Efficacy of Continuous Professional Development Training on Rwandan Upper Primary Teacher's Content Knowledge in Mathematics and Science and Elementary Technology Subjects

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Abstract

The current study seeks to evaluate the Content Knowledge (CK) of Mathematics and Science and Elementary Technology (SET) upper primary teachers who received Continuous Professional Development training on Pedagogical Content Knowledge (PCK) offered by Rwanda Quality Basic Education for Human Capital Development (RQBEHCD) project. The study adopted a quasi-experimental design. The achievement tests were used to collect data from 290 trained teachers including 166 males and 124 females. A Repeated measures ANOVA was used to analyze whether or not there is a statistically significant difference in the mean score between pre and post-test, male, female, and working experience. Results revealed that the intervention increased content knowledge of teachers in both subjects but there was no difference between male, female, and working experience. Therefore, the study recommends Mathematics and SET teachers conduct CPD in their respective departments.

Keywords: CPD training, conceptual understanding, teacher's performance, and pedagogical content knowledge

Introduction

Teachers are the cornerstone of education. This means that they must be well-equipped with subject-matter expertise, have access to laboratories, and creative teaching strategies for the teaching and learning process (Tallvid, 2016). In this regard, the quality of education that teachers deliver to students depends on their knowledge and understanding of mathematics and science. Different researches showed that teachers are expected to possess a wide range of knowledge, including subject content knowledge (SCK), Innovative Pedagogical Knowledge (IPK), and supportive, collaborative, and creative skills to plan what and how to teach students in the twenty-first century (Kind, 2014; Erdas Kartal et al., 2018). Therefore, Continuous Professional Development (CPD) is an important opportunity for teachers' professional growth and is vital for advancing their subject matter, enhancing their instructional strategies, and delivering high-quality instruction to their students. Indeed, the greatest influence on students' learning has been attributed to teachers' competence (Khoirudin et al., 2016).

Continuous professional development (CPD) and Teachers' Content Knowledge (TCK) are directly and reciprocally related (Wermke, 2012). Teachers' content knowledge can be improved through CPD, and a strong content knowledge of the teachers enhances their practice (Knowles et al., 2018). Teachers have the chance to improve their subject-matter knowledge through CPD, learn the most recent professional developments, and develop fresh perspectives on teaching strategies (Makgato, 2012). In this sense, teachers who participate in CPD are expected to use the gained knowledge to enhance students' learning and subject-matter mastery. However, previous studies reported that Mathematics and sciences teachers have difficulties in their subjects (Ukobizaba et al., 2019; Langoban, 2020; Kiarsi and Ebrahimi, 2021). In addition, the study conducted by Maniraho and Christiansen (2015) illustrated

that most Mathematics teachers do not have enough competence in delivering this subject, especially in the topics of algebra, statistics, and probability. Similarly, the study of Dushimimana and Uworwabayeho (2020) showed that Rwandan in-service Mathematics primary teachers had different misconceptions in the concept of statistics and probability. In this regard, the performance of mathematics and science teachers in Rwanda primary schools has been reported to be not sufficient to support students' competencies due to limited content knowledge.

To address these problems, the Ministry of Education in Rwanda through Rwanda Quality Basic Education for Human Capital Development Project (RQBEHCD) have introduced the CPD programs to raise the standard of Mathematics and Science instruction in primary schools. The project placed a strong emphasis on the use of scripted lessons alongside with series of laboratory activities prepared by the staff from the University of Rwanda, College of Education. The created scripted lesson plans include content, questions, tasks, and evaluation strategies. They are designed as a practical tool to give teachers direct access to knowledge resources and to deliver organized, well-paced, and easy-to-follow lessons. The World Bank in collaboration with the Government of Rwanda launched the Rwanda Quality Basic Education for Human Capital Development Project (RQBEHCD), which had three main goals that are enhancing teachers' proficiency in science and mathematics, enhancing students' retention, and enhancing learning. Through a tailored training program, the project's sub-component 1.2 specifically aimed to modernize teaching resources and improve the knowledge and pedagogical practices of mathematics and science teachers in upper primary.

This research sought to evaluate the effects of the RQBEHCD project's CPD training on the CK of Mathematics and SET teachers in Rwanda's upper primary schools. Additionally, this study investigated the performance of the upper primary Mathematics and SET teachers per gender and teaching experience. Analyzing gender issues and teaching experience is paramount in the research on the efficacy of Continuous Professional Development (CPD) training for Rwandan upper primary teachers in Mathematics and SET subjects. This scrutiny is vital as it acknowledges the potential existence of gender-based disparities and diverse teaching experiences, which can significantly influence the impact and outcomes of professional development initiatives. Understanding how male and female teachers respond to CPD training ensures a nuanced evaluation, addressing gender-specific needs and promoting gender equity within the teaching profession. Simultaneously, examining the interaction between teaching experience and the efficacy of training acknowledges that educators at different career stages may have distinct starting points and learning needs. This analysis informs the tailoring of CPD programs to cater to the unique requirements of both genders and teachers with varying levels of experience, contributing to more inclusive, effective, and equitable professional development strategies in the realm of mathematics, science, and technology education in Rwandan upper primary schools. Considering these, the current study makes a significant contribution by extending the body of knowledge about the degree of learning attained and teachers' subject-matter expertise as of training.

Research questions

The study answered three research questions:

1. What is the efficacity of CPD training on upper primary teachers' Content Knowledge in mathematics and SET subjects?
2. What are the misconceptions of mathematics and SET teachers before and after attending CPD training?
3. Do the performance of male and female teachers in mathematics and SET subjects differ significantly after CPD training?

Methodology

Research approach and design

A quantitative approach was taken in this study. The research was conducted using a quasi-experimental (one-group pretest-post-test) design. The same dependent variable (teachers' content knowledge) is measured in a single group of participants before (pretest) and after (posttest) treatment administration. The participants of this study received the same Mathematics and SET achievement test before and after treatment in the form of a pretest-posttest to determine whether any changes in terms of content knowledge can be attributed to the treatment (CPD training).

Population and method of sampling

The study's target population was composed by all Mathematics and SET teachers from upper primary schools in ten districts. These are the districts covered by the RQBEHCD project. The Mathematics and SET teachers were selected purposively selected considering that they were public and had electricity. The head teachers of the selected schools were requested to selected two upper primary teachers (one for Mathematics and other SET) to participate in the study. Thus, a total of 290 teachers were used during the analysis because they took both pre-and post-test. In Mathematics, they were 151 including 89 male teachers and 62 female teachers, while in SET the sample size was made of 139 teachers including 77 male and 62 female teachers.

Method of data collection and analysis

Mathematics and SET achievement tests were used to collect data. Some of the test questions for those instruments were taken from standardized tests based on the Rwandan competence-based curriculum found at https://njctl.org/online-learning/teachers/, while others were modified to be in line with the principles of Competence-Based Curriculum assessment and appropriate for primary teachers. The test items were developed based on the content taught in the Rwandan upper primary curriculum.

In Mathematics test, the test item were classified in this way: six questions (Q1, Q2, Q19, Q21, Q22 & Q35) were numbers and operations related questions; eleven questions (Q4, Q5, Q17, Q20, Q23, Q25, Q37, Q38, Q39, Q40 & Q44) were fractions, decimals, and proportional reasoning related questions; twelve questions (Q6, Q7, Q9, Q10, Q11, Q28, Q32, Q41, Q45, Q47, Q48, and Q50) were metric measurement related questions, six questions (Q12, Q13, Q14,

Q24, Q36 & Q46) were Algebra related questions; five questions (Q15, Q16, Q27, Q42 & Q43) were geometry related questions, and three questions (Q31, Q33, and Q49) were statistics and elementary probability.

The SET test comprised 52 questions: 17 questions (Q1-Q17) were biology-related; 13 questions (Q18-Q30) were physics-related; 14 questions (Q31-Q44) were chemistry-related whereas eight questions (Q45-Q52) were ICT-related.

To make sure that the instruments cover all the material intended for the training manuals, additional item questions were created by the RQBEHCD project staff in collaboration with UR-CE lectures. Before the intervention, all teachers did a pre-test to test their conceptual understanding before attending training. After conducting a pre-test, the RQBEHCD project organized training for upper primary teachers in Mathematics and SET. The participant was trained in two modules. The first module covered e-learning and ICT in education, while the second covered innovative teaching techniques which are divided into three components that are pedagogy, content, and laboratory activities. In close collaboration, staff from the University of Rwanda College of Education (UR-CE) and Rwanda Basic Education (REB) trained mathematics and SET teachers on e-learning and the integration of ICT tools, with a focus on the use of scripted lessons. Teachers were given access to, and navigation of scripted lessons developed by UR-CE lecturers relevant to the subject they teach. After training the teachers did post-test to evaluate the impact of CPD training on the upper primary Mathematics and SET teachers' content knowledge.

The project also concentrated on teaching mathematics and SET material, placing more emphasis on the subject matter that has been noted as challenging and in which teachers tend to have more misconceptions. 14 units in mathematics were the focus of the training. Teachers received training in 24 units in SET (five were related to biology, six to chemistry, nine to physics, and four to ICT). In addition, teachers received extensive practical training and training on lab experiments related to those units.

The repeated measures Analysis of Variance was used to test whether there was a significant difference between pre and post-test and a significant effect of gender and working experience on trainees' performance. Prior to statistical analyses, the normality and variance homogeneity of data were tested using the Kolmogorov-Smirnov and the Levene's test, respectively.

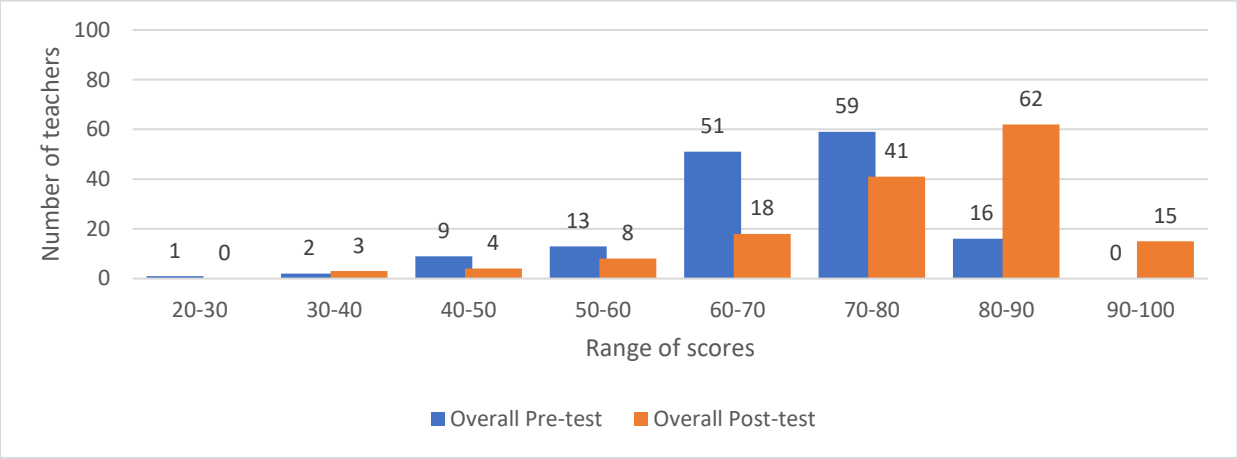
Results interpretation

Mathematics teachers' performance in the pre-and post-test

The results in Figure 1 showed that most teachers in both pre-and post-tests were in the range of 70-80 (Figure 1). In this context, 12% (18) of teachers scored less than 50% in the pre-test, while 7(10) scored below the percentage of 50% in the post-test. It was also found that none of the teachers scored between 90-100 in the pre-test while 10 % (15) teachers scored between this range in the post-test.

Figure 1

Scores range of primary Mathematics d teachers in pre-test and post-test [N=151]

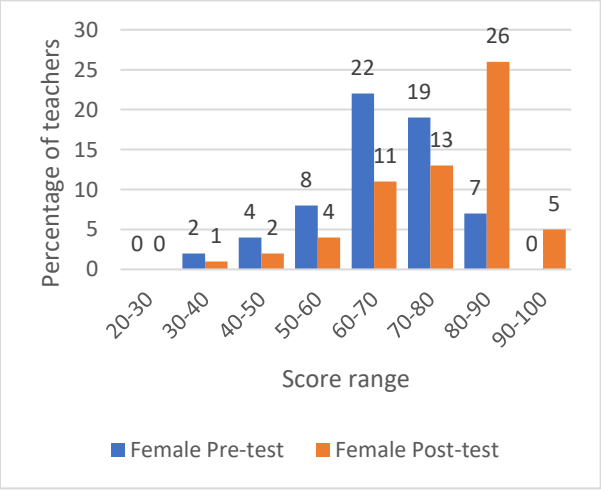


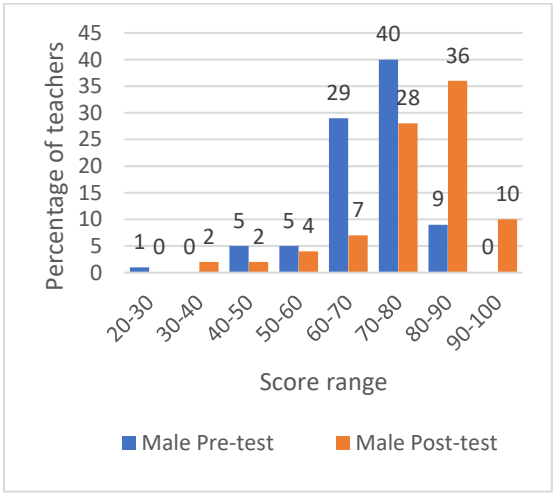
Mathematic teachers' performance in the pre and post-test per gender

Figure 2 shows the scores of Mathematics teachers by comparing females and males in pre-and post-test. The results showed that 22% (35) and 40% (64) females teachers scored in the range of 60-70 and 80-90 in both pre-and post-test, respectively. While 26% (30) and 36% (40) of their counterpart male teachers are in the range of 80-90 in the pre and post-test, respectively. However, there is a higher performance observed in the range of 90-100 in post-test for females and males with percentage of 5%(8) and 10% (9) respectively. None female or male teachers scored in the range 80-90 in the pretest.

Figure 2

Scores range of primary Mathematics teachers per gender in pre-and post-tests. [Female =33, Male= 115, all teachers =151]





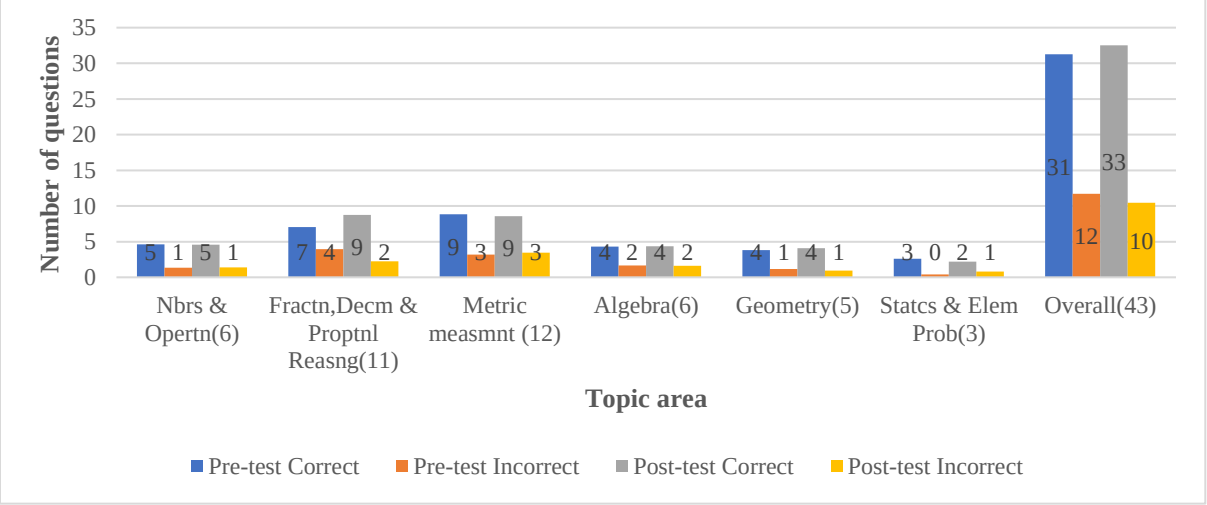
Mathematics teachers' performance per topic area in both pre and post-test

The results showed that the overall average score in numbers and operations-related questions was 77.3% and 76.5% in the pre-post-test, respectively, in the Fractions, Decimals and Proportional Reasoning related questions were 64% and 79.5% in the pre-post-test, respectively. In the Metric Measurement related questions was 73.6% and 71.3% in pre-post-test, in the Algebra related questions was 72.1% and 72.8% in the pre and post-test, respectively, in the geometry related questions was 76.7% and 81.6% in the pre-post-test respectively and in the Statistics and Elementary Probability was 86.8 % and 73.5% in the pre-post-test, respectively.

The figure 3 shows correctly answered questions per topic area. In the pre-test, all three questions asked in the statistics and elements of probability were correctly answered. However, in the post-test, only two questions (66.67%) were answered correctly while one (33.33%) answered incorrectly. The five questions of geometry were correctly and incorrectly answered in both pre-and post-test at the same extent 80% which is equivalent to four questions. Also, the six questions asked in the algebra were answered correctly and incorrectly in both pre and post-test at the level of 4(66.67%) in the pre-test and 2(33.33%) in the post. on the other side, 12 questions asked in the metric measurement were answered at similar extent in both pre-and post-test of 9 (75%) and 3(25%) pre-and post-test, respectively. Teachers scored correctly 7 questions and 4 questions in the pre- and post-tests, respectively, out of the eleven questions asked in the area of fraction and decimals. Out of six questions asked in the operation and numbers, teachers answered at the same rate in both pre and post-test, respectively, at level of 5 (83.33%) and 1(16.67%).

Figure 3

Correct and incorrect answers in mathematics subject



Note. The following are abbreviations used Nbrs& Opertn: Numbers and operation, Fractn, Decm & Proptnl Reasng: Fraction, decimals and proportional reasoning, Statcs & Elem Prob: Statistics and Element of probabilit.

Inferential analysis of Mathematics results by gender and working experience in both pre and post-test

Pre- and post-test mean results differed significantly with a medium effect size (η) of 0.450 favoring the post-test (Table 1). The study did not find any significant difference between upper primary females and males Mathematics teachers (p-value = 0.732) with a low effect size (η) of 0. 001. Similarly, the working experience did not significantly influence the performance of mathematic teachers did *(p-value* = 0.345 η= 0.027). See Table 1.

Table 1

Inferential analysis of Mathematic teachers' results in pre and post-test, gender and working experience

Effect		Value	F	Hypothesis df	Error df	Sig. (*p*)	Partial Eta Squared (η)
Test	Wilks' Lambda	.550	121.859[b]	1.000	149.000	.000	.450
Test * Gender	Wilks' Lambda	.999	.118[b]	1.000	149.000	.732	.001
Test*Experience	Wilks' Lambda	.962	1.133[b]	5.000	145.000	.345	.027

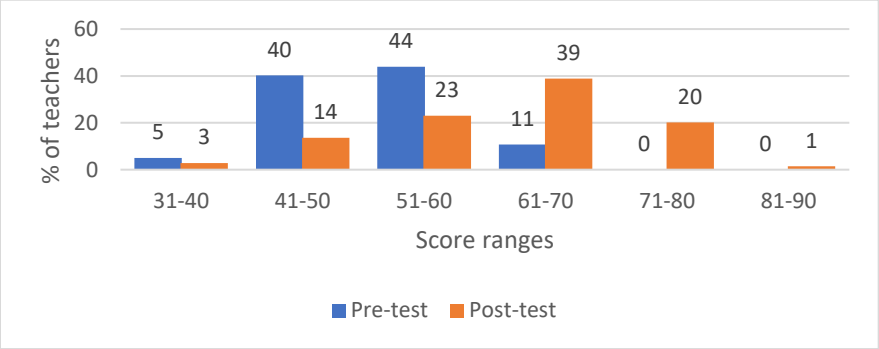
Science and Elementary Technology teachers' results

Overall performance

The results showed that 62 (45%) of SET teachers scored below 50% in the pre-test, while (24)17% of teachers of them scored below 50% in the post-test. This indicates that (38) 28% of teachers have increased their performance in the post-test. The scores of all teachers were above the range of 31-40 in both pre- and post-test. In addition, none of the teachers scored above 70% in the pre-test, while 21% scored above 71% in the post-test in Figure 4.

Figure 4

SET score distribution of teachers by gender [Female =62, males = 72, all teacher = 139]

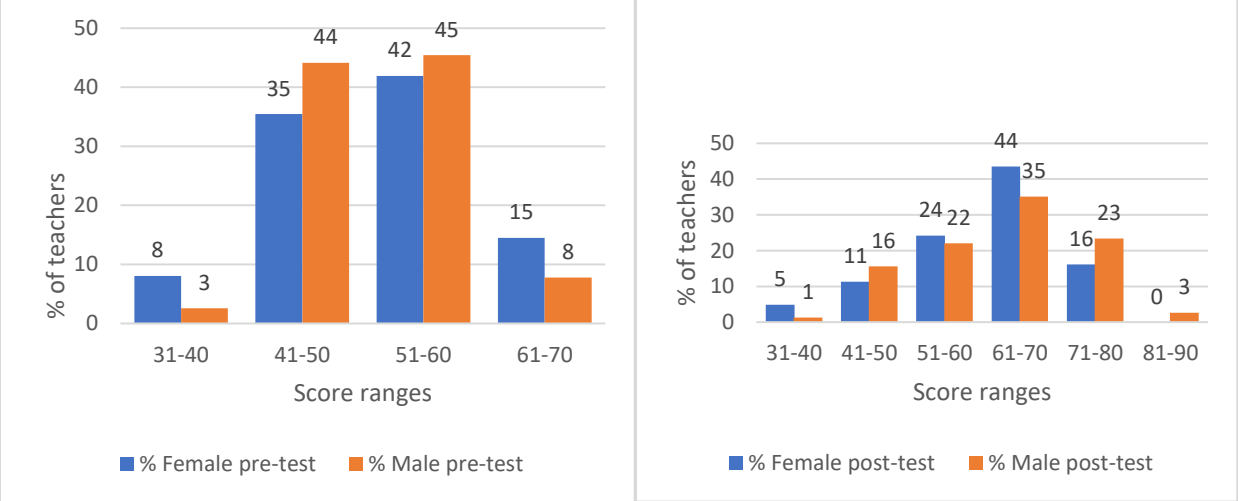


SET teachers' performance in both pre and post-test per gender

Before training, 43% (27) female teachers demonstrated challenges and misconceptions while 47% (36) male teachers also demonstrated challenges and misconceptions in teaching SET because all failed pre-test below 50. The results also showed that none of the females or males scored between above 70% in the pre-test, while in the post-test, 16% (10) and 23%(18) females and males, respectively, scored between above 70 %. In addition, no females scored above 81% and above in the post-test, while 3% (2) of males scored above this range. See figure 5.

Figure 5

SET teacher's performance score distribution per gender in both pre and post-test



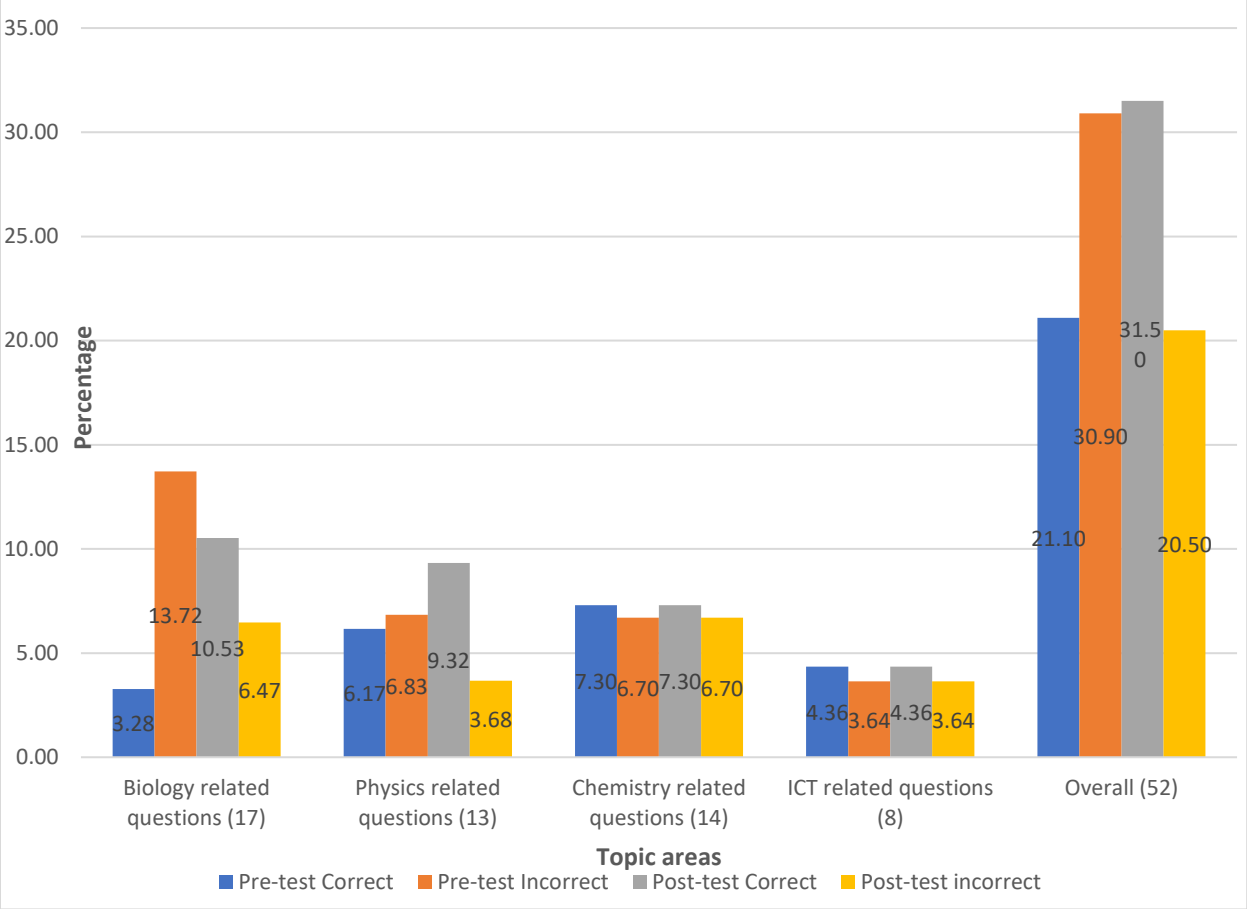
SET teacher performance per topic area

At the completion of the training, SET teachers improved their performance with a gain of 10% (Figure 6). SET teachers answered correctly 32 % of the questions in post-test compared to 21 % in the pre-test. Based on topic areas, among eight questions asked ICT-related questions, 4 (54.45%) were answered correctly, while 4 (45.55%) were answered

incorrectly in both pre-and post-tests. Teachers also scored the same correctly and incorrectly on Chemistry-related questions correctly at the rate of 7 (52.13%) and incorrectly at 7 (47.87%) in the pre and post-test. The rate of answering physics-related questions correctly was increased by 3 (24.27%) from 6 (47.43%) to 10 (71.70%) from pre to post-test, respectively, the same as in biology-related questions, the rate of answering correct answer was increased by 7 (42.65%) from 3 (19.29%) to 11 (61.94%) from pre- to post-test. These results indicate that biology and physics-related questions demonstrate improvement after training, while ICT and chemistry-related questions did not demonstrate improvement.

Figure 6

Correct and incorrect answers in SET subject



Inferential analysis of SET teachers by gender and working experience in the pre-and post-test

The results in Table 2 showed that the obtained *p*-value is less than the expected value of 0.05 ($p < 0.001$) which indicates a statistically significant difference of upper primary SET teachers in pre and post-test in favor of post-test with medium effect size ($\eta = 0.432$). However, there was no significant difference in mean performance of males and

female upper primary (p <0.05, η = 0.018). Furthermore, the result did not also find statistics in terms of teacher working experience with *p-value* of 0.126 with a small effect size (η = 0.021)

Table 2

Inferential analysis of Mathematic teachers' results in pre and post-test, gender and working experience

Effect		Value	F	Hypothesis df	Error df	Sig. (p)	Partial Eta Squared (η)
Test	Wilks' Lambda	.568	104.204[b]	1.000	137.000	.000	.432
Test * Gender	Wilks' Lambda	.982	2.442[b]	1.000	137.000	.120	.018
Test* experience	Wilks' Lambda	.938	1.756[b]	5.000	132.000	.126	0.021

Discussion

Mathematics teacher's performance and content misunderstanding

Generally, teachers performed better in the post-test than pre-test. This indicates Continuous Professional Development (CPD) training plays a pivotal role in enhancing the content knowledge of primary mathematics teachers. Through targeted and ongoing professional development initiatives, teachers gain exposure to updated curriculum standards, innovative teaching methodologies, and best practices in mathematics education. This better performance results from different reasons such as the incorporation of the latest pedagogical approaches, teaching methodologies, and curriculum updates. It also provides exposure to diverse teaching strategies, diverse learning styles, and, and reflective practices. The obtained results are in agreement with O'Meara and Faulkner (2022) who found that CPD training fosters a reflective and collaborative learning environment, allowing teachers to engage with new content, exchange ideas with peers, and apply effective instructional strategies in their classrooms. This was also supported by Srinivasacharlu (2019) who illustrated that CPD training foster a deeper comprehension of mathematical concepts among primary teachers. The impact of CPD training, therefore, extends beyond individual teachers, contributing to an overall improvement in the quality of mathematics education at the primary level. However, there are some topics where teachers captured complexity such as fractions, statistics, and probability. In this regard, this complexity may due to their varied backgrounds, prior knowledge, and the complexity of these topics. A tailored approach, including follow-up sessions and resources, can help address these misunderstandings and improve understanding. Teachers not only showed difficulties in Geometry and Metric measurement but also failed in fraction and Statistics and Elementary Probability topic areas. For instance, Q41, Q45, and Q49, 41%, 13%, and 39%, respectively, were poorly performed in the post-test. This is simply because the area of Statistics and Elementary Probability is newly included in the P6 syllabus. In addition, teachers have failed in the Fraction topic area because they may have been taught this

topic area abstractly, while this topic area should be taught using concrete materials. This poor performance probably may be caused by other factors such as poor motivation, lack of attention, organization of training, teacher's responsibility, experience, and method of assessment.

The obtained results are in good agreement with the study conducted by Maniraho & Christiansen (2015) on Rwandan grade 6 mathematics teachers' knowledge which revealed that Rwandan mathematics teachers performed better in some topics such as numbers and measurement but had misunderstandings in statistics, algebra, geometry, and element of probability. This was also confirmed by Dushimimana and Uworwabayeho (2020) whose they found that Rwandan primary mathematics teachers raised misconceptions that need to be solved in statistics and elements of probability. Also, it seems that the topic area of fractions was difficult for teachers though they received training. We, therefore, concur with Van Luit & Schopman (2000) illustrated that fraction is not only difficult for students but also for primary Mathematics teachers. Similarly, Park et al. (2013) reported that teachers experienced difficulties in fractions, especially while conceiving fractions as numbers that involve the whole number system due to mathematics errors.

Science and Elementary Technology teacher's performance and content misunderstanding

The obtained results showed that Continuous Professional Development (CPD) training has a profound impact on SET teachers' content knowledge after CPD training. This indicates that by engaging in targeted professional development, SET educators gain access to the latest advancements in their respective fields. This exposure translates into a deeper and more nuanced understanding of scientific principles in science and elementary technology. This is in a good agreement with Fraser (2010) who found that CPD training integrate newfound knowledge and instructional techniques in the classrooms. This helps students to benefit from a more enriched and up-to-date educational experience, preparing them for the demands of the rapidly evolving fields of science, engineering, and technology. The impact of CPD training on SET teachers is integral to nurturing a skilled workforce and cultivating a passion for inquiry and innovation among students (Murphy et al., 2015).

Comparing the mean scores of SET teachers who received QBEHCD training, this study found a very high statistically significant difference before and after attending training. As a result of the training, there was also no statistically significant difference in the mean scores between males and females and working experience. The absence of a statistically significant difference in mean scores between male and female teachers and those with varying levels of working experience suggests that the training's benefits are uniformly distributed across gender and experience levels. This finding highlights the inclusivity and broad applicability of the training, affirming its capacity to positively impact a diverse group of SET educators, irrespective of gender or professional background.

However, the results revealed that some teachers still have some misconceptions because even after training, they failed to answer some questions correctly. Especially those misconceptions were observed in biology and chemistry-related questions. For instance, remarkable misconceptions in biology-related questions could be observed

in Q2, Q4, Q8, and Q15. Q2 and Q8 were related to rabbit and chicken farming, respectively. To concretize these lessons, teachers must visit a farming site for a study visit. Q4 and Q15 are associated with the Sensory and respiratory systems, respectively. These concepts are abstract, so trainers must use animation, simulations, and videos to help teachers understand really what happens in the human body. Teachers' misconceptions could be linked to different factors, such that some of its concepts are too abstract and difficult to understand (Byukusenge et al., 2022).

The study also found misunderstandings in chemistry, physics, and ICT-related concepts. For instance, teachers displayed misconceptions about questions pertaining to the state of matter. In this context, it was discovered that some educators have trouble using technical terms like melt, cool, solidify, and liquefy. The present findings are following previous research findings (Fokides & Mastrokoukou 2018; Aligo et al., 2021). For instance, Bayuni et al. (2018) showed primary science teachers demonstrated misconceptions on state of matter topics.

Besides, Kanamugire et al. (2019) who showed a heavy workload for teachers in primary as one of the challenges in grasping all curriculum content. In this regard, it can be said that, on the one hand, the study's teachers did not have enough time to review the material after the training. Therefore, to address teachers' content knowledge and self-efficacy, is important to note that a continuous professional development approach should be used.

Conclusion and implication

The goal of the current study was to determine how well Mathematics and SET teachers' content knowledge and mathematics training have fared. The study also looks into the areas where SET and mathematics teachers misunderstood concepts for potential future improvement. According to the findings, the study shows that CPD training improves Mathematics and SET teachers content knowledge. In addition, the results did not reveal the difference of gained content knowledge in terms of gender and working experience. However, some Mathematics teachers have shown misconceptions in some topics such as fractions, statistics, and probability that require a lot more attention for future instruction. Likewise, the study also showed that some SET teachers still have some misconceptions, particularly in biology and chemistry-related concepts. Future researches also need to concentrate on correlation research design studies that look at the connection between teachers' performance and teaching practice as well as a thorough analysis of the related factors that significantly contribute to these misunderstandings.

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Data availability statement

The data that support the findings of this study are available in the Mendeley repository with the identifier(s) [Data DOI(s) available at https://data.mendeley.com/datasets/6xv7z8rh54/1 and Doi: https://doi.org/10.17632/6xv7z8rh54.1

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