observed each of the three tutors once before and after intervention. Similarly, the sample size was three observations in the experimental group before and 12 observations after intervention, since we observed each teacher once and four times during the intervention. We then averaged the before and after mean, standard deviation, and standard error (SE) scores for a repeated measurement. We computed a pooled standard error using SE for control and experimental groups, as $SE_{pooled} = \sqrt{[(SE_{control}^2 + SE_{exp}^2) / 2]}$

We finally computed lower bound [$CI^- = (Mean\_{control} - Mean\_{exp}) - 1.96 * SE\_{pooled}$ and upper bound ($CI^+ = (Mean\_{control} – Mean\_{exp}) + 1.96 * SE_{pooled}$ of confidence interval. The z-score for a 95% confidence interval is approximately 1.96. When the CI- and CI+ interval does not include zero, the interpretation is that there is a statistically significant difference between the compared groups on a certain practice.

RESULTS

In this section, we present the findings related to the first research question, how tutors' practices evolve following TPACK-informed training, and then the second research question on specific aspects of tutors' practices that are significantly affected by TPACK-informed lesson planning.

RQ1: How did tutors' practices evolve following TPACK-informed training, comparing the period before and after the intervention?

The described differences in practices before the intervention reflect similarities in the frequency and emphasis on certain instructional approaches between tutors in the control and experimental groups. These findings contribute to understanding the baseline practices, laying the groundwork for assessing the impact of the intervention within the TPACK framework (see Figure 1). More pronounced practices were "asking the closed question," "providing encouragement," and "use examples to illustrate a concept" which took an average of more than 600 seconds in an 80-minute class.

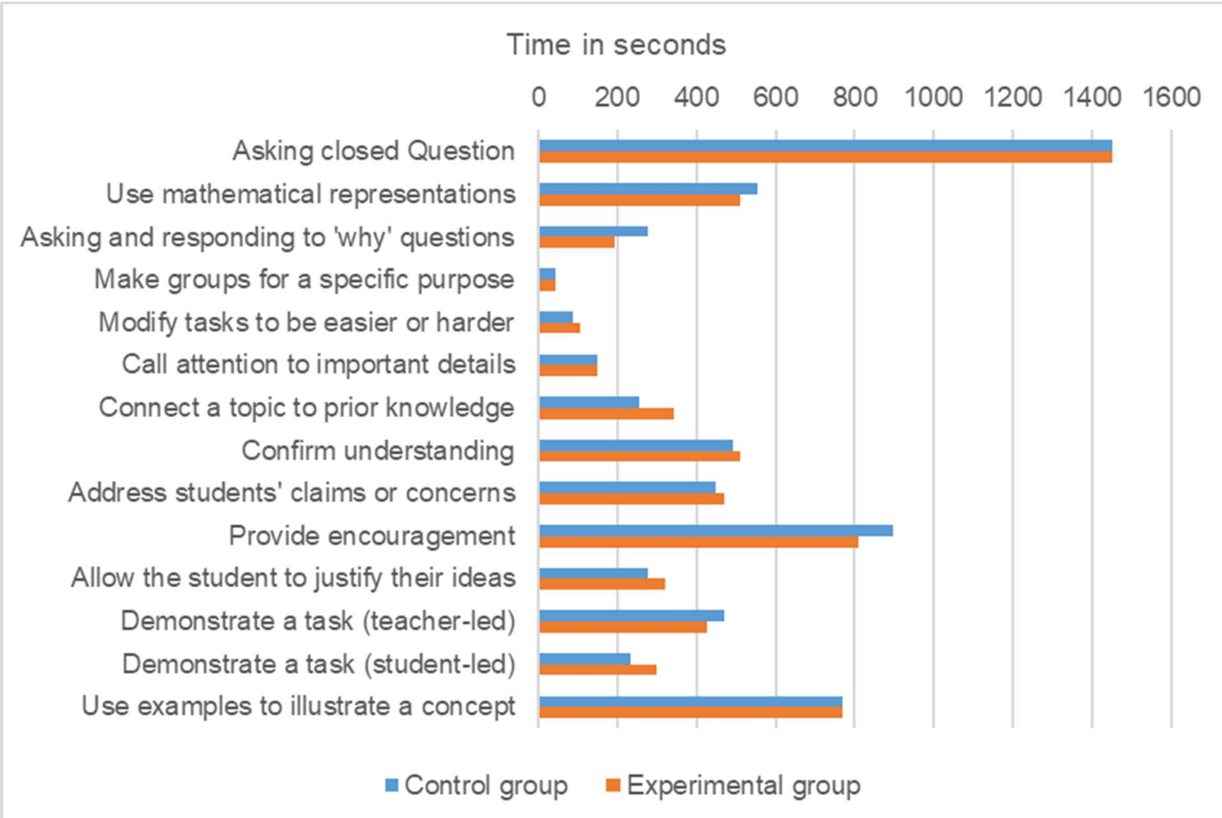

Figure 1. Tutor's classroom practices before teaching intervention

Asking Closed Questions: In both groups, tutors spent a substantial 1451 seconds asking closed questions. This big portion of time in a class suggests a potential similarity in the frequency and emphasis on closed questioning as an instructional approach.

Provide Encouragement: Both groups allocated substantial time to providing encouragement, with the control group spending 896 seconds and the experimental group dedicating 811 seconds. This similarity suggests a shared recognition of the significance of positive reinforcement in motivating and supporting students.

Use examples to illustrate a concept: Tutors in both groups allocated the same time (768 seconds) to use examples to illustrate a concept. This similarity suggests a shared recognition of the significance of positive reinforcement in the usage of concrete from abstract to improve students understanding.

Use of Mathematical Representations: While tutors in both groups used mathematical representations, those in the control group invested slightly more time (555 seconds) than the experimental group (512 seconds). This subtle difference indicates a shared recognition of the importance of visual aids in conveying mathematical concepts.

Confirm Understanding: Both groups demonstrated a commitment to confirming understanding, with the experimental group dedicating 512 seconds and the control group spending 491 seconds. While the difference is marginal, it indicates a shared emphasis on assessing comprehension within both instructional settings.

Demonstrate a task (teacher-led): Tutors in the control group allocated more time (469 seconds) to connect a topic to prior knowledge compared to the experimental group (427 seconds). This difference suggests a potential variation in how tutors in the control group sought to demonstrate a teacher-led task.

Address Students' Claims or Concerns: Both groups demonstrated a commitment to addressing students' claims or concerns, with the experimental group dedicating 469 seconds and the control group spending 448 seconds. While the difference is marginal, this shared focus underscores the importance placed on attending to individual students' needs and fostering a supportive learning environment across both groups.

Connect a Topic to Prior Knowledge: Tutors in the experimental group allocated more time (341 seconds) to connect a topic to prior knowledge than the control group (256 seconds). This difference suggests a potential variation in how tutors in the experimental group sought to build on students' existing understanding through connections to prior knowledge.

Post-Intervention Observations

The post-intervention observations revealed nuanced changes in teaching practices within both the control and experimental groups. These shifts include a decreased reliance on closed questions, an increased emphasis on 'why' questions in the experimental group, modifications in the confirmation of understanding, notable adjustments in group activities, student justifications, and a reduction of teacher-led task demonstrations. These findings provide valuable insights into the evolving teaching practices following the intervention within the TPACK framework (see Figure 2).

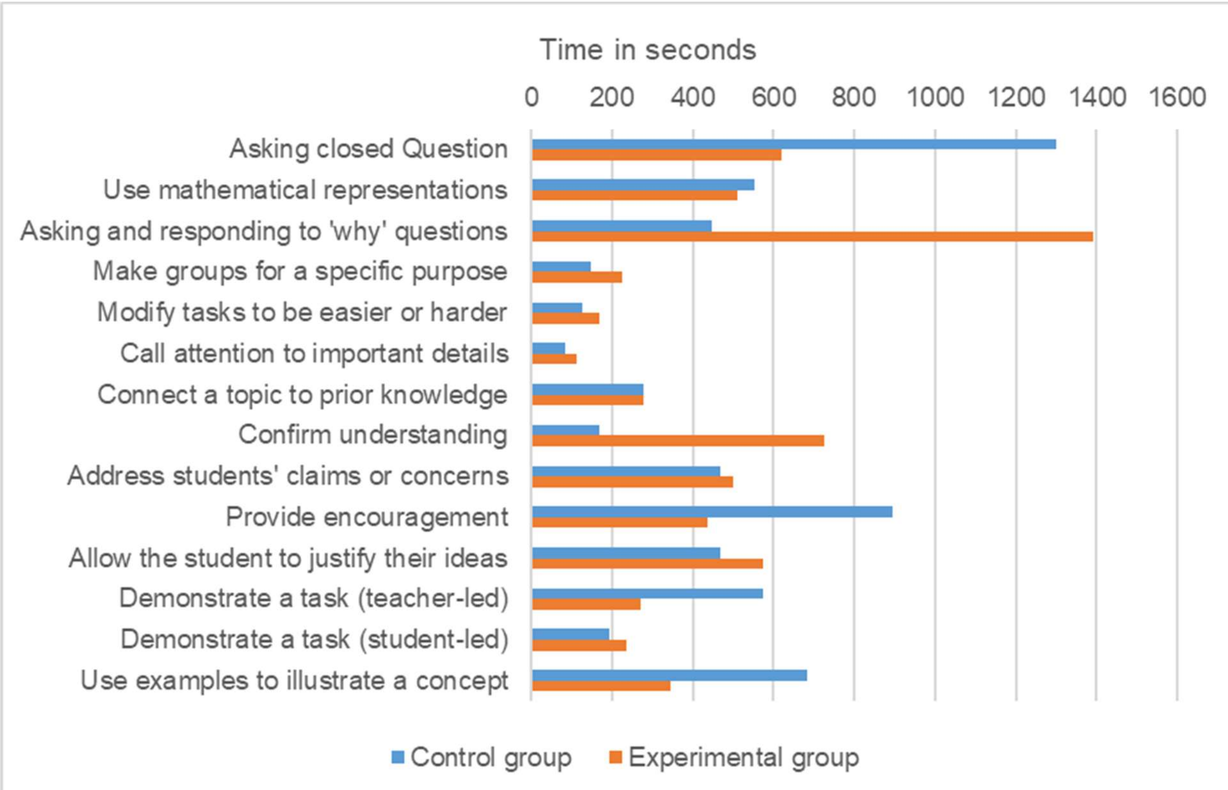

Figure 2. Tutor's classroom practices after the teaching intervention

Asking Closed Questions: Following the intervention, the control group showed a decrease in asking closed questions, spending 1301 seconds compared to the pre-intervention period. In contrast, the experimental group experienced a more substantial decrease, allocating only 619 seconds to this practice. This suggests a significant shift away from relying on closed questioning, with the experimental group demonstrating the effectiveness of helping tutors improve their lesson planning through the TPACK framework.

Asking and Responding to 'Why' Questions: A noteworthy change occurred in the experimental group's practice of asking and responding to 'why' questions. Tutors in the control group spent 448 seconds on this, while those in the experimental group significantly increased this practice post-intervention, dedicating 1392 seconds. This suggests a deliberate effort within the experimental group to foster deeper understanding and critical thinking through the exploration of 'why' questions.

Confirm Understanding: Tutors in the control group dramatically decreased the time spent on confirming understanding (from 491 to 171 seconds), while the experimental group experienced a more significant increase from 512 to 725 seconds. This suggests a collective effort in both groups to place a heightened emphasis on assessing and ensuring comprehension.

Provide Encouragement: There was a considerable decrease in the time allocated to encouraging the experimental group after the intervention, dropping from 811 to 437 seconds. In contrast, the control group maintained a similar level, spending 896 seconds before and after the intervention. This divergence suggests a notable and negative shift in the experimental group's approach to providing encouragement.

Use of Mathematical Representations: Both groups exhibited consistent results in the use of mathematical representations after the intervention. The control group spent 555 seconds before and after the intervention, indicating a consistent approach. However, the experimental group showed a consistent reduction before and after, both at 512 seconds.

Use Examples to Illustrate a Concept: Tutors in the experimental group demonstrated a substantial decrease in using examples to illustrate a concept after the intervention (from 768 to 347 seconds), while those in the control group showed a more moderate decrease (from 768 to 683 seconds). This implies a notable reevaluation of the role of examples in the instructional practices of the experimental group.

Allow the Student to Justify Their Ideas: Tutors in the experimental group showed an increase in allowing students to justify their ideas, spending 576 seconds after the intervention compared to 320 seconds before. This indicates a deliberate effort within the experimental group to promote student reasoning and expression of ideas.

Address Students' Claims or Concerns: All tutors in both groups demonstrated increased practice, with more in the experimental group (from 469 to 501 seconds).

Demonstrate a Task (Teacher-led) and (Student-led): Both groups experienced changes in demonstrating tasks after the intervention. The experimental group showed a decrease in teacher-led demonstrations (from 576 to 272 seconds), while tutors in the control group kept increasing this practice (from 469 to 576). However, tutors in both groups consistently decreased results in student-led demonstrations, though control demonstrated a greater decline (from 235 to 192 seconds).

Make Groups for a Specific Purpose: Both groups increased the time spent making groups for a specific purpose after the intervention. The control group went from 43 to 149 seconds, while the experimental group increased from 43 to 224 seconds. This indicates a shared recognition of the value of purposeful group formations, with the experimental group demonstrating a more substantial increase.

Connect a Topic to Prior Knowledge: Tutors in the experimental group failed to connect a topic to prior knowledge, demonstrated by a decrease in time (from 341 to 277 seconds) dedicated to this practice after the intervention.

Modify Tasks to be Easier or Harder: Tutors in both groups showed an increasing dedicated time but with the same trend.

Call Attention to Important Details: Tutors in both groups decreased the time dedicated to this practice after instruction.

RQ2: Which specific aspects of tutors' practices were significantly affected by TPACK-informed lesson planning, as observed in the changes before and after the training?

Based on the mean, SE_{pooled}, and confidence intervals (CI- and CI+), 6 out of 14 tutors' practices revealed statistically significant differences after intervention, 4 in favor of tutors in the experimental group and 2 in favor of tutors in the control group. Other groups did not show any statistically significant difference before and after intervention.

The mean time spent on (1) *asking closed questions* in the control group (1376 seconds) is statistically significantly different from the mean time in the experimental group (1034.67 seconds). The 95% confidence interval ranged from 180.73 to 501.93. The estimated difference in the mean time for asking closed questions between the control and experimental groups is statistically significant, with the control group spending more time and the experimental group spending less time. Therefore, this practice translated into the mean time spent on (2) *asking and responding to 'why' questions* in the control group (362.67 seconds), which is statistically significantly different from the mean time spent in the experimental group (792 seconds). The 95% confidence interval ranged from -553.70 to -304.97. Thus, the estimated difference in the time spent asking and responding to 'why' questions between the control and experimental groups is statistically significant, with the experimental group spending more time.

The mean time spent on (3) *confirming understanding* in the control group (330.67 seconds) is statistically significantly different from the meantime in the experimental group (618.67 seconds). Confidence Interval (95%): [-384.25, -191.75]. The estimated difference in the mean time for this practice was significant, with the experimental group spending more time. However, for the (4) *"provide encouragement"* activity, the mean time spent by the control group was 896 seconds, while the experimental group spent 624 seconds (with confidence intervals for the difference in means (CI- and CI+) of 198.35 and 345.65, respectively). This indicates that the experimental group, on average, spent less time providing encouragement compared to the control group. The negative values in the confidence intervals suggest that the experimental group spent less time while the control group spent enough time on this activity.

The mean time spent on (5) *demonstrating a task in a teacher-led* approach in the control group (522.67 seconds) is statistically significantly different from the meantime in the experimental group (349.33 seconds). Confidence Interval (95%): [62.10, 284.56]. The estimated difference in the meantime for this practice is significant, with the control group spending more time and the experimental group reducing time. However, the mean time spent on (6) *using examples to illustrate a concept* in the control group (725.33 seconds) is statistically significantly different from the meantime in the experimental group (557.33 seconds). Confidence Interval (95%): [40.88, 295.12]. Thus, based on the statistical analysis, the time spent on using examples to illustrate a concept differs significantly between these groups, favoring the control group.

DISCUSSION

Interestingly, both the control and experimental groups started with similar baseline practices, suggesting a common foundation in their instructional approaches. The similarities observed in these practices may reflect the existing pedagogical norms or training received by the tutors before the intervention. In delving deeper into the baseline practices of tutors within Teacher-Training Colleges (TTCs) in Rwanda, a notable pattern emerges—a commonality in instructional approaches. The tutors, equipped with a university background in mathematics and education, have undergone Continuing Professional Development (CPD) training facilitated by the Rwanda Education Board (REB) and developmental partners (Ndihokubwayo et al., 2021; REB, 2018). This shared educational foundation among the tutors lays the groundwork for understanding their instructional practices.

The post-intervention phase illuminates a canvas of transformative dynamics within the teaching practices of tutors in TTCs in Rwanda. The observed changes reflect a conscious effort to depart from conventional instructional methods and embrace a more nuanced, student-centric pedagogical approach. The intervention consisted of a structured training program designed to guide tutors in incorporating TPACK elements into lesson planning. This included workshops on aligning learning objectives with CBC standards, selecting and integrating digital tools (e.g., GeoGebra, PowerPoint, and videos) for mathematical concepts, and designing student-centered tasks that foster reasoning, group interaction, and justification. Tutors received individualized support through planning discussions and reflective sessions after each lesson implementation. These targeted supports are likely responsible for the significant post-intervention shifts observed in the experimental group—such as reduced reliance on closed questions, increased use of ‘why’ questions, and improved methods for confirming understanding. The training emphasized a shift from procedural instruction to conceptual understanding, reinforcing MKT's pedagogical and content dimensions within a TPACK framework. Some practices showed statistically significant differences between the control and experimental groups post-intervention, providing insights into the effectiveness of the training.

The mean time spent asking closed questions emerges as a significant difference between the control and experimental groups post-intervention. The experimental group invested less time in this practice and advocated more time for asking a 'why' question to induce deep understanding. This shift suggests a move away from rote questioning toward practices that encourage reasoning and justification—an essential aspect of student-centered learning and MKT development. The realm of 'why' questions becomes a focal point, underscoring the experimental group's commitment to nurturing a culture of inquiry and critical thinking. These changes suggest a shift towards more student-centered and inquiry-based instruction (Habiyaremye et al., 2022a). The observed shifts in post-intervention teaching practices hold profound implications for the development of MKT in the context of TPACK-informed lesson planning (Hill et al., 2008). The decreased reliance on closed questions suggests a move towards more interactive and open-ended pedagogical approaches (Ukobizaba & Byukusenge, 2023). The increased emphasis on 'why' questions in the experimental group indicates a conscious effort to foster deeper understanding and critical thinking, aligning with the goals of TPACK integration.

The mean time spent on teacher-led task demonstrations unravels a significant difference, with the control group surpassing the experimental group. Tutors in the experimental group declined investment in teacher-led demonstrations, reflecting a pedagogical preference induced by the effective intervention of TPACK-led lesson planning, a hint at fully embracing student-led approaches. Recognizing the interdependence of content knowledge and pedagogical skills, TTCs can play a critical role in developing highly effective mathematics educators who not only have a deep understanding of the subject matter but also excel at communicating complex concepts in a way that resonates with their students, ultimately improving the overall quality of mathematics education at the collegiate level (Kleickmann et al., 2013). The landscape of confirming understanding unveils a significant transformation post-intervention, with the experimental group dedicating more time than the control group. This distinction prompts inquiry into the underlying dynamics. This heightened focus on confirming understanding indicates a more deliberate approach to assessing comprehension and the ripple effects it creates in the learning environment (Uwurukundo & Tusiime, 2022). This, in turn, can lead to more targeted and tailored instructional strategies, addressing individual student needs effectively. Furthermore, adjustments in the confirmation of understanding highlight a nuanced approach to assessing comprehension, emphasizing the importance of formative assessment strategies (Ukobizaba & Byukusenge, 2023). This aligns with the principles of MKT development (Arnal-Bailera & Oller-Marcén, 2020), emphasizing what is taught and how students comprehend it.

The statistical analysis sheds light on the practice of using examples to illustrate a concept, favoring tutors in the control group. This prompts a deeper inquiry, depending on how these examples resonate with student comprehension and what factors contribute to the observed variations in approach. Likewise, encouraging takes center stage, revealing a nuanced divergence. The control group maintained a consistent level, while the experimental group witnessed a reduction. This reduction signifies a recalibration of motivational strategies, which negatively impacts student motivation and confidence in mathematical exploration. The complexity of conceptualizing teacher knowledge involves understanding teaching processes, the nature of knowledge, and practical application in the classroom (Habiyaremye et al., 2022a). Empirical research highlights that teacher quality significantly influences student achievement, emphasizing the need for a comprehensive understanding of teacher knowledge that contributes most to positive learning outcomes (Filgona et al., 2020). The decrease in encouragement and the use of examples in the experimental group warrants further investigation into potential challenges in implementing positive reinforcement strategies post-training. This is critical for ensuring that educators have the necessary skills and knowledge to effectively teach mathematics in accordance with the CBC standards, thereby contributing to the success and efficacy of the educational system (Aksu & Kul, 2016).

In practical terms, these changes signify a potential enhancement in teaching effectiveness, fostering a more dynamic and interactive learning environment. Students may benefit from increased engagement, deeper understanding, and improved critical thinking skills. The observed shifts, therefore, contribute to the theoretical framework of MKT and hold tangible implications for the day-to-day teaching practices and overall learning experiences within the teacher-training context. These implications underscore the effectiveness of TPACK-informed training in shaping teaching practices that resonate with the objectives of MKT development (Nzaramyimana & Umugiraneza, 2023). Integrating technological, pedagogical, and content knowledge in lesson planning emerges as a catalyst for transformative shifts in instructional strategies, ultimately contributing to the enhancement of MKT among TTC tutors.

All core intervention materials were developed to support replication and validation of this study and can be shared upon request. These include the TPACK-based lesson planning framework used during training, observation checklists, planning templates aligned with the CBC, example lesson plans co-developed with tutors, and the customized LOAP tool. The training module focused on guiding tutors through structuring learning objectives, selecting digital resources (e.g., GeoGebra, videos, and PowerPoint), integrating technology during instruction, and embedding student-centered questioning strategies. While not all these materials are embedded in this paper, they are available via the project repository and can be provided to interested researchers for replication or adaptation.

CONCLUSIONS

The analysis of tutors' classroom practices before and after the intervention, which involved training teachers in TPACK-informed lesson planning, offers valuable insights into the impact of the training on their instructional approaches. The findings reveal nuanced shifts in teaching practices within the control and experimental groups. Before the intervention, both groups demonstrated similarities in the frequency and emphasis on certain instructional approaches, such as asking closed questions, providing encouragement, and using examples to illustrate a concept. The observed practices reflected a baseline understanding of pedagogical methods, laying the groundwork for assessing the intervention's impact. Post-intervention, notable changes were observed in both groups. There was a collective decrease in the reliance on closed questions, an increased emphasis on 'why' questions in the experimental group, modifications in the confirmation of understanding, adjustments in group activities, student justifications, and a reduction in teacher-led task demonstrations. These shifts provide valuable insights into the evolving teaching practices within the TPACK framework. After the intervention, the statistical analysis revealed significant differences in certain practices between the control and experimental groups. Notably, the control group spent more time asking closed questions and demonstrating a task in a teacher-led approach, while the experimental group exhibited a more pronounced decrease in asking closed questions and an increase in asking and responding to 'why' questions. Tutors in the experimental group also reduced time spent on teacher-led demonstrations and increased time for confirming understanding. However, there was a loophole in providing encouragement and using examples to illustrate a concept among the tutors of the experimental group. These findings suggest that the TPACK-informed training has influenced specific teaching practices, promoting a shift towards more interactive and student-engaged methods. The observed changes align with the goal of enhancing teachers' Mathematical Knowledge for Teaching through effective lesson planning within the TPACK framework. Therefore, it is recommended that teachers receive training in order to deliver mathematical content competently.

LIMITATIONS

This study only focused on tutors' practices. Therefore, more studies are needed to reveal the students' practices in mathematics and other subjects. We randomly picked six schools (one teacher from each) to implement our intervention extensively. Due to the long period of intervention that took six months, we could not involve many teachers or schools; however, we acknowledge this as a limitation of generalization.

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DECLARATIONS

Ethics Statement

This study was approved by the Ethics Committee of the Research and Innovation at the University of Rwanda College of Education, with ethics approval reference 03/DRI-CE/066/EN/gi/2020. The INFORMED CONSENT was obtained from all participants for our study.

Conflict of Interest

The authors declare no conflict of interest regarding the publication of this paper.

Data Availability

The datasets analyzed during the current study are available from the MKT DATASET COL-LECTED FOR PHD PROGRAM (figshare.com).

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