Teaching mathematics supported by the Interactive Mathematics Software for primary schools in Rwanda: Analysis of teachers' perceptions and learning outcomes

Author: Ms. Innocente Uwineza

Supervisor: Prof. Alphonse Uworwabayeho (Ph.D.)

UNIVERSITY of RWANDA

Thesis Submitted to the School of Education of the College of Education of the University of Rwanda in Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Mathematics Education.

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Declaration

This is a declaration that this thesis is entirely original with no submissions made for credit toward any other degree at the University of Rwanda or another university. The approved version is the one that follows after it was deemed acquiescent by the plagiarism system: *Teaching mathematics supported by the Interactive Mathematics Software for primary schools in Rwanda: Analysis of teachers' perceptions and learning outcomes.*

Signature………… ……….

Innocente Uwineza, Registration number: **216366305**

Supervision

Signature… …………….

Supervisor: Prof. Alphonse Uworwabayeho (PhD)

Date: 22nd July 2024

Dedication

To my children: Uwera Ange Bernice, Ikuzwe Christian Regis and Umukiza Aurel Celeste,

To my family,

To my friends.

Acknowledgements

I am profoundly grateful to Almighty God for saving my life, empowering me, and opening doors of support throughout my Ph.D. journey. I also extend my heartfelt thanks to the many individuals, including relatives, friends and colleagues who have supported and contributed to this work, creating stimulating environments from which I have greatly benefited. I am deeply grateful to my supervisor, Professor Alphonse Uworwabayeho (Ph.D.), for his invaluable guidance, coaching, mentoring, and kind-heartedness that were instrumental to the success of this work. I acknowledge his encouragement and patience, which significantly motivated me to persevere with my research during challenging times. I am grateful to Associate Professor L.L. Yadav and the ACEITLMS management team for their invaluable support. Prof. Yadav introduced me to the IM software, and ACEITLMS funded my pilot project, motivating me to consider IM as a technological resource for teaching primary school mathematics in my research. I would like to express my gratitude to the UR-SIDA program for providing a grant for my research project. I am deeply thankful to Dr. Kizito Ndihokubwayo (Ph.D.) for his invaluable assistance in coaching me in data analysis and advising me on important research areas. I also extend my thanks to the UR-CE postgraduate coordinator, UR-CE registrar, and research and innovation administrative officers for their invaluable help with registration and administrative research-related services. I wish to acknowledge the significant role of my parents, sisters, and brothers in my education. Their love, dedication to my education, and support have been the foundation that shaped who I am today, and their support will forever remain etched in my memory. I also wish to recognize my Ph.D. classmates, workmates, and friends for sharing the emotional and intellectual journey with me, offering advice on my work, and sharing their academic experiences. I appreciate their warmth and generosity toward me. I am grateful for the support provided by the primary school leaders and teachers who participated in this study. Finally, I extend my thanks to Mr. Kenya Yokoyama, CEO of SAKURASHA, K.K., and the entire SAKURASHA, K.K. team, along with the JICA agents, especially Ms. Marico Macida, for their collaborative efforts with SAKURASHA, K.K. I deeply appreciate their diligent and intelligent work, which has significantly contributed to the enhancement of quality mathematics education.

Abstract

Modern life, shaped by advanced technologies, prioritizes technology-supported instruction in education systems to ensure quality education and promote sustainable global development. This study aimed to explore teachers' views on the use of Interactive Mathematics (IM) software in teaching and its impact on learning outcomes, focusing on students' performance and conceptual understanding in Rwandan primary schools. The stratified random sampling method was used to select 16 classes assigned to control and experimental groups from 4 public and 3 private schools. Purposive and convenient sampling methods were used to select seven teachers. Guided by the post-positivist paradigm, mixed research methods, through a quasi-experimental design, were employed to collect data via tests and interviews. Before and after the teaching intervention, a test was administered to the traditional and the IM groups to assess students' baseline knowledge equivalence and the effect of IM on learning outcomes, respectively. This study was supported by the frameworks of Technological Pedagogical Content Knowledge (TPACK), the Theory of Acceptance Model (TAM), and the Cognitive Theory of Multimedia Learning (CTML). Learners' pre- and post-test results were analyzed with SPSS 23.0 and MS Excel 2016 using descriptive and inferential statistics. The qualitative data from semi-structured interviews was thematically analyzed with an inductive coding method using Taguette software. The findings indicated that the IM class performed better than the traditional class. In primary 5, the mean pre-test score was 39.56 (SD=19.77), and the mean post-test score was 64.83 (SD=18.46), with $p<.001$, $f=1.32$, and $g=.41$. Moreover, IM demonstrated an effect on learning outcomes between the control and experimental groups when all classes were combined. Additionally, findings indicated an improvement in conceptual understanding through the use of IM, as evidenced by an increase in the percentage of learners who performed well on items across the two tests and by the improvement of learners' sample works from the pre-test to the post-test. From inferential statistics, the ANOVA indicated that private school learners performed better than public school learners in the IM environment, though the effect was weak (effect size of $\eta^2 = 0.016$ in the post-test). Furthermore, the findings indicated better improvement in upper primary learners' performance than lower primary learners' through the use of IM, with a strong effect (effect size $\eta^2 = 0.269$ in the post-test). From the interviews, inductive coding through open, axial, and selective coding generated three themes presented by all teachers (100%) through various codes. Teachers' perceptions consisted of the disadvantages of the traditional teaching method, the benefits, and the challenges of using IM in the teaching process. The results had implications for primary school teachers' training programs in technology-supported instruction for effective curriculum implementation. Moreover, the implications extend to re-examining TPACK-based studies in classroom practices with a focus on the perceptions of technology users. Various contributions were explained, and recommendations for effective integration of IM into the competence-based curriculum were discussed. For generalizability purposes, suggestions for further similar studies using standardized tools and other scientific methods were formulated.

Key words: Interactive Mathematics software, learning outcomes, mathematics education, perceptions, technology, TPACK.

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List of acronyms and abbreviations

ACEITLMS: African Centre of Excellence in Innovative Teaching and Learning Mathematics and Science

CBC: Competence- Based curriculum

CEO: Company Executive Officer

ICT: Information and Communication Technology

IM: Interactive Mathematics

JICA: Japan International Corporation Agency

12YBE: Twelve Years Basic Education

9YBE: Nine Years Basic Education

EDPRS: Economic Development and Poverty Reduction Strategy

EFA: Education For All

OLPC: One Laptop per Child

Ph.D.: Philosophiae Doctor or Doctor of Philosophy

REB: Rwanda Education Board

SSA: Sub-Saharan Africa

SDG4: Strategic Development Goal four

STEM: Science, Technology, Engineering and Mathematics

SPSS: Statistical Package for the Social Sciences

UR-CE: University of Rwanda, College of Education

UR-SIDA: University of Rwanda-Swedish International Development Cooperation Agency

List of publication related to the Thesis

This thesis was designed based on the following publications:

1) Uwineza, I., Uworwabayeho, A., Yokoyama, K. (2023a). Effects of Interactive Mathematics Software on Grade-5 Learners' Performance. *International Journal of Learning and Educational Research, 22*(1), 166-190. https://doi.org/10.26803/ijlter.22.1.10

2) Uwineza, I., Uworwabayeho, A., Yokoyama, K. (2023b). Grade-3 Learners' Performance and Conceptual Understanding Development in Technology-Enhanced Teaching With

Interactive Mathematics Software. *European Journal of Educational Research, 11*(1), 69–81. https://doi.org/10.12973/eu-jer.12.2.759

3) Uwineza, I., Uworwabayeho, A., Yokoyama, K. (2023c). Lower and upper primary learners' difference in performance and conceptual understanding: Support of interactive mathematics software for Rwanda. *Education and Information Technologies*. https://doi.org/10.1007/s10639-023-11860-z

4) Uwineza, I., Uworwabayeho, A., Yokoyama, K. (2023d). Perceptions of using interactive mathematics software among Rwandan primary school teachers. *Cogent Education, 10*(1). https://doi.org/10.1080/2331186X.2023.2170113

List of conference presentations

The following is a list of conferences attended by the researcher in relation to the present study. Oral presentations and posters related to this thesis were presented in the first three conferences:

1) The 1st International Conference on Reshaping Education for Sustainable Development. March 2023, Kigali, Rwanda.
2) The 43rd International conference of the International Group for the Psychology of Mathematics Education (PME 43). July 2019, Pretoria, South Africa.

3) The 4th and the 5th Strathmore International Mathematics conferences (SIMC). June 2017 and August 2019, Nairobi, Kenya.
4) The 5th Africa Regional Congress of ICMI on Mathematical Education (AFRICME 5). August 2018, Dare-salaam, Tanzania.
5) The 8th International Conference to Review Research in Science, Technology and Mathematics Education (epiSTEME8). January 2020, Mumbai, India

Chapter I: Introduction

The present chapter provides readers with an overview of the research. The chapter begins by detailing background information on the study by highlighting the global situation of ICT in education and issues in mathematics education, as well as the Rwandan situation. It proceeds by stating the problem under study, the study aim and importance, the study scope and limitation, the study paradigm, theoretical and conceptual frameworks, a brief methodology description, the study contribution to knowledge, the thesis structure, and the chapter summary.

1.1. Study background

1.1.1. Trends in quality education across education systems

Quality education achievement is a common goal for education systems worldwide to secure sustained economic expansion. To that end, the United Nations (UN) has set out one of its sustainable development goals (SDGs) as "ensuring inclusive and equitable quality education and promoting opportunities for lifelong learning for everyone" (Ministry of Education, 2018a, p. 5). The acquisition of high scores and fostering conceptual understanding are among the objectives of high-quality mathematics education (Taram, Rahmawati, Rustaman, & Hamidah, 2018). Mathematical proficiency strands include mathematical understanding and performance (Haji, 2019; Serantos, Georgios, & Michail, 2013; Mendezabal, & Tindowen, 2018). Education systems are eager to achieve quality mathematics teaching and learning due to issues like inadequate pedagogies (Madaki, 2021). Currently, the world is being transformed by the promotion of technology and everyday life connections under the 4th industrial revolution (Alaloul, Liew, Zawawi, & Kennedy, 2020; Azid et al., 2020). In education, this revolution focuses on influencing school curricula to adjust to the demands of the job market by raising the minimum educational standards (Popović, 2020). Although the past decades have been marked by advancements in mathematics education due to technology integration, discrepancies in mathematics achievement between developed and developing countries persist (Bethell, 2016). According to Bethell (2016), reports about mathematics performance in international competition reveal that students from developing countries, especially from African education systems, perform poorer than those from developed countries. Furthermore, studies mention that, traditional educational practices dominate today's teaching and learning activities and that the use of educational technologies is still in emergence (Hussin, 2018; Madaki, 2021). Other studies have noted that most African countries are far from being aware of and ready to accommodate the 4IR (Ukobizaba, Nsabayezu, & Uworwabayeho, 2022). This reflects the ever-widening gap in quality education and sustainable development achievement through education between developed and developing countries. Nonetheless, educational technology has experienced robust growth in the Sub-Saharan Africa region over the past few years (Madaki, 2021). Various studies have pointed out that some Sub-Saharan African (SSA) education systems have made technology integration in the classroom a top priority to improve instruction quality and to support young people in facing challenges related to globalization and the labor force (Byungura, Hansson, Masengesho, & Karunaratne, 2016; Lee, Siew, Cher, & Hwee, 2012).

When intentionally used in classroom activities, new digital technology in SSA has been shown to enhance the quality of topic teaching and learning (Hennessy, 2010). In order to mitigate pedagogical difficulties and achieve high-quality learning outcomes, education institutions are heavily incorporating a variety of interactive, engaging, and readily available technology into the teaching of basic mathematics. Wolf, Aber, Behrman, and Tsinigo, (2019) found that mobile device-accessible interactive learning and SMS-based quiz apps give students new learning opportunities by allowing them to practice mathematics outside of the classroom. As for Donkor and Tagoe (2021), Google Classroom systems and the Moodle platform facilitate online instructional activities and increase access to online materials. Furthermore, unlike traditional teaching styles, successful lessons that grab students' attention can be delivered using interactive whiteboards and a modernized classroom (Hennessy, 2010). However, effective technology integration in teaching results from teachers' attitudes, expertise, readiness, and confidence in using ICT support.

Drawing on SDG4, the Rwandan education system is ambitious to deliver quality education at an exceptional level in the region (Ministry of Education, 2018a). The system has made significant improvements, including the implementation of free education for all (EFA), the promotion of sciences and mathematics-related subjects, and the administration of the competence-based curriculum (CBC) since 2015 (Ministry of Education, 2018a). Educational technologies were identified as suitable to mitigate barriers to the CBC effective implementation which include lack of teaching resources, inadequate pedagogies and poor learning outcomes. This new curriculum dramatically altered teachers' continuous professional development programs and gave rise to numerous drives and interventions. For example, the One Laptop per Child (OLPC) initiative supplied laptops and XO machines for teachers and learners. Later, schools were equipped with ICT infrastructures under the Smart Classroom program (Ministry of Education, 2016). Since then, some laptops supplied and other ICT appliances were simply used in administrative activities, while others (e.g., XOs) were steadily declining day after day at school supply stores without being used in any classroom activities. In addition to that, there are other projects aimed at teacher professional development programs for raising teachers' teaching competences in effectively implementing the CBC. For example, from 2017 through 2019, a World Bank project entitled Mathematics and Science for Sub-Saharan Africa (MS4SSA) tackled teacher training programs in ICT and pedagogy in mathematics and other science subjects. That project was hosted by the African Centre of Excellence in Innovative Teaching and Learning Mathematics and Sciences at the University of Rwanda, College of Education (UR-CE) and focused only on high school level. Supplementing the MS4SSA, Quality Basic Education for Human Capital Development (RQBEHCD), another World Bank-run project in Rwanda, aims at promoting learner-centered methods and ICT in mathematics and science subjects at the basic education level (including the primary school level). The improvement of mathematics education in the education system of Rwanda benefited tremendously from these projects (Nkundabakura, Nsengimana, Uwizeyimana, Mbonyiryivuze, & Ukobizaba, 2023; Nsengimana, Nkundabakura, Iyamuremye, Mutarutinya, Mugabo, & Nsabayezu, 2024). This underscores the progress so far achieved in the pursuit of quality teaching and learning in the Rwandan education system.

While competence-based teaching encompasses skills beyond traditional teaching methods, it was found that numerous teachers in Rwanda are not ICT proficient (Ndihokubwayo, & Habiyaremye, 2018; Mugiraneza, 2021). Thus, the promotion of learner-centered teaching techniques and ICT use to support classroom practices are still unachieved milestones, especially at the public primary school level. Issues including populated classrooms, teachers' heavy teaching load, insufficient teaching resources, poor pedagogies, and ICT skills (Ministry of Education, 2016; Nyirahabimana, & Twagilimana, 2019; Nizeyimana, Nzabalirwa, Mukingambeho, & Nkiliye, 2021; Umuhoza, & Uworwabayeho, 202) dominate public primary schools in Rwanda.

Specifically, it was said that the student-teacher ratio in public schools was higher (50:1) than in private schools (30:1) (Ministry of Education, 2018b), which affects instruction differently in favor of private schools. This highlights the disparity in mathematics instruction between the two types of schools, with individualized attention in favor of private schools. Moreover, annual evaluations from the national examination and school authority (NESA) indicate that private school learners' consistently performed better than public schools' in all subjects, including mathematics. In 2019, 94% of private school pupils passed mathematics, compared to 49% in public schools. By 2021, private school pass rates had decreased to 81%, while public school rates had increased to 56%. In 2022, private schools again led, with 88% passing, while public schools remained at 56%. A similar pass rate trend was reported for ordinary educational level (grade 7, grade 8, and grade 9) national leaving examinations for the same school years: 65.4% in 2019; 82.4% in 2021; and 91.9% in 2022 (for private schools) against 46.7% in 2019; 77.2% in 2021; and 88.3% in 2022 (for public schools) (NESA, 2023). Yet, lots of learners enroll in these types of schools because they are financially affordable compared to private schools that enroll learners from wealthier families. This underscores the need to find strategies to improve mathematics instruction at the primary public school level. This study contributes to unveiling how IM can support quality teaching of mathematics at the primary school level and how public schools can mitigate pedagogical issues in mathematics classes using IM.

1.1.2. The Interactive Mathematics Software for Primary Schools in Rwanda

The education system of Rwanda had prioritized ICT-supported teaching to improve instruction and assist in the achievement of desired quality education (Ministry of Education, 2018a). In this line, the Rwanda Basic Education Board (REB) collaborated with a Japanese company, SAKURASHA K.K., through JICA and created the Interactive Mathematics (IM) software for primary school curriculum, drawing from the IM software used in Japan. IM for Rwanda was developed with the intention of being installed in primary schools' teachers' laptops and students' XOs to promote the successful teaching of mathematics. Unlike other mathematical software, whose effective use requires the user's advanced computer skills to design ICT-enhanced mathematics activities, IM is specific and appropriate for primary school-level learners and teachers. Developed based on the CBC of mathematics at the primary school level, IM software settings cater to primary teachers' and learners' learning abilities and interests. Effective use of IM encompasses simple basic ICT skills like switching on and off a computer, opening and closing the software, and using a mouse to navigate the IM content. Easy to install by simply copying and pasting it, IM is not yet available online. The completely developed IM version is not editable. It is interactive and allows the instructor and the students to interact with mathematical objects using a mouse.

The IM settings consist of three levels of understanding, quick exercises, and evaluation. At the understanding level, learners are engaged in exploring unknown relationships by manipulating semi-concrete mathematical objects presented as attractive pictures associated with sounds, movements, and text. This level triggers learners' questions like, "What kind of mechanism is it?" By undertaking several repeated activities using different exercises at the understanding level, learners manage to figure out and progressively grasp clear relationships. After understanding relationships, learners are taken to the next level, where mathematical objects are presented in an abstract way to practice multiple times. Sometimes, they switch back to an understanding level whenever they forget the relationship and return to quick exercises. At the evaluation stage of IM content, learners perform several exercises rewarded by the software for a correct or wrong answer. At that level, learners can also check the answer.

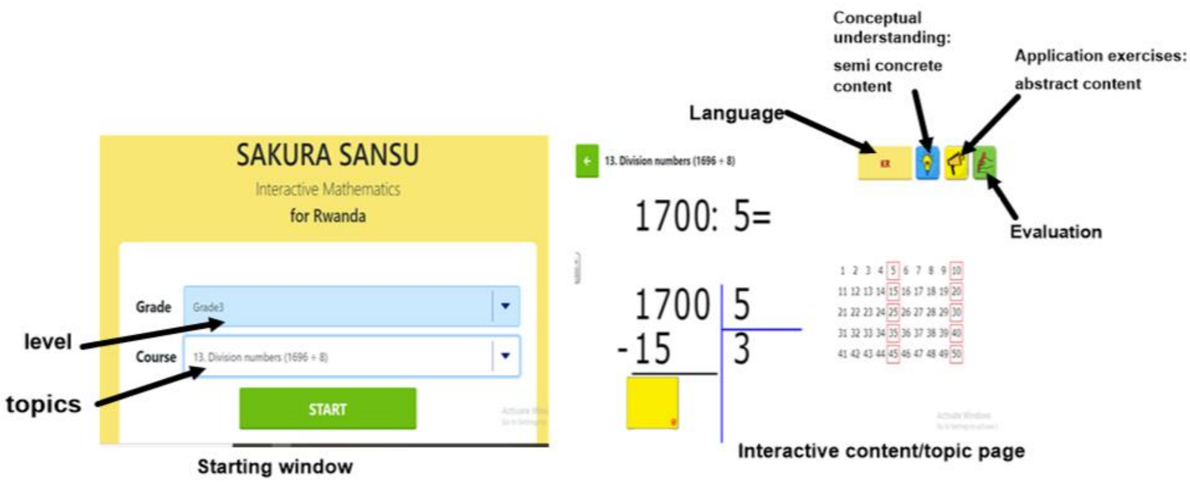

Figure 1. Screenshot of IM content outlook of starting window (left), and topic page (right)

From 2019 to 2022, the formal piloting of IM in Rwandan primary schools provided an opportunity for a researcher with a background in curriculum and instruction in mathematics to scientifically investigate its academic merits in promoting quality mathematics education at the primary school level through technology-supported instruction. The aim of that activity consisted of verifying the effectiveness of the localized IM to enhance math instruction by instructors and math learning accomplishment by students by using ICT through the verification of IM's introduction into six Kigali primary schools equipped with necessary facilities such as OLPC laptops and so forth (https://libopac.jica.go.jp/images/report/1000048943.pdf).

During this activity, the researcher collaborated with the SAKURASHA team and mathematics teachers to conduct the piloting of IM in a normal classroom situation and follow the planned scheme of work. As new interactive software for teachers and learners of primary schools in Rwanda, the researcher was motivated to scientifically investigate IM about its academic merits of boosting quality education before it is recommended to be used as an instructional tool supporting the CBC implementation in Rwandan primary schools. Therefore, this study was drawn from research articles that were developed from data collected during IM piloting in normal class settings and published in international journals.

1.2. Research problem description

The use of learner-centered teaching methods supported by educational technology is recommended to achieve effective CBC implementation. Thus, the teachers' technologically enhanced teaching competencies in terms of knowledge, skills, and perceptions are of paramount importance. However, primary schools in Rwanda face hindrances to effectively implementing the CBC. Elementary classrooms are overpopulated with high student-teacher ratios (Ministry of Education, 2018a). Studies found that some in-service teachers in Rwanda teach without sufficient content knowledge (Habiyaremye, Ntivuguruzwa, & Ntawiha, 2023) and knowledge about ICT tools (Mugiraneza, 2021). Moreover, the existence of students' negative attitudes towards mathematics, including anxiety and lack of confidence, creates a gender gap in learning outcomes (Uwineza, Rubagiza, Hakizimana, & Uwamahoro, 2018). In addition, the chalk-and-talk teaching strategies, which promote a teacher-centered teaching approach, dominate primary school mathematics classes.

Therefore, improving pedagogical practices by promoting ICT-supported teaching and learning processes that advance learner-centered teaching strategies should be encouraged in basic education in Rwanda. In fact, it was found that learner-centered teaching methods are better than traditional teacher-centered approaches because they foster learners' confidence in subject mastery, in-depth understanding and long-term memory storage of knowledge, the development of analytical reasoning while solving problems, and the development of favorable perceptions of the material being presented (Pereira & Sithole, 2020). Furthermore, it was mentioned that customizing lessons to meet each learner's learning needs is one of the most successful ways that technology may be used in the classroom (Ringstaff & Kelley, 2002). Therefore, conducting research on IM as an educational technology designed particularly for the primary school level and emphasizing learning through manipulation of concrete and semi-concrete mathematics knowledge with teachers' simple ICT skills may contribute to promoting the achievement of desired learning outcomes for quality mathematics education.

1.3. Research aim, specific objectives, and questions

The present study investigates IM-supported teaching effects on learning outcomes.

Following specific objectives allowed the achievement of the research aim:

a) To find out the effects of IM-supported teaching on learning outcomes across all selected primary school levels.

b) To comparatively analyze the results of IM-supported instruction in selected schools' upper and lower primary levels.

c) To explore teachers' perceptions of using IM in classroom practices and their importance to the achievement of quality learning outcomes.

To achieve these objectives, this research was guided by questions that follow:

a) What are the effects of IM-supported teaching on learning outcomes at all selected primary school levels?

b) How did IM-enhanced teaching affect mathematics learning outcomes differently at lower and upper primary schools' levels?

c) How did teachers perceive IM-enhanced mathematics instruction and related quality learning activities?

1.4. Scope of the study and limitations

As social activities, teaching and learning are affected by various factors that may be manageable or not and that impact the quality of learning outcomes. These include the teachers' competencies, the instructional tools, and the teachers and learners attitudes towards a particular subject. As a part of IM piloting, this study's focus was limited to IM software use in teaching mathematics at primary public and private schools in Kigali City. It investigated learners' outcomes with a focus on performance and conceptual understanding. It also tackled teachers' perceptions of IM use. Research activities were conducted during the first terms of 2019–2020 and 2022, as interventions were limited to available IM content, which was found to be on the schemes of work of the first terms.

1.5. Importance of the study

The modern world is driven by ICT, which has permeated every aspect of existence. Given the current barriers to educational globalization, labor market demands, and competition for daily survival, ICT knowledge and use are unavoidable prerequisites in education to support young people in fitting into their future lives. Thus, it is crucial to redesign education now to accommodate the realities of tomorrow. Given how quickly ICT is encroaching on every aspect of life, increasing ICT use in classrooms should be a priority so that students may acquire ICT skills through learning with and from ICT. For the sake of learning and to prepare them for higher educational levels, it is important for educators to use ICT as an instructional tool from the primary school level to effectively teach and assist learners in becoming accustomed to using ICT tools at an early age. Focusing on this level can be a way of promoting the achievement of SDG4 goals. This study serves as a contribution to enriching the literature on technology-enhanced mathematics education at the primary school level using IM software. It also contributes to preparing the youth to keep up with a knowledge- and technology-driven society (Halai, & Tennant, 2016).

1.6. Study paradigm

According to Khatri (2020), a paradigm refers to a theoretical or philosophical ground for the research work. It “defines a researcher’s philosophical orientation and exerts significant implications for every decision made in the research process, including the nature of reality, types and sources of knowledge, and choice of methodology and methods, (Khatri, 2020, p. 1346)”. Thus, it explains the study’s position on reality’s nature (ontology), how and where to get knowledge (epistemology), axiology, and methodology (Rosida, Amaliah, Mahardika, & Suratno, 2023).

There exist multiple paradigms as there are various educational researches. Positivist paradigms focus on highly objective investigations related to those in the natural sciences, validating or invalidating components through empirical analysis (Taylor, & Medina, 2011). These paradigms are prevalent in the social sciences with large sample sizes but may overlook individual influences. According to Stoilescu (2021), there exist constructivist paradigms that emphasize how learners understand and teachers assist students during knowledge acquisition. Accordingly, constructivist ideas are elaborated into social constructivists through the use of artifacts, including technology, and peer participation in classroom activities. Educational research also acknowledges interpretive philosophies that take into account personal influences and qualitative elements of educational experiences on knowledge development (Khatri 2020; Creswell 2014). In light of interpretive paradigms, Khatri (2020) advanced the idea that social consciousness, common understanding, and artifacts are the sources of knowledge. In addition, post-positivist paradigms extend from the interplay of positivist and interpretive perspectives (Panhwar, Ansari, & Shah, 2017). According to Taylor and Medina (2011), post-positivist paradigms overcome the drawbacks of positivism in the social sciences by promoting the use of diverse research techniques and perspectives to advance the understanding of the phenomena under study. Thus, the conduct of this study adhered to post-positivist viewpoints.

The adoption of post-positivists draws on their adaptability to a range of various research methods, which is consistent with the study's focus on IM-supported teaching and learning at the primary school level. This paradigm prioritizes contextual factors and guarantees that the study accurately reflects the natural researchable conditions and provides unbiased and objective results (Taylor, & Medina, 2011). Thus, this paradigm values all results as crucial to expanding knowledge and promotes the triangulation of qualitative and quantitative methods (Panhwar et al., 2017). Qualitative methods and quasi-experimentally designed quantitative methods are the mixed methods considered in this study. Triangulating these two methods aims at offering a complete representation of the impact of IM on mathematics classroom activities in primary schools in Rwanda.

This study's epistemological stance is based on a positivist argument asserting that knowledge is derived from factual observation and measurement (Al-Saadi, 2014) and on an interpretivist's consideration of the mutual interaction between researchers and the social world under study (Al-Saadi, 2014). It is also inspired by perspectives promoting multiple sources in knowledge creation and arguing against the limitations of other approaches in capturing the complexities of reality (Turyahikayo, 2021). This study's positivist standpoint consists of conducting a quasi-experimental design to observe and analyze learning outcomes in terms of conceptual understanding and performance. Given that teaching is a social action that fosters interactions between teachers, learners, and instructional tools, it is crucial to interpret quantitative data to better understand the phenomenon under study. In fact, post-positivist epistemology advances the idea that knowledge is not absolute but constructed through inquiry to find what works (Panhwar et al., 2017). This philosophical position gives researchers the freedom to use diverse approaches and methods, which is essential for conducting mixed-methods studies that explore different viewpoints and assumptions (Creswell, 2014). Thus, this study triangulated quantitative and qualitative methods to effectively investigate the impact of IM on learning outcomes and perceptions.

Furthermore, this study ontology is drawn from constructionism, which contends that reality is approximate and socially constructed through ongoing interactions (Al-Saadi, 2014). It recognizes that learning outcomes are influenced by various factors, including teaching competencies, learning environments, and contextual elements. Knowledge production in this context focuses on understanding the meanings and interpretations constructed by social actors, including researchers themselves (Al-Saadi, 2014). In terms of axiology, this study acknowledges the researcher's influence on qualitative data through interactions with participants and during data processing and interpretation. In spite of this intrinsic bias, the post-positivist paradigm pluralistic approach strives for more objective judgments by reducing individual subjectivity and prejudices (Turyahikayo, 2021). Nevertheless, based on the variety of research approaches valued in educational research, the generalization of the study's findings should result from investigation (Turyahikayo, 2021).

1.7. Theoretical framework

1.7.1. The technological pedagogical content knowledge framework (TPACK)

Introduced by Punya Mishra and Matthew Koehler in 2006 (Sri, & Mardhiyah, 2019; Soler-Costa, Moreno-Guerrero, López-Belmonte,, & Marín-Marín, 2021), technology pedagogical content knowledge (TPACK) supported this study in terms of teachers' competences to teach with technology. TPACK is likely one of the instructional strategies that is now gaining ground on others in terms of successfully encouraging efficient technology inclusion into classroom educational practices (Soler-Costa et al., 2021). The notion of TPACK emerged from pedagogical content knowledge (PCK), which was first introduced by Shulman in 1986. This framework aimed to explain the high-quality information that teachers needed to succeed in their jobs. With the introduction of educational technologies, a pedagogical paradigm shift was hinted at, which altered how students and teachers interacted and learned in a technologically advanced setting. Thus, the phenomenon of educators using technology in their teaching gave rise to a new model known as the TPACK model (Koehler, Mishra, & Cain, 2013). Accordingly, effective teachers' TPACK level results from a simultaneous manifestation of integrated mastery of the content, pedagogy, and technological pedagogical strategies to influence quality teaching and learning.

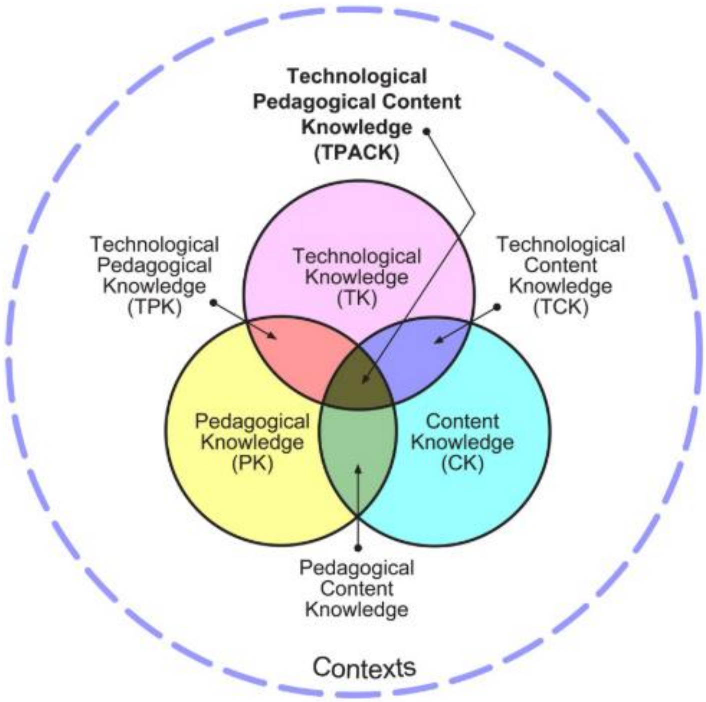

Figure 2. TPACK framework components (Koehler et al., 2013, p. 63)

Taopan (2020) claims that TPACK is a dynamic framework that defines the knowledge required for educators to plan, carry out, and assess technology-based curriculum and instruction for effective teaching in a technology-enhanced environment. An extended TPACK model was produced by conceptually analyzing the breadth of instructors' technological pedagogical content knowledge. Teachers' abilities to integrate topic-specific representations with activities appropriate to particular subjects (pedagogy) utilizing cutting-edge technology to support student learning were described as the elaborated TPACK model (Cox, & Graham, 2009). Furthermore, a new contextualized version of TPACK was developed in response to concerns over its pedagogical elements, and it can be used in Taiwan's elementary and secondary educational settings (Jang, & Tsar, 2013). The findings demonstrated a significant variation in TPACK between teaching experience and gender among secondary school science instructors, with male teachers having more experience and having taught science courses (Jang, & Tsar, 2013). Another study discovered that there were notable variations in the TPACK competencies of instructors between differently accredited schools and between qualified and non-qualified teachers working at the same institution (Busnawir, Aryanti, Sumarna, Kodirun,, & Samparadja, 2023). A study found a moderately positive correlation between TPACK abilities and instructors' opinions toward computer-assisted instruction (Baturay, Gökçearslan, & Sahin, 2017). Additionally, there was a correlation between pre-service teachers' TPACK, their values towards incorporating simulations into the classroom, and their opinions on the value of simulations (Lehtinen et al., 2016). However, it was discovered that teachers' attitudes and TPACK considerably predicted their use of technology (Raygan, & Moradkhani, 2022). Thus, the TPACK framework may be conceptualized differently depending on the context and the scope of teachers' knowledge. Furthermore, a study found a divergence between teachers' self-reported TPACK and their actual knowledge of technology, also referred to as the jingle-jangle fallacy (Schubatzky, Burde, Große-Heilmann, Haagen-Schützenhöfer, Riese, & Weiler, 2023). TPACK as a competency, it was assumed that teachers may be just exposed to particular technologies and possible curriculum standards to develop their TPACK knowledge, which implied more studying technology than how to use it in an educational setting (Koehler et al., 2013). However, competency development results from gaining a suitable blend of abilities, attitudes, and knowledge (REB, 2015). Therefore, teachers' mere exposure to educational technology cannot be enough to develop TPACK competencies. Enough teacher training and practices about educational technology should be conducted prior to undertaking technology-supported teaching in normal class situations. Moreover, teachers' values attributed to that tool should also be considered.

Existing literature from international databases explores the TPACK theoretical framework in education, focusing on pre-service and in-service instructors' professional growth (Moreno, Montoro,, & Colón, 2019). This framework was found in studies focusing on all educational levels, from pre-primary to tertiary educational levels, where the most common research types were found to be mixed studies, case studies, and empirical studies (Moreno et al., 2019). It was found that technology-enhanced teaching and learning activities may create an inspiring, motivating, and engaging teaching and learning environment that fosters professional development and offers various opportunities for multifaceted products (Abubakir, & Alshaboul, 2023). Considering that educational technologies are differently designed, their effective integration into classroom activities encompasses appropriate strategies to effectively benefit learning outcomes. According to Halai and Tennant (2016), different methods may be applied to integrate ICT into educational classroom practices. Accordingly, laptops or desktop computers may be used through the teacher's presentations (e.g., with PowerPoints), demonstrations (e.g., using a geometer sketchpad), or through learners' individual or group activities while being facilitated by the teacher (Halai, & Tennant, 2016). Nevertheless, given the difficulties that more recent technologies provide for educators, integrating technology into classroom activities effectively is highly difficult (Koehler et al., 2013). Teachers must overcome obstacles including internet connectivity, IT literacy, and a lack of creativity to develop technology-based assignments that are useful (Abubakir, & Alshaboul, 2023) and how they view technology-supported teaching combined with their limited strategies to teach a particular topic meaningfully (Nurwahidah, 2023). Nonetheless, educational technologies can benefit teaching and learning activities once they are effectively integrated into classroom practices.

During the present study, teachers' TPACK manifested at the level of IM-enhanced lesson preparation and mathematical content presentation supported by IM manipulation. Thus, learning outcomes achieved in an IM-enhanced learning environment resulted from the teachers' TPACK level of preparing and delivering IM-supported lessons. While considering teachers' TPACK knowledge as any other competence that develops from the interplay of cognitive, psychomotor, and affective knowledge domains, the choice of a new educational technology in education seems to influence the users' perceptions about its effectiveness and the innovation it brings to the existing system. Thus, theories supporting technology users' acceptance and related literature are worth exploring.

1.7.2. Technology acceptance model (TAM)

The technology acceptance model (TAM) introduced in 1989 by Davis supported this study's teaching side in addition to the TPACK framework. TAM explains the importance of technology user population behavior (Lee, Kozar, & Larsen, 2003) on the effectiveness of technology-supported activities. According to Davis Lee et al. (2003), the acceptance of technology in a system results from the interplay between the perceived degree to which technology would enhance job performance (usefulness) and its perceived degree to require less effort to use it or its perceived ease of use. Momani (2020) argues that technology users' perceptions and evaluations of its usability and ability to achieve desired goals determine how satisfied they are with the technology and how effectively they use it. Thus, the perceived technological usefulness or ease of use may result in its users' likes or dislikes, which may affect technology-supported instruction and outcomes. Similarly, considering perceived technological long-term benefits like workload reduction and performance improvement can enhance technology usefulness and simplicity of use (Sun, Lee,, & Law, 2019). Previous research has indicated that the two main variables of TAM that have been shown to be precursors to technology acceptance are perceived utility and ease of use (Grani, & Marangunic, 2019). Additionally, the TAM studies that are currently in existence have characterized simplicity of use and usefulness of technology as significant factors that influence intentions to embrace new systems (Lee et al., 2003).

Consequently, it is important to consider an institution's cultural values, educational settings, and technology users' perceptions of technology's usability and usefulness. This should allow the analysis of technology-enhanced learning outcomes by taking into account the teachers' technological competence levels, which are a function of their perceptions of technology-supported teaching. Teachers' views about technology-supported teaching have been a variable for numerous scientific studies that found its effects on promoting students' enjoyment, engagement, and effective learning (Mundy, Kupczunski, & Kee, 2012).

A study conducted by Jannah in 2020 indicates that, teachers' perceptions of improving learning outcomes should draw on learners' increased motivation, enjoyment, and capacity for analytical thinking. According to a pre-primary survey, the majority of teachers had positive attitudes towards the use of ICT in teaching and administration, although some expressed mild misgivings because of worries about teachers' ICT resources and skills (Chen, Chen, Lin, & Liu, 2019). The ways teachers consider the use of technology in education influence learning outcomes. It follows that thinking about teachers' attitudes and roles in relation to educational technology should lead to better learning, drawing on the idea that some educators view technology as a tool that supports rather than suppresses their function (Chen et al., 2019).

Thus, while TPACK informs this study regarding teachers' abilities to teach using IM, TAM contributes insights into teachers' perceptions of IM-supported teaching. Consequently, teachers' TPACK levels and their perceptions of IM use are hypothesized to influence IM-supported teaching and learning outcomes, as illustrated in the conceptual framework (see next figure).

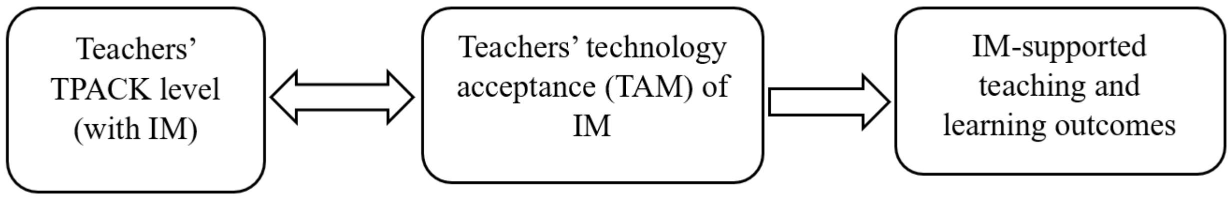

Figure 3: TPACK, TAM and learning outcomes relationships (Source: authors' own conceptualization)

1.7.3. Theory of learning in technology supported environment

This study was grounded not only in theories of technology-supported teaching but also in Mayer's (1998) cognitive theory, which advocates for efficient learning in a multimedia environment. According to GebreYohannes et al. (2016), multimedia refers to computer-mediated software that integrates text, color, diagrams, audio, and animation or video motion into a single application. Mayer's Cognitive Theory of Multimedia Learning (CTML), developed in 1998, is rooted in cognitivist principles and pertains to learning within multimedia contexts. CTML is considered an effective theory for enhancing learning through instructional multimedia (Rudolph, 2017). The CTML has long proven useful for adult learners who can learn independently with the aid of educational multimedia resources (Rudolph, 2017). By considering the current educational technology advancements, the CTML should adapt to the multimedia learning environment with a particular focus on basic education that fosters the teacher's presence indispensably. Thus, more intervention studies that promote learner-centered pedagogies at that educational level are much needed for quality learning improvement. Sorden (2012) contends that increased scores on students' tasks and exams show that the CTML promotes students' active and meaningful learning.

Multimedia in a mathematics learning environment combines both traditional modes of teaching using chalk and blackboard with computer-based educational materials like graphs and animation (Milovanovic, Perišic, Vukotic, Bugarcic, Radovanovic,, & Ristic, 2016) using delivery media like a computer and a projector (Bhatti, Mahesar, Bhutto,, & Chandio, 2017). This allows learners to engage with the material, their peers, and the teacher to build knowledge and cultivate higher-order thinking abilities (Ringstaff, & Kelley, 2002). It was argued that contemporary multimedia approaches to learning may suit various levels of education and with varying degrees of involvement (Milovanovic et al., 2016).

According to Ojose (2008), mathematics learning moves progressively from performing operations and solving concrete problems logically in one direction to solving abstract problems in a logical fashion in accordance with Piaget's idea of cognitive growth. It follows a hierarchy of content where learning one topic draws on the prerequisite knowledge that must be understood before the next topic is introduced (Murphy, 2016). According to Jalinus and Alim (2019), the quality of mathematical knowledge is improved when ICT technologies are used in the instruction being taught, as they are adaptive to students' age and educational level, making them perform and enjoy the lesson accordingly. It was also pointed out that technology-enhanced pedagogies promote motivation for learning and a longer attention span, better teacher-student and student-student interaction, learners' confidence and deeper conceptual understanding, and the acquisition of in-depth critical thinking abilities in high school (Murphy, 2016) and elementary school levels (Asodike, & Jaja, 2012).

In the USA, a teacher-researchers' study found middle school students' increased motivation, active learning, and engagement with objective-driven behaviors during the utilization of technology and after intervention (Godzicki, Godzicki, Krofel, & Michaels, 2013). It was also mentioned that at the pre-primary school level, learners' developmental errors (e.g., in language) may be prevented, corrected, and eliminated through various technology-supported activities, games, and exercises (Gabaľová, Stoffová, & Kočišová, 2022). Therefore, technology use in education promotes quality learning across all educational levels.

In the Rwandan education system, primary-level learners' ages range from 6 to 11 years, during which learning takes place through solving concrete problems using hands-on activities based on Piaget's concrete operational stage. Primary education is organized into six levels, grouped into lower primary, which focuses on learners' acquisition of numeracy and literacy skills, and upper primary, which trains early analytical reasoning and problem-solving abilities in students. Therefore, the design of educational technologies should draw from learners' needs. Thus, considering the different learning focuses at the two education levels, this may imply differences in IM-supported achievements. Effective technology use in education should consider learners' educational level and cognitive development to acquire the desired quality learning outcomes. According to Milovanovic et al. (2016), this study concentrated more on using ICT for mathematics instruction in a multimedia setting while still employing the chalk and blackboard approach. The IM software utilized in this study, which contains multimedia tool features (GebreYohannes et al., 2016), was intended for use in primary school mathematics instruction.

1.7.4. Technology-supported mathematics instruction in sub-Saharan Africa

Achieving high-quality mathematics education in Sub-Saharan Africa is fraught with difficulties. The issues encompass inadequate comprehension among learners due to ineffective teaching techniques, outdated teacher education curricula, and inadequate technology infrastructure to facilitate equal access to high-quality mathematics instruction (Luneta, 2022). Moreover, anxiety towards mathematics dominates primary school leavers and graduates who consider it a foreign subject that does not make sense in an African context (Madaki, 2021). Numerous intervention studies conducted in sub-Saharan Africa have shown how effective technology-supported training is in helping participants overcome these obstacles (Luneta, & Sunzuma, 2022).

Reviews of ICT integration in STEM education in Kenya have shown positive effects on academic performance, with EdTech interventions focusing on personalized learning platforms that enhance numeracy by emphasizing effective technology integration principles and learning processes (Marcharia, 2022; Otieno, & Taddese, 2020). Emergent Literacy in Mathematics (ELM) software was tried out and demonstrated learners' improvements in mathematics abilities, including improved understanding of mathematical language and ideas and improvement of problem-solving skills (Lysenko, Abrami, Wade, Kiforo, & Iminza, 2022). Furthermore, the findings included teachers' increased comfort in teaching mathematics and improved confidence in technology-supported instruction (Lysenko et al., 2022). An interventionist study in the teaching and learning of elementary mathematics supported by digital game-based learning (DGBL) in Ghana found that learning was enjoyable and engaging, which resulted in boosting students' performance and interest in the subject (Letsa-Agbozo, Susuoroka, & Donnoe, 2023).

In summary, these studies indicate that the SSA education systems are evolving to prepare for the Fourth Industrial Revolution, enhancing the quality of mathematics education, and achieving this through technology. These highlights support the opportunity in mathematics performance of developed and developing nations' education systems, hence aiding in the realization of the SDGs. SSA education systems, however, face various challenges related to pre-service teacher training and the availability of a sufficient number of qualified teachers with ICT skills (Agyei, 2021; Agyei, & Voogt, 2011). According to Agyei, & Voogt (2011), Ghanaian education systems suffer from teachers' limited access to educational technological tools and their poor technological pedagogical competences in mathematics teaching. Moreover, in-service teachers still struggle with applying the knowledge and skills they have gained from professional development programs to their classroom practices (Agyei, 2021).

To increase pre-service and in-service training in technology-supported teaching, however, SSA counts a number of foundations and programs that are underway and bode well for the future. In South Africa, the Strengthening Innovation and Practice in Secondary Education (SIPSE) initiative and the Zenex Foundation's Senior Phase Mathematics Teacher Project both prepare teachers to teach with ICT tools in STEM subjects, particularly mathematics (Hofmeyr, 2016; Marcharia, 2022).

Similarly, in Rwanda, in-service teacher training about technology-supported teaching has been the focus of various projects, like the Mathematics and Science for Sub-Saharan Africa (MS4SSA) project, followed by the Rwanda Quality Basic Education for Human Capital Development (RQBEHCD) project, both backed by the World Bank and hosted by the ACEITLMS in the UR-CE (Nkundabakura et al., 2023; Nsengimana et al., 2024). In parallel, other programs, like the MasterCard Foundation's Leaders in Teaching (LT) program, assist educators in utilizing technology to enhance science and math instruction. Nonetheless, it was advised to look at how educators apply the knowledge they have gained from their training, particularly in elementary education, and incorporate it into their regular instruction to enhance their competencies. These interventions resulted in improved teachers' technology-supported teaching competences, increased students' engagement in learning, and improved learning outcomes in mathematics (Nkundabakura et al., 2023; Nsengimana et al., 2024).

Despite unquestionable advancements in promoting technology-supported mathematics teaching in SSA education systems, it is important to investigate implementation issues for ensuring that training outcomes are linked to an improvement of everyday teachers' teaching competencies. This study underscores the importance of conducting research on integrating educational technology in basic mathematics teaching and learning activities for the improvement of quality outcomes and lifelong learning in Rwanda (Iyamuremye, Njiku, Maniraho, & Ndayambaje, 2022).

1.7.5. The impact of technology-assisted instruction on primary school learning outcomes

Achieving a basic quality education is crucial for promoting lifelong learning and the sustainable development of an educational system, as well as for increasing the living standards and economic growth of graduates. As a result, basic education levels should be the starting point for technology-supported teaching since they provide a solid foundation for secondary and tertiary education levels (Ministry of Education, 2018a). Jalinus' and Alim's (2019) findings point out that the improvement of teachers' teaching competencies and students' self-study skills result from technology-enhanced elementary mathematics instructions. In the same way, it has been argued that a technology-supported environment can be used as an effective control approach to alleviate students' unfavorable learning attitudes (Chen et al., 2021). Thus, using technology as an instructional tool in elementary education is a priority to ensure quality education achievement and lifelong learning.

Certain research indicates that the use of ICT in education simplifies instructional methods for elementary school students (Golzar, Momenzadeh,, & Miri, 2022) by increasing achievement (Das, 2019) and facilitating numerous assessments for tracking student development (Munyengabe, Yiyi, Haiyan,, & Hitimana, 2017). However, elementary schools face a number of issues interfering with the achievement of quality technology-enhanced teaching. Some technological tools, like Geogebra, require advanced computer skills and were found to better fit with higher education levels than primary school, where these skills are less common (Mazur, Creech, Just, Rolle, Cotner, & Hewlett, 2021). Similarly, inadequate information and communication technology infrastructure, as well as inadequate ICT proficiency among educators and students, impede the successful incorporation of technology into educational endeavors (Rajan, & Manyala, 2021). In addition, gaps were found in the literature about the integration of technology in primary education, especially when compared to higher education levels (Mazur et al., 2021; Rajan, & Manyala, 2021). Additionally, there are differences in academic performance at the elementary school level across various school statuses as a result of socioeconomic backgrounds and teacher-student ratios (Cobbold, 2015; Shabbir, Wei, Fu, & Chong, 2014). Research has shown that private schools outperform public ones due to available and quality resources and more hospitable learning environments (Shabbir et al., 2014; Dag, 2015). As previously stated, the primary school leaving examination review in Rwanda reveals that, in the 2019–2021–2022 school years, students attending public schools performed worse than those attending private schools (NESA, 2023).

Therefore, taking into account the school status element is crucial for assessing and evaluating performance in technology-supported contexts, even as efforts are made to address gaps that exist in various learning environments. This study thus supports the claim that, in order to improve educational quality, it is critical to identify accessible, reasonably priced educational technology solutions that instructors and students can use (Naidoo, 2020). IM software is deemed appropriate as an instructional ICT tool, meeting Naidoo's standards for high-quality ICT tools. IM software is easy to use with basic computer abilities such as a computer and a mouse, in contrast to other software used in mathematics education that requires significant ICT skills (Sun, Lee,, & Law, 2019). Furthermore, conducting scientific research on newly developed educational software is vital to ensuring its quality and its ability to impact advanced teaching and learning activities, particularly in elementary schools. It is mandatory that education institutions consider a variety of contextual factors in order to guarantee services that can effectively cater for equity and equal opportunities for technological users' needs (Iyamuremye et al., 2022; Sun, Lee,, & Law, 2019).

1.8. Conceptual framework

According to Tamene (2016), a conceptual framework is a network or relationship of presumptions, expectations, and beliefs. It supports researchers in communicating the theoretical underpinnings of their work; modeling the relationships between theories and variables; condensing theoretical data into simple-to-understand statements or models; and helping researchers to visualize and explain the topics they plan to explore (Shikalepo, 2020). A conceptual framework is unique to every area of study. It is something the researcher creates by fusing a theoretical framework and research concepts into a cohesive system to form a provisional theory that directs the investigation.

Based on the theories discussed above, the conceptual framework was designed to depict IM-supported teaching and learning as independent variables or inputs (IV-1 and IV-2), with learning outcomes and teachers' perceptions of IM-supported teaching as the dependent variables (DV-1 and DV-2). IM-supported teaching included teachers’ competencies to teach using IM. This implied their mathematical content knowledge, their knowledge of instructional content, and their appropriate pedagogy to effectively use IM as an instructional tool to support mathematics teaching. However, it was believed that instructors' proficiency or inability to use IM in light of its complexity or ease of use affected the quality of instruction. This depended on many factors, including teachers’ level of basic computer skills and the fact that IM was a new technology that necessitated teachers’ mastery level before being used. Besides, the aspects of IM that boost quality teaching and learning influenced teachers’ expectations about IM-supported teaching usefulness and outcome, which also affected the teaching activities in a certain way. IM-supported learning involved the presentation of mathematical concepts as colorful text and graphs, with mathematical processes presented as movements. Besides, mathematics activities were emphasized by clearly informing the learner about performance or failure. Furthermore, the reinforcement of learning was done through software rewards or punishment at the evaluation level. The dependent variables consisted of learners’ performance and conceptual understanding resulting from IM-supported teaching and learning activities. In addition, the dependent variables included teachers’ perceptions of the benefits or challenges of teaching using IM. This was drawn from their experience in teaching using IM as an instructional tool and from their views about IM influences on learning achievements. The framework articulating the variables is visualized in the figure below:

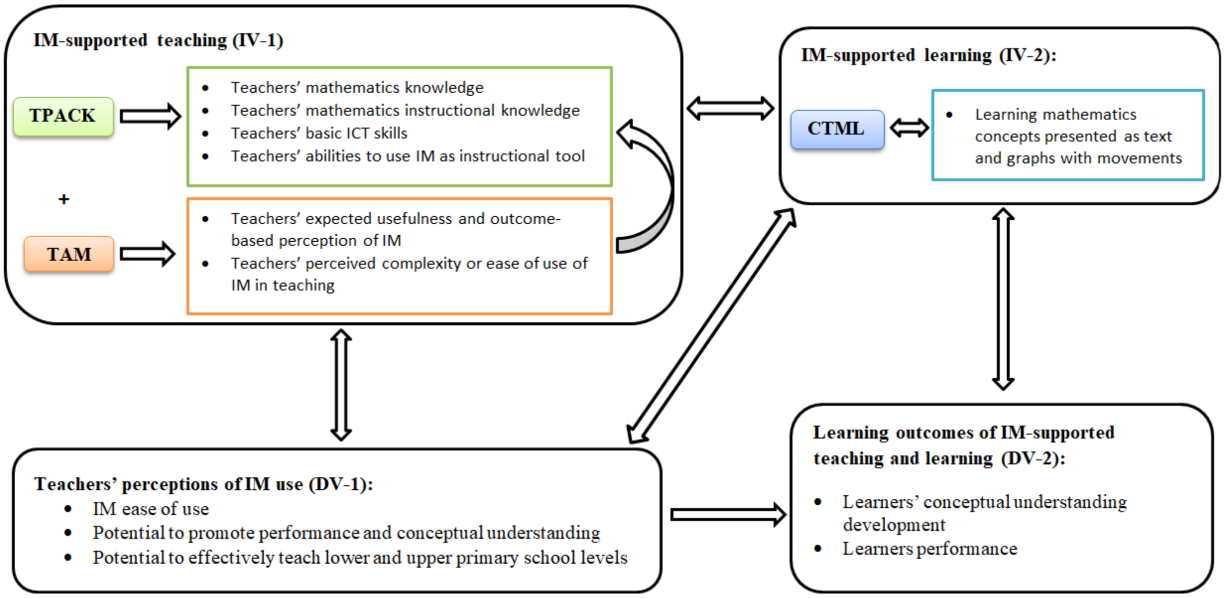

Figure 4. Relationships between independent and dependent variables

1.9. Description of research methodology

1.9.1. General description of study approach and methods

This study was drawn from IM formal piloting in normal classrooms during the 2019 and 2020 school years and slightly extended to the 2022 school year following Covid-19 pandemic lockdowns that resulted in school closures. It was influenced by mixed methods of research approaches (Cresswell, 2014) to get both quantitative and qualitative information. Applying a mixed-method research approach was influenced by the post-positivist paradigm, as explained in the background of this study. Quantitatively, this study identified a control group consisting of classes taught mathematics using the traditional or chalk-and-talk teaching technique. Concurrently, an experimental or intervention group consisting of classes taught mathematics supported by IM software installed on a laptop computer and with a projector was identified. The two groups were selected to provide quantitative data in the form of learners' test marks for the test administered before intervention (pre-test) and another administered after intervention (post-test) (Fraenkel, 2012; Cresswell, 2014). Pre-determined set of open questions for interviews and probing techniques were used in this study to gather qualitative data. Tuffour (2017) asserts that qualitative research in education values the interpretations that individuals provide about their experiences. Because of what the subject says, a semi-structured interview is adaptable, allowing for the incorporation of new questions and material (Lindlof, 2009). As a result, the researcher devised additional probing questions based on the interviewers' responses, facilitating the development of a comprehensive and coherent understanding of the status of the phenomenon being studied by them.

1.9.2. Population

This study's population consisted of primary school mathematics teachers and learners from schools located in Kigali City. The study focused on this area not only because the piloting of IM was mainly based in Kigali City schools compared to rural areas', but most importantly because Kigali City offers more opportunity to find private primary schools, which would be hard to find in rural areas. Furthermore, it was reported that Kigali City has the highest proportion of elementary school children using computers compared to rural areas (Ministry of Education, 2016). Thus, it was assumed that Kigali City primary school students can effectively learn with IM as they are more computer literate compared to rural area students. Besides, both public and private schools in Rwanda implement the same curriculum, which is assessed at the completion of each educational cycle on a national basis. They do, however, show differences in settings that encourage effective learning. For instance, by 2017, private schools had the lowest ratio of learners per classroom (32:1), and public schools had the greatest ratio (88:1) (Ministry of Education, 2018b). There are discrepancies in the quality learning environments in public and private schools in Rwanda due to issues stemming from overcrowded public school classrooms. Thus, quality teaching as well as catering for individual learners' quality acquisition in public schools in Rwanda is far from achieved compared to the learning environment in private schools.

1.9.3. Participants

Mathematics teachers and students from selected primary schools participated in this study. The common sampling methods drawn from a normal distribution, an acceptable margin error, and a confidence interval were used to determine the study's sample size (Ajay, & Micah, 2014). This research's components consisted of primary school educational levels (lower and upper primary levels), the type of school (private and public school), and a quasi-experimental research design that necessitated the splitting of the sample into two groups: the experimental or intervention group and the control group. Furthermore, the availability and functionality of ICT facilities at selected schools were ensured by the Rwanda Education Board (REB) through site visits prior to sample school selection. The study was intended to encompass primary levels from P2 to P5, thus involving four class levels (P2, P3, P4, and P5) with two classes per level per school status (one control and one experimental class from each public and private school level), totaling 16 classes in the sample. The stratified random sampling technique guided the sample selection to warrant representation of each school status as independent in the study sample (Taherdoost, 2016). Thus, of the 16 classes that participated in this study, 8 were from public primary schools (1^{st} strata), while the other 8 were from private primary schools (2^{nd} strata).

Finally, probability sampling techniques were employed to select the eight schools, respectively, from the public and private sectors identified in Kigali City as hosting the IM piloting project and others willing to participate in the research activities. In total, 848 primary school learners from selected schools and classes and from P2 to P5 were considered to participate in this study. However, after identifying those learners who regularly attended all research activities over the whole research period (2019 and 2020), including the two tests, the number of learners whose scores were taken to data analysis dropped to 771. In addition, seven teachers who taught IM-supported classes were purposefully and conveniently selected to participate in qualitative interviews, providing insights into their experiences during the intervention (Taherdoost, 2016).

1.9.4. Study design

Piccioli (2019) asserts that any research design is the product of considering the variables, factors, procedures, and referential procedures for the series of precise logical steps necessary to arrive at a conclusion. Furthermore, physical or virtual tools can be utilized as components of an objective-based technique and the methods, strategies, or principles guiding the application. Thus, three important phases consisting of pre-intervention, intervention, and post-intervention describe how this study was designed.

Phase 1: Pre-intervention research design

At the beginning of this study, primary school teachers were instructed about the familiarity with and effective use of IM in education. As the IM piloting and research activities were conducted during every first term of the 3 school year piloting periods, the teacher training used to take place every 2 weekend days before the start of the IM piloting and research activities. The pilot team involved 3 SAKURASHA, K.K. agents, including 1 working for JICA, and 5 IM experts. Besides, the research team consisted of the researcher herself and two research assistants from UR-CE. However, the five IM experts collaboratively contributed to research activities as well. Thus, eight research assistants collaboratively contributed to this study's research activities. The training of teachers was hosted on REB premises, and REB administration, together with SAKURASHA K.K. and JICA officials, directed the whole process. Teachers were first informed about IM software and the rationale behind its development. They were then trained to connect a computer and a projector and to navigate mathematics content in IM software. They developed IM-enhanced lesson plans and tried them out in microteaching sessions.

Together with the research team, teachers identified lessons from the curriculum that were potentially challenging to teach, and these were fully developed within the IM software. It is noteworthy that all 16 teachers participated in the training; however, those demonstrating higher levels of basic computer skills and pedagogical proficiency and who expressed willingness to teach using IM were selected for the intervention group, while others taught using traditional methods in the control group. The researcher acted as a teacher's collaborator about the effective integration of IM in their lesson planning and their instructional practices (Creswell, 2014). That collaboration was negotiated in advance, planned, and established seriously to maintain an environment of mutual learning and respect. The goal was to enable teacher-researcher consensus on what can be referred to as realistic restrictions in a multimedia context to support meaningful learning and learner-centered instruction, as well as the advancement of educators' technological pedagogical content knowledge.

After the training period, the experimentation period started with the administration of a pre-test to the learners. The pre-test items were prepared from the mathematics topic of intervention by the teachers in collaboration with the research team using primary mathematics syllabuses and learners' mathematics books by respecting the CBC formulation of test items. Teaching and testing activities were structured as follows: in Primary 2, focusing on counting, ordering, comparing, adding, and subtracting numbers less than 500; in Primary 3, on counting, adding, and subtracting numbers less than 1000, as well as multiplying and dividing by single-digit numbers (7, 8, and 9); in Primary 4, on locating integers on a number line, integer inverses, integer comparisons, integer addition, distance between integers, and integer ordering between -10 and +10; and in Primary 5, on locating integers on a number line, comparing, placing numbers in ascending/descending order, integer inverses, and integer addition and subtraction between -20 and +20. The number of test items varied across grade levels, with each item being scored out of one mark: ten items for a total of 10 marks in Primary 2, fifteen items for 15 marks in Primary 3 and 4, and twenty items for 20 marks in Primary 5.

Generally, the tests consisted of simple items involving direct solutions or quick problem-solving exercises. To evaluate the level of knowledge equivalence among learners, a test was given to both the control and experimental groups before intervention. The mathematics teachers and research assistant, together with the SAKURASHA K.K. team, administered and invigilated the pre-test, which used to take place for 30 minutes. The test papers and learners' works were then all collected, marked, and kept confidential during the whole intervention phase to avoid learners' familiarity with the test questions.

Phase 2: Intervention research design

After the pre-test administration, the two research groups engaged in teaching activities supported by IM and traditional teaching methods, respectively. In the experimental groups, the IM-assisted teaching was conducted by the mathematics teachers in their normal class setting and in accordance with the mathematics content planned for the experimentation period, which was also selected from the content planned to be taught during that term. The teacher delivered the lesson by projecting IM content on the screen and navigating it using a wireless mouse. At some teachers' instruction, learners were given the wireless mouse to interact with IM content through exploration of concepts and basic mechanisms and through performing some problem-solving activities. In some other instances, learners were given time to work on the projected mathematics activity on the blackboard or in their exercise books before verifying and comparing their answers to the IM one. The researcher or assistant researcher was following IM-supported teaching and recording observation while also providing some IM-related technical assistance. However, the data collected from the observation of classroom practices was not considered in the present report. The researcher's and teachers' collaboration initiated at the beginning of research activities (pre-intervention phase) continued wherever it was necessary.

Phase 3: Post-intervention research design

Following the experimental teaching time, learners took a post-test, which was administered and scored by the same team that administered the pre-test. The pre-test items were somewhat altered in terms of ordering and data for the post-test items, but the construct measurement remained the same. The purpose was to limit learners' reproduction of the first test answers. Like the pre-test, the second test was administered for 30 minutes. Within a week of the post-test being completed, participating teachers and students received the findings of the pre- and post-test marking by the research team. Teachers conveniently chosen from the experimental group at their different schools were then given the opportunity to share their firsthand experiences teaching with IM in an interview. The structuring of the interview was inspired by questions related to the academic benefits and challenges of teaching with IM or without IM, its academic merits realized during experimentation together with the challenges of chalk-and-talk teaching methods that may be solved by using IM software. The interview questions were first piloted to test the richness of responses and to adjust the interview guide adequately. The interview was designed in Kinyarwanda and English to facilitate the respondents' choice of language of communication. However, respondents were free to switch from one language to another while elaborating on their opinions. The researcher herself conducted the semi-structured interview of the 7 teachers in a one-to-one approach. Drawing on the teachers' contributions to the planned open-ended questions of the interview, the researcher provided additional probing questions to the teacher to provide enough information necessary to enrich the qualitative data. The interview was recorded, and notes of important information were written with a pen in a notebook. After data collection, the researcher conducted remedial sessions to control group classes. Some control group teachers who were willing to teach with IM conducted IM-supported teaching in two sessions assisted by the researchers. However, for other teachers who were not confident with ICT-supported teaching, the researcher herself conducted IM-supported teaching sessions. The purpose was to achieve equity familiarity with IM-supported teaching among control group participants and the opportunity to widen awareness about technology-supported teaching and learning.

1.10. Crucial study issues: Trustworthiness, reflexivity, and ethical consideration

1.10.1. Validity, reliability, and trustworthiness

According to Cresswell (2014), the consideration of mixed methods promotes the accuracy or validity of each instrument and helps it to better explain or explore different types of questions than the other instrument. This study used mixed methods of data collection involving students' tests of their performance and conceptual understanding and teachers' semi-structured interviews about their perception of teaching with IM. It used quantitative research designs and statistical techniques of sampling, data collection, and analysis pertinent to reaching appropriate results. For reliability purposes, the study used test-retest reliability (Ajayi, 2013) of research tools developed by the researcher, participant teachers, and SAKURA-SHA team using mathematics syllabuses and learners' books for primary school (lower and upper primary). Before experimentation, test items' internal consistency was examined using Cronbanch's alpha scaling, which stipulates that an acceptable range should be between 0.7 and 0.95 (Tavakol, & Dennick, 2011). Thus, research tools were improved and harmonized to maximize their effectiveness based on the outcomes of trials conducted at different occasions before intervention, which resulted in a Cronbanch's alpha value of 0.703 for all test items. This value falls in the range of acceptable internal consistency.

According to Shenton (2004), the validity and reliability of qualitative research are critical for establishing the trustworthiness of study findings. In this regard, the study ensured the credibility, transferability, dependability, and conformability of instruments through semi-structured interviews administered to teachers and tests administered to learners. These instruments were tried out before and harmonized as one of the means to ensure dependability or reliability in this study. Besides, the interview questions were asked differently, using varied probing items to ensure consistency. The use of teachers' direct quotes to supplement the codes and tags in qualitative research methods and their triangulation also allowed for the elimination of possible biases and increased the study's credibility and conformability (Cresswell, 2014; Quintão, 2020). Member check techniques consisting of allowing participants (teachers) to check the transcribed data and confirm their views (Birt, Scott, Cavers, Campbell, & Walter, 2016) were also employed to strengthen the validity of the results. Furthermore, the detailed description of the methodology used was a means to account for this study's transferability, which may give rise to further studies that may use the same or different methodologies as this study's. Diverse methods to cater for carryover effect mitigation were employed to prevent learners from becoming familiar with the test items (Moore, & Martin, 2019). They included giving pre-test feedback following the completion of the post-test, the shuffling of question item order during the post-test, and the changing of question data and statement without altering the measurement. However, the pre-test order of the question was reconsidered during the paired t-test analysis process.

1.10.2. Ethical consideration and reflexivity

Before field activities, the researcher was given ethical clearance by the School of Education at UR-CE. Research activities were simultaneously conducted during the IM formal pilot period in a normal class situation under REB recommendation. From this point on, the research efforts did not interfere with the regular academic schedule. Additionally, consent forms were signed by teachers and school administrators to collect data in their specific classrooms and schools. The study was conducted in normal class settings, but learners were not involved in any interview or in any other activity that would display their identity. Thus, parents' consents were not inquired about, as they were implicitly dependent on school authorities' and teachers' consents. Participants and school administrators were assured anonymity during data presentation, analysis, and interpretation. Therefore, during data collection and analysis, participants were referred to as teacher #1 (T1), learner #1, school #1, etc. Pre- and post-test student work was kept in hard copies as well as soft copies of the data that had been recorded and analyzed. In addition, data from interviews was stored as audio records and transcribed into copies with notes taken during the interview period.

Existing literature points out that the researcher's' role and position vis-à-vis the research process, his or her relationship with participants, and their potential shared experiences should be made known to readers (Dodgson, 2019). This is what is referred to as reflexivity, or the researcher's explanation of how data collection, analysis, and interpretation were impacted by his or her involvement in the study. According to Dodgson (2019), reflexivity is an interactive procedure that involves repeated notice, reflection, and action concerning our commonalities and differences. It is a procedure that can be useful in guiding therapists on therapeutic journeys when they are working with clients from similar or distinct cultural backgrounds (Teh, & Lek, 2018).

This study's use of mixed methods involved the researcher in an interaction with participants during the interview because they were all involved in mathematics education in the same cultural context but at different educational levels, which influenced data collection, analysis, and interpretation. As a result, the researcher's participation in the interview with the participant was consistent with her regular procedures for the formulation of instruction in mathematics education, which had an impact on the relative data collection and analysis. Considering that all participants' first language was Kinyarwanda, the researcher herself interviewed all participants in Kinyarwanda to ensure the accuracy of the information. Moreover, she conducted verbatim transcription in Kinyarwanda, followed by translation in English. The research occasionally succeeded in organizing, interpreting, rephrasing, or triangulating quantitative and qualitative data to improve comprehension of the study results and obtain pertinent data. Additionally, several implications were discovered from the practical experience of teaching mathematics at the primary school level, which helped form this study's overall conclusion.

1.11. Analysis

1.11.1. Analysis of quantitative data

The students' responses were collected after each test and categorized by both test and class. Subsequently, the marking process was carried out collaboratively by the researcher and other team members, who established consensus on marking guidelines and considerations. These guidelines included assigning one mark for correct responses and zero for incorrect ones, along with analyzing student work to assess their levels of conceptual understanding. Each learner's total marks per test were recorded on working sheets and entered into an Excel spreadsheet. Additionally, scores for each test item across all learners were computed to gauge their conceptual understanding. Average learner performance, overall class performance, and average item performance were all calculated as percentages. Together with mark recording, learners' attendance was also checked and coded as 1 for presence and 0 for absence to allow the filtering of learners who regularly attended all research activities and whose scores were considered for the analysis. From test scores, quantitative data analysis was conducted in two dimensions. The first dimension was to analyze learners' performance at the class level and in all the same-level classes combined. The second dimension was learners' conceptual understanding development.

For the quantitative data analysis, Microsoft Excel 2016 and SPSS 23.0 were employed to conduct descriptive and inferential statistics. Following data collection, entries were made into an Excel sheet. After eliminating students who completed only one test, a total of 771 students (129 in 2019 and 642 in 2020) who completed both tests were included in the analysis from a sample of 812 students. The analysis was systematically conducted separately for Primary 5 learners in 2020, Primary 3 learners in 2019, and combined for Primary 2 (2019) and Primary 4 (2020) to compare lower and upper primary levels. However, P2 and P4 results were not compared because of the different levels, different tests, and different school years. The average percentage of each learner across all the test items was computed across all the test items. The analysis of the treatment and test groups focused on information about the percent mean score, significance of difference (p-value), standard deviation (STD), learning gains (g), and effect size (f). Using formulas, statistical measures, the effect size, and the learning gains of significance were determined (Ndihokubwayo, Ralph, Ndayambaje, & Uwamahoro, 2021). Statistical significance was interpreted as $p < .05$, highly significant as $p < .01$, and very highly significant as $p < .001$. Learning gains (g) were calculated as the quotient of differences between tests over the mean standard deviation to determine effect size (f). Histograms were used to plot the distribution of scores among students.

Furthermore, using 2020 data, descriptive and inferential statistics were conducted to analyze the combined impact of IM on learners' performance across different school statuses and educational levels. Differences in learners' performance on test items were analyzed to assess their conceptual understanding development (Ndihokubwayo et al., 2021). Next, the percentage of students who completed each task satisfactorily was computed and averaged. Plotting of histograms was done on item performance from a single test type, or for both tests taken together, one research group or both research groups combined were plotted. In addition, a comparative analysis at the school status level was conducted. Test items that were performed by a larger number of learners were compared in the two tests, and those items performed by a smaller number of learners were identified and compared in the two tests. Particular attention was directed to item performance in post-test, compared to pre-test, in IM-supported classes. In addition, a sample of learners working from the two tests was analyzed to find out their improvement in scores, in their working, or errors reduction, to serve as evidence of conceptual understanding development that resulted in scores improvement in the post-test.

1.11.2. Analysis of qualitative data

With reference to Rampin and Rampin (2021), while conducting interviews, the researcher documented teachers' perceptions of IM use in teaching and took detailed notes using pen and paper (Appendix #5). Each recorded interview and corresponding notes were saved in individual folders labeled as teacher #1, teacher #2, and so forth. Upon gathering the data, the researcher transcribed the audio and then translated the transcribed data from Kinyarwanda into English. Data collected via pen and paper was also integrated into the transcripts. A free and open-source software for qualitative data analysis (QDA) known as Taguette software (https://www.taguette.org/) in conjunction with a word document was used to conduct thematic analysis of data following data-driven coding or inductive coding techniques (Rampin, & Rampin, 2021).

As per Williams and Moser (2019), the aim of inductive coding is to explain research findings by constructing a theory based on collected and analyzed data. Coding followed an open, axial, and selective coding pattern (Williams, & Moser, 2019), which resulted in themes. Thus, open-coding, also known as the concept-indicator model, aims at articulating occurrences and facts conceptually. It creates wide codes from unprocessed data, contrasts indicators, and concentrates on textual content that appears frequently. It also continuously codes themes as a concept indicator, always contrasting it with earlier indicators that were coded in a similar fashion. In order to prepare for selective coding, which merges related codes into a theme, the procedure is completed with axial coding, which entails aligning, harmonizing, classifying, and forming unique thematic categories for the themes (Williams, & Moser, 2019). Taguette software supported the coding method by allowing the researcher to move through each coding phase and an easier capture of coding (Williams, & Moser, 2019), while the Word document supported the capturing and refining of themes prior to coding. The interview transcript was imported into Taguette software, which supported the reading over, the tagging and coding, and computing the frequencies of tags by exporting the Taguette project into the Excel codebook. Each of the seven teachers' interviews was coded, and the frequency of occurrence was generated for every code. The total frequency for a code for all seven teachers was provided to allow a generalized analysis of all teachers' perceptions. The distribution of codes among the participants is next illustrated:

Table 1. Distribution of codes among interviewed participants

Themes	Codes	T1	T2	T3	T4	T5	T6	T7	Tot
Disadvantages of the traditional teaching of mathematics	Teacher heavy load	1	0	0	0	2	0	2	**5**
	Low understanding	2	1	3	3	4	1	2	**16**
	Low motivation	1	0	0	2	4	1	1	**9**
Benefits of teaching and learning aspects with ICT and interactive mathematics software	Teacher easy load	2	2	1	0	0	0	2	**7**
	Easy lesson plan	2	1	1	0	2	0	3	**9**
	Easy to teach big classes	3	2	2	2	1	1	3	**14**
	Easy to manage the time	1	0	1	0	3	1	0	**6**
	Increase understanding	1	8	9	1	10	3	6	**38**
	Easy to manage distraction	2	2	1	2	1	0	0	**8**
	Learners' engagement	1	0	1	0	7	0	0	**9**
	Increase interest in learning	1	3	5	3	9	0	2	**23**
Challenges of using ICT and interactive mathematics software	Teaching various content	1	0	1	3	0	1	3	**9**
	Insufficiency of computers	1	1	0	2	0	1	0	**5**
	Training time and period	2	2	0	2	1	0	2	**9**
	Errors in terminologies	0	0	1	0	0	0	0	**1**

Before embarking on the actual coding, the researcher's first coding of interview responses was counter-checked by the other two qualitative researchers with the aim of addressing the researcher's potential coding errors and biases. After screening the first generated codes, twenty-five codes falling under three themes were allowed to be used to analyze teachers' perceptions of IM use in teaching. They detailed teachers' perceived advantages and challenges of IM-supported teaching as well as the challenges faced in traditional modes of teaching. Besides, a Word document was opened to facilitate the caption of emerging themes, their categorization, and organization by related tags or codes. Specific direct quotes were selected from interview responses and directly used in the interviewee's term to discuss discrepancies to ensure that a consensus was reached or to support the explanation and demonstrate the robustness of each theme (Bouzo et al., 2022; Maghiar, & Brown, 2022).

1.12. Study contribution to knowledge

Doctoral theses should, in the opinion of Baptista et al. (2015), make a substantial, unique, inventive, and creative contribution to the body of knowledge in their subject worldwide. Thus, this study helped to enhance the use of technology in education to reduce the challenges of poor pedagogies prevalent in mathematics education (Madaki, 2021) and to attain excellent education that is relevant to current educational trends (Byungura et al., 2016; Lee et al., 2012; Ministry of Education, 2018a; Popović, 2020). Uniquely, this study enhanced the data and research approach in the mathematics education domain, which could help in conducting more research along the same lines. Particularly, this research contributed to generating additional data in the mathematics education domain that may be considered for potential further studies. Moreover, this study helped to practically change the customary teaching and learning activities by utilizing IM software, enabling primary school mathematics teachers to interact with the researcher and develop a new IM-enhanced mathematics instruction. Teachers seized the chance to try technology-supported teaching in their regular classroom settings and participated in technology-supported education. Thus, the interventionist component of this study involved using IM software to change the way that primary school mathematics was taught as usual. During the research period, attention was paid to teachers' actual experiences with IM, the outcomes that emerged from its use, as demonstrated by students' performance and conceptual grasp, and teachers' perspectives regarding IM's ability to raise the standard of education. Basically, this study helped to establish a primary school mathematics smart learning environment that is aligned with 21st century education standards and fosters the discourse around creative teaching aided by technology.

1.13. Thesis organization

This thesis development was inspired by the thesis by publication (TBP) model (Merga, 2015). Accordingly, the TBT model of thesis writing consists of an integrated, coherent collection of peer-reviewed published research articles together with other binding additional topic-related materials that are developed and discussed in the thesis introduction (Merga, 2015). As a result, a TBP can enable doctorate candidates to make progress straight toward a completed dissertation while meeting publication expectations that are comparable to those of international peer-reviewed journals while also meeting increasing levels of expected publication output. In addition, TBP benefits the doctoral candidates in various ways, including building confidence in academic writing, developing publication and resilience skills, and answering detailed criticism from numerous other professional scholars. Therefore, four papers published by international peer-reviewed educational journals contributed to the development of this thesis, which is structured into five chapters.

The first chapter tackles the general introduction. It describes the thesis introduction through the research background, the study aim and objectives, the study significance, the study paradigms, the theoretical and conceptual framework, the overall study methodology, and the overall research organization.

The second chapter is made up of two papers that relate to the first objective concerning the impact of IM-supported teaching on learning in primary schools in Rwanda. In paper #1, the question about learners' performance under IM-supported instruction was partially addressed with specific reference to P5. The article is cited as: Uwineza, I., Uworwabayeho, A., and Yokoyama, K. (2023a). Effects of Interactive Mathematics Software on Grade 5 Learners' Performance. International Journal of Learning and Educational Research, 22(1), 166–190. https://doi.org/10.26803/ijlter.22.1.10

In paper #2, the IM impact on teaching and learning, tackling the component of learners' conceptual development, was carried out with special reference to P3. Therefore, the first objective was completely addressed by this paper, published under the following citation: Uwineza, I., Uworwabayeho, A., and Yokoyama, K. (2023b). Grade-3 Learners' Performance and Conceptual Understanding Development in Technology-Enhanced Teaching With Interactive Mathematics Software. European Journal of Educational Research, 11(1), 69–81. https://www.scopus.com/inward/record.uri?partnerID=HzOxMe3b&scp=85160244308&origin=inward

The third chapter is a peer-reviewed paper about lower and upper primary learners' difference in performance and conceptual understanding: support of interactive mathematics software for Rwanda. It has been published as: Uwineza, I., Uworwabayeho, A., Yokoyama, K. (2023c). Lower and upper primary learners' difference in performance and conceptual understanding: Support of interactive mathematics software for Rwanda. Education and Information Technologies. https://doi.org/10.1007/s10639-023-11860-z.

The fourth chapter is a published peer-reviewed article about perceptions of using interactive mathematics software among Rwandan primary school teachers. It can be accessed via the following reference: Uwineza, I., Uworwabayeho, A., Yokoyama, K. (2023d). Perceptions of using interactive mathematics software among Rwandan primary school teachers. Cogent Education, 10(1). https://doi.org/10.1080/2331186X.2023.2170113

The fifth chapter consists of general conclusion. It presents the study conclusion, the limitation and recommendations

1.14. Chapter summary

This first chapter serves to provide a general overview of this study, with particular emphasis on global and national issues in mathematics education in Rwanda, as well as the rationale for using IM in Rwanda's CBC. It explains the study's goal, the statement of the research problem, the study's paradigm, a brief description of research methodology, and theoretical and conceptual frameworks. It highlights the significance of the research and its contribution to knowledge in mathematics education. The next three chapters present published papers, and the last one presents the discussion and conclusions.

Chapter II. Effects of IM-supported teaching on learning outcomes in primary school mathematics

2.1. Introduction

This section provides the results of IM-supported teaching on learning outcomes. It first discusses learners' performance in IM-supported teaching of mathematics in grade-five (paper #1). Next, discusses learners' conceptual understanding development in IM-supported mathematics class (paper #2). Therefore, it addresses objective number one of the studies about the role of IM-supported teaching on learning outcomes in form of performance and conceptual understanding. Details about methodology, theory and findings can be accessed via each of the 2 articles next posted.

2.2. Effects of IM-supported teaching on learners' performance

2.2.1. Detailed account of the 1st paper (Next page):

International Journal of Learning, Teaching and Educational Research Vol. 22, No. 1, pp. 166-190, January 2023 https://doi.org/10.26803/ijlter.22.1.10

Received Sep 14, 2022; Revised Dec 19, 2022; Accepted Jan 16, 2023

Effects of Interactive Mathematics Software onGrade-5 Learners' Performance

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Abstract. In order to cope with globalization and the growing world of work, educational systems are challenged to improve the quality of education. The use of technology in education attracts the focus of developing countries aiming at raising their educational status to fit the global scale. Therefore, Rwanda education system is promoting the use of ICT in primary and secondary education as an instructional tool. Interactive Mathematics (IM) software for Rwanda was developed to support the effective implementation of the Competence Based Curriculum (CBC) of mathematics in primary level. Designed as quasi- experimental using control and experimental groups, this study was conducted in urban public and private schools to investigate the effect of IM software on grade-5 learners' performance. Considering IM software as a new technology under piloting phase, this study was grounded in TPACK framework with theories of technology acceptance model. Data collected through pre-test and post-test in form of scores were analysed using SPSS 23.0 to compute the statistical effect of the teaching interventions. From results, IM software descriptively showed a greater performance than the traditional class, based on the effect size of significance and learning gains. Using repeated measures ANOVA through the general linear model, it was found that IM improved learners' performance more in public than private schools, although private schools showed a high-performance level at both pre- and post-test stages. Despite that, males' performance remained higher than females' although females descriptively improved in post-test. The study suggests conducting qualitative studies that would bring more information about the features of IM in quality mathematics education.

Keywords: Interactive Mathematics software; grade-5 learners; learners' performance; experimental group; control group

Introduction

The major goal of any education system is to enable learners to achieve learning outcomes in relation to national aspirations. The current globalisation vision stresses the development of 21st century competences through education. This pushes education systems worldwide to a race of providing quality and the right education to equip the youth with the necessary skills to fit in the evolving world of work. In fact it was argued that education should change as quickly as the technology does to enable young people embrace the rapidly changing environment (Khun-inkeeree, 2016). In education systems, the aspect of quality education is generally translated into learning outcomes which are drawn from national aspirations. According to Dev (2016), learning outcomes are generally reflected by learners' academic performance. For example, in India, learning outcomes have become a phenomenon of interest such that many scholars have been working hard to untangle factors that militate against good academic performance (Dev, 2016).

Since 2015, Rwanda education system adopted a competence based curriculum (CBC) and different teaching and learning resources have been developed to support the effective implementation of the CBC. Information and Communication Technology (ICT) tools were prioritised to address barriers related to CBC effective implementation including insufficiency of resources, poor pedagogy and mediocre performance. In fact, it was argued that availability of technological aid could improve the quality of mathematics learning, the learning environment and performance of both boys and girls (Khun-inkeeree, 2016). Therefore, the Interactive Mathematics (IM) Software was developed to support the teaching and learning of mathematics in primary or grade level schools.

Drawing on this background, this study explored the effect of Interactive Mathematics (IM) software on grade-5 learners' performance. The objectives that guided this study consisted of a) investigating the role of IM on learners' performance; b) comparing the role of IM in different performances of public and private school learners; c) comparing the difference in females' and males' performance in IM supported mathematics classes.

Review of Literature

Existing literature on changes brought by Information Communication Technology (ICT) in human life highlights the importance of technology in empowering young people with skills to embrace the rapidly changing environment (Khun-inkeeree, 2016). Therefore, education systems opted to use ICT to stay updated with the dynamic life constraints and studies were conducted to analyse the effect of technology integration in education. For example, in mathematics education, a study argued that the availability of technological aid could improve the quality of mathematics learning and performance of both boys and girls (Khun-inkeeree, 2016). Other studies found that the best mathematics performers in International Mathematics and Science Study (TIMSS) among the OECD countries like Japan and Singapore mostly use computers in their classrooms (Gronmo et al., 2016; House, 2007). Seemingly, most advanced education systems, especially in developed countries which adopted ICT in teaching and learning many years ago, succeeded in producing learners who excel in mathematics worldwide. In light of advanced countries in mathematics performance, the promotion of the use of computers in basic levels of education, like primary school is of paramount importance (Gronmo et al., 2016). Therefore the use of IM software to support the implementation of the CBC in mathematics education in Rwandan primary schools would likely contribute to creating a classroom learning environment that would improve quality teaching and learning.

The purpose of quality education (Alshammari et al., 2017) is to improve learners' achievement. Learners' academic performance is the ultimate expectation for all educational stakeholders in general and for themselves in particular, without excluding teachers, parents and school administration (Dev, 2016). In elementary school learners, academic performance predicts the future of the youth and the whole nation (Dev, 2016). The ranking of schools from schools of excellence to the rest of the schools is guided by many criteria, but emphasis is always put on learners' achievement or academic performance. For example, in Rwanda's education system, it is a habit to rank schools from the best to the worst by considering many criteria but, most importantly, by putting an emphasis on academic achievement or learners' performance. Therefore, all schools aspire to be excellent by allowing learners to improve their achievements. These include time for self-study, the increase in assignments or tests and the urge for teachers to provide feedback timely and to integrate ICT in teaching and learning activities.

In education systems, different factors influence the quality of education and learners' performance. These include the school statuses, gender issues, and learners' educational level, qualification of teachers, the type of pedagogy and the availability of instructional material as well as the scope of the subject content. The type of school is a factor of the effective teaching and learning process and school academic performance based on the differences between public and private schools including class population and teachers' qualifications. Khun- inkeeree (2016) investigated on the performance between public and private elementary schools in Thailand. Using ANOVA, he compared the difference between two public schools and one private school and found that private schools showed better performance compared to public schools. Therefore, strategies to empower public school learners so that they can perform in the same way as their colleagues who study in private schools are necessary if they are all expected to achieve the same learning outcomes. In Rwanda, learning environment in private primary schools presents more opportunities to promote learners' better performance than public schools. These include a limited number of learners per classroom making it easier for the teacher to take care of individual learners and to teach them well. Therefore, the use of IM in public primary schools teaching will promote the learning environment of overpopulated class resulting in learners' increase in performance. Many other factors, including lack of instructional materials, lack of qualified teachers, teachers' poor pedagogical content knowledge or technological pedagogical content knowledge (TPACK), influence the quality of education and academic performance of learners in general and particularly in a mathematics lesson.

Literature on gender differences in mathematics performance reported that boys and girls have different perceptions about their difference in performance (Dev, 2016; Uwineza et al., 2018). Girls attribute their mathematics learning and performance more to external factors and less to abilities, while boys' abilities' to learning and performing well in mathematics were credited more to internal factors like reasoning and effort or commitment and less to external factors (Dev, 2016). Accordingly, the way IM content is developed and presented together with other features which makes the teaching attractive and enjoyable to learners show the potentials of IM to likely fit both female and male learning styles. Drawing on Dev, (2016)'s findings, IM supported class can change the learning environment from traditional learning environment using chalk and talks to smart learning environment which is ICT enhanced. In addition, mathematics content in IM software is developed from semi-concrete level to abstract level allowing learners to develop critical thinking and reasoning while learning. Therefore, IM software seems to be an instructional tool that may address female and male differences in learning styles as explained by

Dev (2016) and may bridge the potential gap in females' and males' performance. In addition, teachers should be empowered to develop the learners' understanding of mathematics without distinction between females and males (Habineza, 2018) using instructional resources including ICTresources.

According to Uworwabayeho (2009), formal mathematics education in Rwanda started with arithmetic and developed through many curriculum reforms. It had long time been facing challenges to quality delivery related to but not limited to pedagogy (Maniraho, & Christiansen, 2015), gender differences in attitudes and perceptions (Habineza, 2018), teaching and learning resources (Nyirahabimana, & Twagilimana, 2019) and mostly the lack of professional mathematics teachers (Uworwabayeho, 2009). For example, a study conducted by Maniraho and Christiansen, (2015) revealed primary teachers' poor pedagogical content knowledge in unpacking mathematical content. At the same time, Nyirahabimana and Twagilimana (2019)'s study findings from one public secondary school mentioned insufficiency or sometimes unavailability of textbooks to support teachers' commitment to influence learners' performance. In another study, Umuhoza and Uworwabayeho, (2021) identified insufficiency or total lack of instructional materials for teaching mathematics. According to Msafiri (2017), teachers and students need instructional materials to easily achieve instructional objectives, increase learners' motivation to learn and increase understanding in practical ways.

Therefore, instructional materials are necessary for successfully teaching and learning any subject including mathematics. It is worth noting that in Rwanda, nearly all studies conducted in mathematics education focused only on secondary school level. However, it is necessary to shift the focus of research attention to the primary level too, to build quality content delivery from the early level of education. Addressing mathematics issues including those related to pedagogy and instructional resources from primary level would be a means to predicting the quality of mathematics and to indirectly addressing issues at upper educational levels. Therefore, in this study IM technological tool was used as an instructional material that may also help teachers' effective delivery of the content following IM content development which was tailored following CBC framework.

Addressing mathematics issues including those related to pedagogy and instructional resources from primary level would be a means to predicting the quality of mathematics and to indirectly addressing issues at upper educational levels.

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In 1986, Shulman introduced the Pedagogical Content Knowledge (PCK) theory explaining quality knowledge for successful teachers in their teaching careers. According to Sri and Mardhiyah (2019), PCK is a manifestation of content knowledge and pedagogical knowledge, which means that teaching (mathematics) is not only understanding it but also knowing how (and who) to teach it. It is the teacher's ability to manage students in the learning process. According to Akturk et al. (2019), technology integration in education has become a necessity. Therefore, building on Shulman's formulation of "pedagogical content knowledge" in 1986, Punya Mishra and Matthew J. Koehler introduced Technology Pedagogical Content Knowledge (TPACK) theory in 2006 and extended it to the phenomenon of teachers integrating technology into their pedagogy. TPACK is one of the teaching methods which is currently becoming progressively more successful in promoting the effective integration of technology in teaching and learning activities (Soler-Costa et al., 2021).

Many studies used the TPACK theoretical framework in teacher education studies (Beri, & Sharma, 2021; Omoso, & Odindo, 2020; Antony et al., 2019; Bos, 2011). Other few studies used the TPACK framework focusing on the teaching and learning processes, students' learning and self-efficacy and academic achievement (Akturk et al., 2019). Some of the findings highlight that integration of technology and pedagogical content knowledge (TPACK) is beneficial to the school, college and university teachers' professional development (Beri, & Sharma, 2021), teachers' qualifications and teaching experience (Antony et al., 2019). On teaching and learning activities, studies found that the TPACK framework likely helps teachers to update their teaching knowledge, to teach effectively and to increase their teaching experience (Antony et al., 2019; Beri, & Sharma, 2021) and promotes confidence among learners, encourage to learn (Beri, & Sharma, 2021). According to Akturk et al. (2019), TPACK framed lessons has a positive impact on learning outcomes. As for Soler-Costa et al., (2021), TPACK framework is likely appropriate pedagogical approach for content delivery with appropriate ICT tool. In addition, Akturk et al., (2019)'s study found that teachers' TPACK level influence on academic achievement was likely higher than learners' emotional self-efficacy.

The advent of different educational technological tools implies selective attention with respect to their potential to influence quality teaching and learning. Therefore the teachers' attitudes and perceptions about the new technological tool plays a role in developing or adjusting their TPACK with that particular tool. According to Alomary and Woollard (2015), when presented with a new technology, individuals behave differently with respect to acceptance or denial of the tool which affects the end product. Different theories related to technology acceptance have been used over time to explain end users' perceptions and intentions to use technology within and across organisations (Alomary, & Woollard, 2015). In 1989, Davis introduced Technology Acceptance Model (TAM) which was drawn from the theory of reasoned action (TRA) with the aim justifying and explaining technologies user population and behaviour (Lee et al., 2003). According to Momani (2020), the way technology users perceive it or judge it ease of use and quality to produce desired outcomes results in user satisfaction. TAM underwent several empirical studies with a focus on various variables and organizations and has proven to be a robust model for understanding end-user adoption of technology. Several reviews led this model to take different forms, including TAM, TAM2 and the Unified Theory of Acceptance and Use of Technology (UTAUT). The purpose was to harmonise variables, focuses and constructs and address some limitations to identifying end users' perception and attitudes towards the use of technology. In educational settings, nearly all the UTAUT constructs and variables tested proven to have a significant influence on how technology is perceived by users' (Momani, 2020). Among the findings, factors influencing students' technology acceptance and the role of technology in improving students' levels of English were highlighted. Among the technology acceptance model variables measured, the performance expectancy constructs attracted our study's attention. We argue that learners' performance in technology supported class results from teachers' acceptance and attitude to the technology considered which influences the teachers' TPACK level.

Considering the current implementation of CBC in the Rwandan education system, improving the quality of mathematics education using ICT as a tool for teaching and learning is a priority issue. According to Ndihokubwayo and Habiyaremye (2018), CBC requires teachers to teach many skills and teachers' traditional teaching methods are not suitable to assist learners developing desired competences from schools. A study conducted by Rutz et al. (2003) about the use of instructional technologies to improve the learning process for students in fundamental engineering science courses found improvement in students' performance, time on tasks and interest in instructional technology class compared to traditional methods. In addition, students developed satisfaction attitudes towards technology. Therefore, research and policies suggest teachers to embrace participatory and interactive methods that engage learners in the learning process.

Interactive technologies are among the ICT tools which are the most widely used in education that can enhance communication and interaction in the classroom (Eastman et al., 2009). Interactive technologies used in education include interactive whiteboards (Papanastasiou, 2016), iPads and PowerPoint presentation with or without learners' technological tools for their interaction (Eastman et al., 2009). In line with the effective implementation of the CBC in mathematics in primary schools, Sakura-Sha, a Japanese private company, has developed the Interactive Mathematics (IM) software for Rwandan basic education learners. IM software is offline and easy-to-use. It is built to ensure the exploitation of mathematics in all its aspects, following the CBC for respective levels. The IM content software is offline, easy to use, user-friendly even for IT- illiterate people, and portable (simply after copying and pasting it, you start using it).

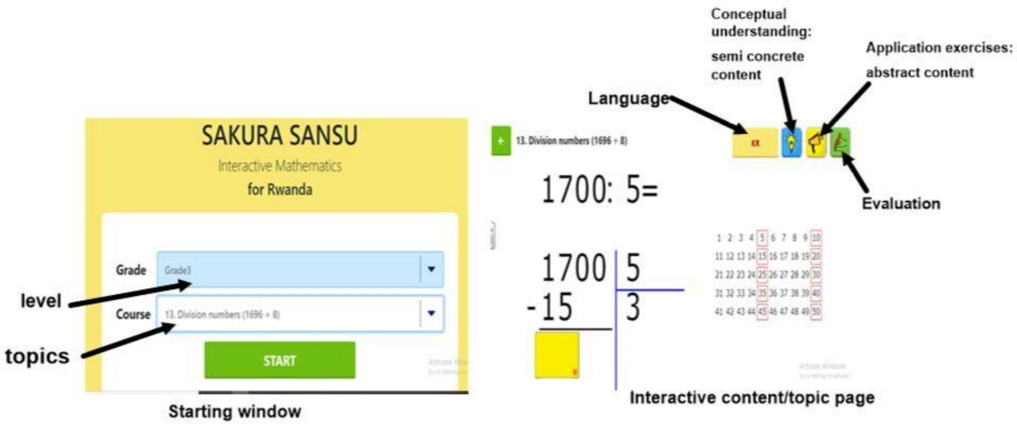

Figure 1. Interactive Mathematics content software outlook of the starting windowand example of an interactive content

With Interactive Mathematics content software, mathematics objects are presented in semi-concrete combined with the abstract nature of mathematics, stimulating interactivity through colorful images, diagrams, movement text, and sound. There are also the speeds of activity as well as variation of mathematics activities at different levels of complication that can stimulate and sustain engagement and interactivity in IM content software supported class.

This study is grounded in the TPACK framework with theories of technology acceptance model with its performance expectancy construct. Considering IM software as a new technology in the piloting phase, teachers' attitude and perceptions about IM software ease of use and its quality in influencing quality teaching and learning will influence their TPACK level. This will result in learners' quality of learning and their performance. Therefore, learners' performance will be a result of teachers' TPACK level, which itself will be influenced by their attitudes and perception towards the IM software.

Methodology

Research Design and Sampling Issues

This study was designed as quasi-experimental involving control and experimental groups. Schools that were involved in the study were selected depending on the availability of ICT infrastructures such as projection facilities, electricity, and computers. The selection focused on public and private schools in an urban area, Kigali, Rwanda. The urban area attracted the focus of our study because of the likelihood of finding there are more private schools of primary level very close to one another and many public schools well equipped with ICT infrastructure compared to a rural area. In addition, the urban area presents more facilities to move from one school to another in a shorter time than in rural area. Therefore, after identifying public and private schools that are ICT equipped, we conveniently selected sample schools and focused on primary-5 learners to participate in this study. Sample schools were assigned to two research groups consisting of treatment and control groups.

The teaching of mathematics in treatment group schools uses IM software as an instructional tool and is supported by a laptop, a wireless mouse, and a projector. All learners were invited to follow the teaching on the projected content and a wireless mouse was used to facilitate the teacher's and learners' interactions with the content. The same content delivered in treatment group classes was delivered in control group classes but with different instructional tools. Before and after conducting research activities, a pre-test and a post-test were given to learners from control and experimental groups to compare their performance. Table 1 summarizes the sample, research groups, and research activities.

Table 1: Sample and activities design

Sample groups	**Samplesize**	**Research activities**		
	Learners	**Time 1**	**Time 2**	**Time 3**
Group 1: Experimental group [IM class]	92	Pre-test	IM assisted teaching	Post-test
Group 2: Control Group [Traditional class]	102	Pre-test	Chalk and talk teaching	Post-test

This study's population consisted of primary-5 learners from public and private schools. The sample size consisted of 202 P5 learners including 83 from private schools and 119 from public schools. This study took place during the usual teaching and learning school activities. The scheme of work and the usual timetable were respected the way they were planned, and research activities were undertaken along with the first term (January–March) of the 2020 school year, depending on the topics. While lower grade (P1, P2, P3) learners study for six periods (one period is equivalent to 40 minutes), there are seven periods per week of learning in upper grade (P4, P5, P6). Thus, IM supported teaching activities ingrade 5 which was the focus of our study, lasted 7 periods per week.

Research Tools and Data Collection

This study used quantitative research methods (Cresswell, 2014) whereby data were collected using pre-tests and post-tests. Japanese mathematics education experts in the Sakura-Sha project, together with mathematics teachers and the researchers worked together to design test questions guided by the Rwandan mathematics syllabus of P5 (REB, 2015). Eight questions in total were developed for each pre-test and post-test (see appendix 1). The tests focused on integers and consisted of the following lessons: finding the equivalent fraction, naming the shaded region or shading a region corresponding to a given fraction, comparing fractions, and changing the denominators of fractions to a given common denominator. Test items were similar in the pre-test and post-test with small differences but measuring the same construct. The purpose was to measure learners' understanding and consistency in their understanding. Test items were selected from those suggested in P5 syllabus and P5 learners' book with respect to related content and by respecting their formulation.

All test items were routine problems requiring providing a direct answer or short problem-solving working. The answers and marks of the pre-test and post-test were given to learners two days after the post-test was done. P5 teachers prepared the test items used in the pre-test and the post-test and the researcher based on the content to be delivered using IM and following their ordinary way of setting test items. The content taught in P5 focused on the unit of integers. The lessons delivered were the following: location of positive and negative numbers on a number line, comparison and ordering of integers, addition of integers, subtraction of integers and solving problems involving addition, and subtraction of integers. This content was the only P5 IM mathematics version available. During the teaching activities, the teachers and the learners were engaged with the soft content using the wireless mouse and manipulated the teaching material, working on examples, and learners' exercises projected on the classroom wall. IM supported teacher presentation was sometimes interrupted by switching on learners' individual or group workings followed by the teacher monitoring of learners' activities

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Research clearance and ethical consent

Before collecting data, the researcher was given ethical clearance to go into the field. In addition, data collection was simultaneously done during the REB- SAKURASHA IM pilot period. Therefore, REB itself prepared schools that participated in the IM piloting phase for hosting the piloting and research activities. The latter took place during the school normal activities and at the exact time fitting the one planned in the scheme of work of teachers. Henceforth, the research did not interrupt the normal school calendar. Instead, it supported/integrated itself into implementing the planned teaching. Before data collection and the implementation of teaching intervention, school head teachers signed consent forms and informed the teachers and learners about the research and project purpose. Teachers were trained and briefed on the traditional and IM teaching activity. The researcher discussed the units of content they were teaching and the concepts to be covered during the research activities.

Data Analysis

In this study, the researchers mainly used SPSS 23.0 to compute the statistical effect of the teaching interventions provided to analyse data. Class #1 (private and control) missed three learners (2 missed pre-test while one missed post-test), Class #2 (public and control) missed one learner that did not do the post-test, Class #3 (private and experimental) missed two learners (one missed pre-test while another missed a post-test), and Class #4 missed two learners who both did not attend post-test. Thus, 45 learners of Class #1, 57 of Class #2, 33 of Class #3, and 59 of Class #4 were taken for analysis.

Firstly, researchers analysed groups of treatment and test and revealed percent mean score, standard deviation (Std. Dev), significance, the difference (p-value), effect size (f), and learning gains (g). The significance was taken at $p<.05$ (statistically significant), $p<.01$ (high statistically significant), or $p<.001$ (very high statistically significant). The effect size was calculated as f = (Post-test Mean – Pre- test Mean) / Average Std. Dev while learning gains were calculated as g = (Post-test Mean – Pre-test Mean) / (100% – Pre-test Mean). Then, histograms showing the number of learners in range scores were plotted and finally, the school and gender variables were analysed after the treatment effect. Considering that there were 8 participant learners who did not sit for both tests, data from 194 (92 in the experimental and 102 in the control groups) learners who sat for both pre-test and post-test were taken to the analysis phase to analyse the change in performance at individual level.

Results

Primary Five Learners' General Performance

Descriptive Statistics

Table 2. Descriptive and inferential statistics in testing (pre-and post-test)

Treatment	Test	Sample	Mean(%)	Std. Dev(%)	p-value	f (Test)	g
Traditional class	Pre-test	102	43.92	25.19	<.001	.52	.22
	Post-test		56.71	23.31			
IM class	Pre-test	92	39.56	19.77	<.001	1.32	.41
	Post-test		64.83	18.46			

Learners in both traditional and IM classes performed well. Results in Table 2 show that the traditional method improved learners' scores significantly from pre- test to post-test (p<.001, effect size (f) =.52). The learners gained .22 of learning (learning gain, g) from this method. Likewise, IM software improved learners' scores significantly from the pre-test to the post-test (p<.001, f =1.32). The learners gained .41 of learning (g). Therefore, the IM class descriptively showed a greater performance than the traditional class, based on the effect size of significance and learning gains.

Table 3. Descriptive and inferential statistics in teaching intervention (treatment)

Test	Treatment	Sample	Mean(%)	Std. Dev(%)	p-value	F (Treatment)
Pre-test	Traditional class	102	43.92	25.19	>.5	-.19
	IM class	92	39.56	19.77		
Post-test	Traditional class	102	56.71	23.31	<.01	.38
	IM class	92	64.83	18.46		

Table 3 demonstrates the descriptive difference observed in Table 1. Learners in both traditional and IM classes showed no statistically significant difference (p>.05, effect size (f) =-19) in the pre-test (before learning), while such significance was found to be highly significant (p<.01, f=.38) after learning (in post-test) in favour of IM software. Table 2 shows that learners in the traditional class got an average score of 56.71%, while those in the IM class got an average score of 64.83. This shows a statistical mean difference in performance between traditional and IM supported teaching.

Figures 2 and 3 present the number of learners in a specific range of scores. Figure 2 shows that the number of learners in the pre-test and post-test seem to be at the same level along with each score range.

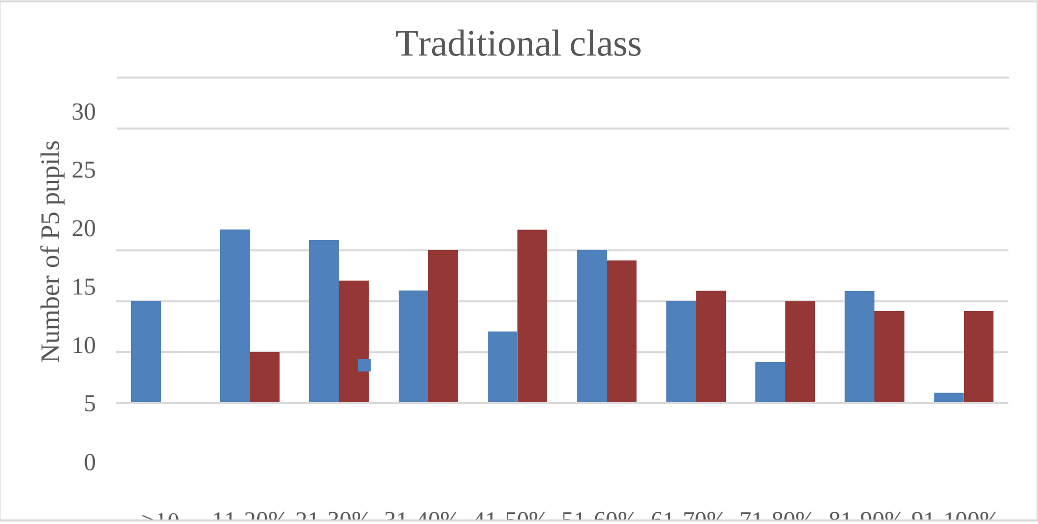

Figure 2. Histogram of traditional class

However, Figure 3 shows a different outlook. Many learners are below 50% scores in the pre-test, while many learners got above 50% on the post-test. Therefore, descriptive analysis shown by these two histograms shows that the IM class improved learning more than the traditional class did.

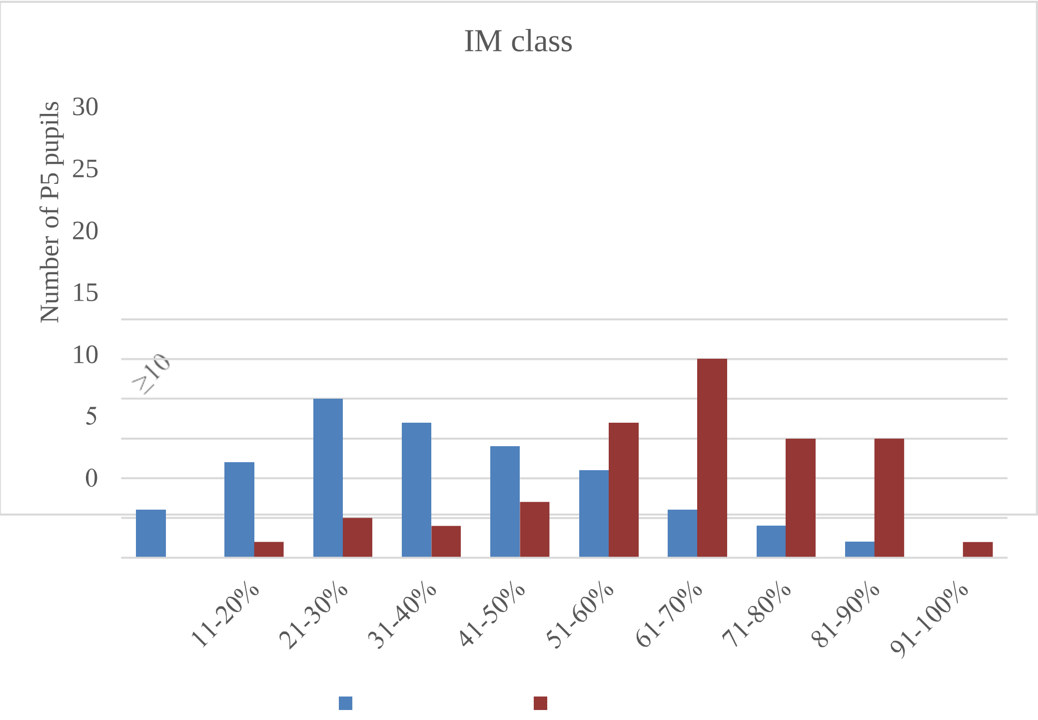

Figure 3. Histogram of IM class

Variables Analysis with Repeated Measures ANOVA in General LinearModels

After analysing the general characteristics of teaching intervention delivered, researchers opted to look into other different factors, such as the type of schools (public or private) involved and the gender (male or female) of learners involved in the treatment. Private schools (N=78) showed a higher level of performance both before and after learning than public schools (N=116), although public schools showed a slight improvement in post-test (see Figure 4).

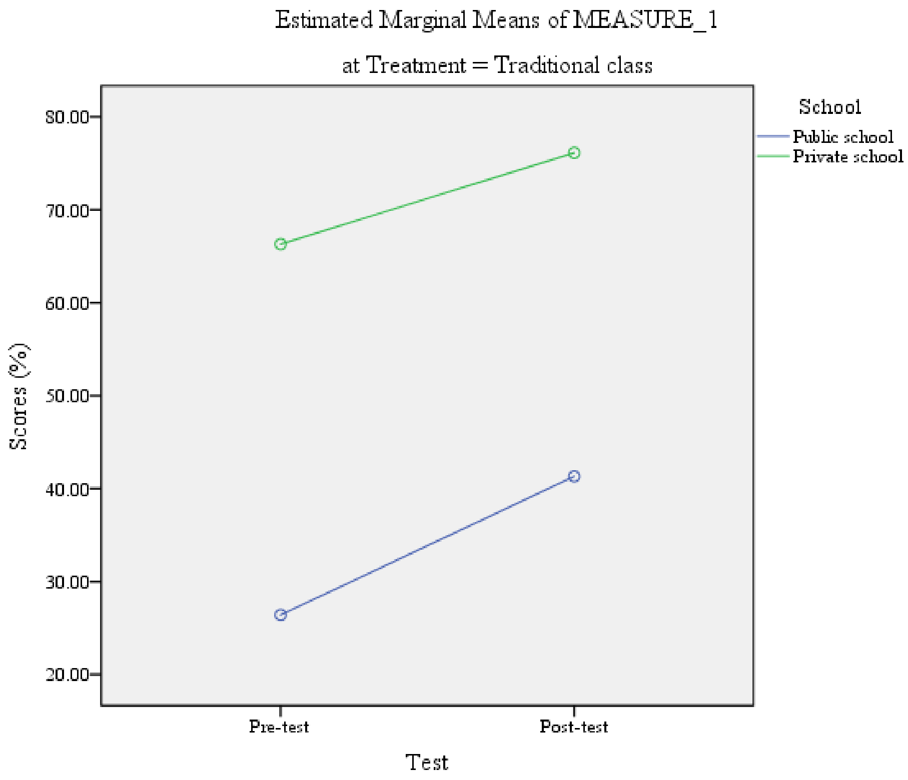

Figure 4. Interaction between Tests, treatment, and schools [Public and private schools performance] in a traditional class

In IM class, such a difference was not large as in traditional class. But still private was higher than public schools, and public schools showed an improvement from the intervention offered more than private (see Figure 5).

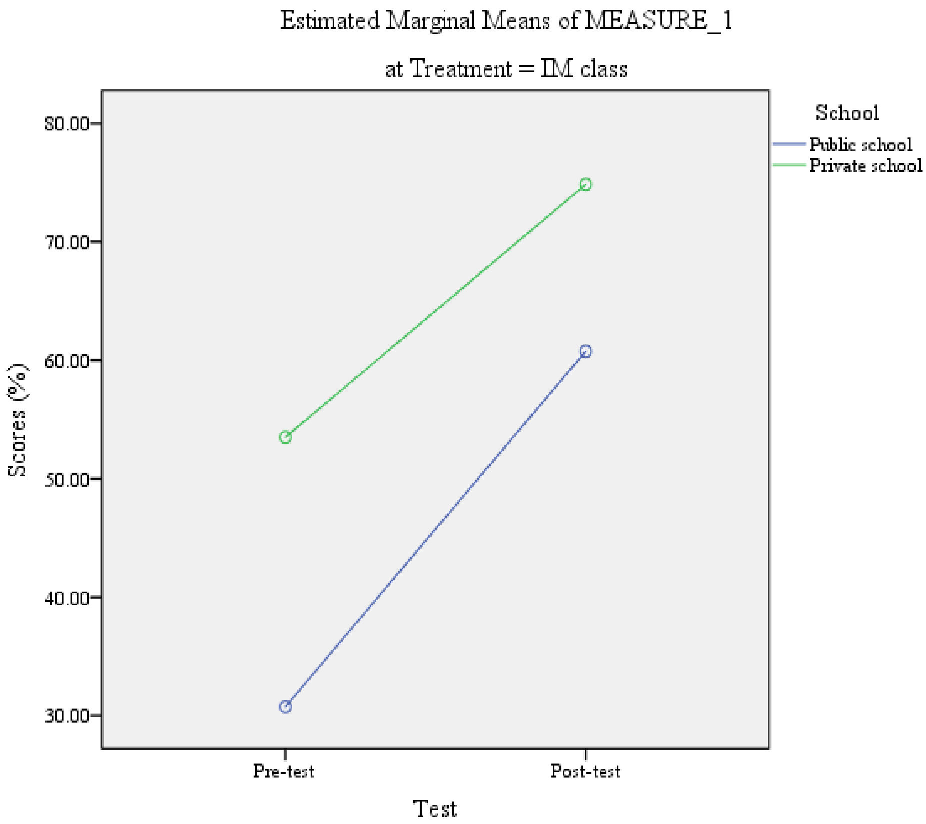

Figure 5. Interaction between Tests, treatment, and schools in IM class

Similarly, an investigation done on gender differences showed male learners (N=100) performing higher than their female counterparts (N=94). For instance, Figure 6 shows that male learners in traditional classes got higher pre and post-test scores. Interestingly, females showed a will to improve in the post-test, descriptively, of course.

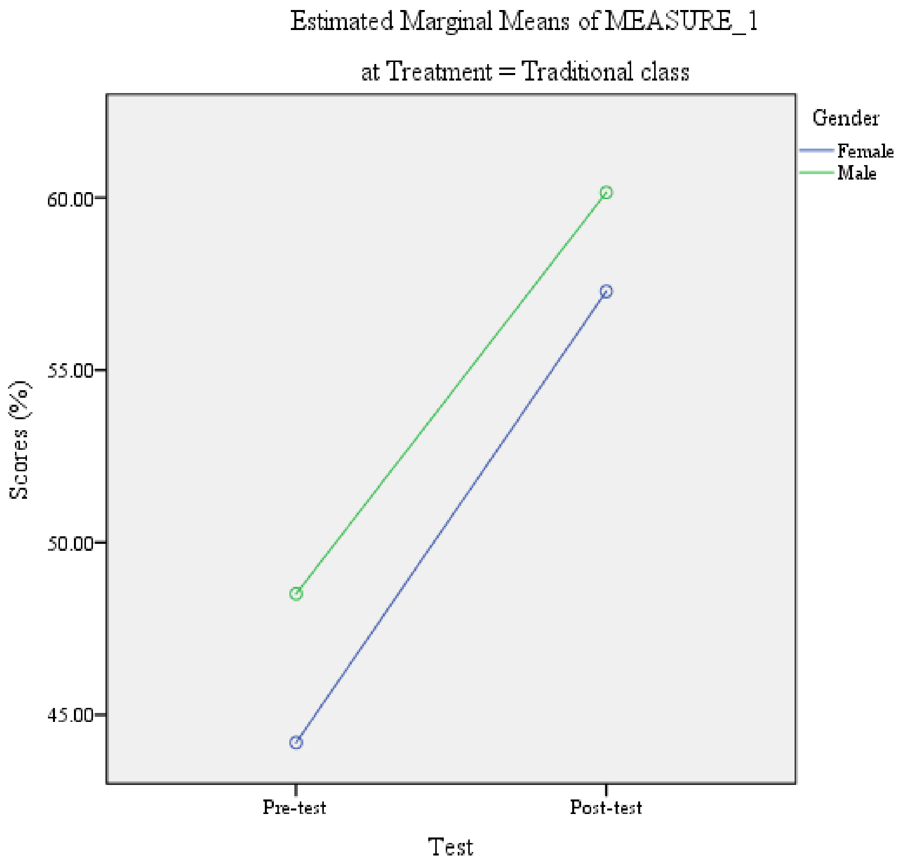

Figure 6. Interaction between Tests, treatment, and gender in the traditional class

Figure 7 shows that male learners in IM class got higher scores in both pre-and post-test, and females showed a will to improve in the post-test.

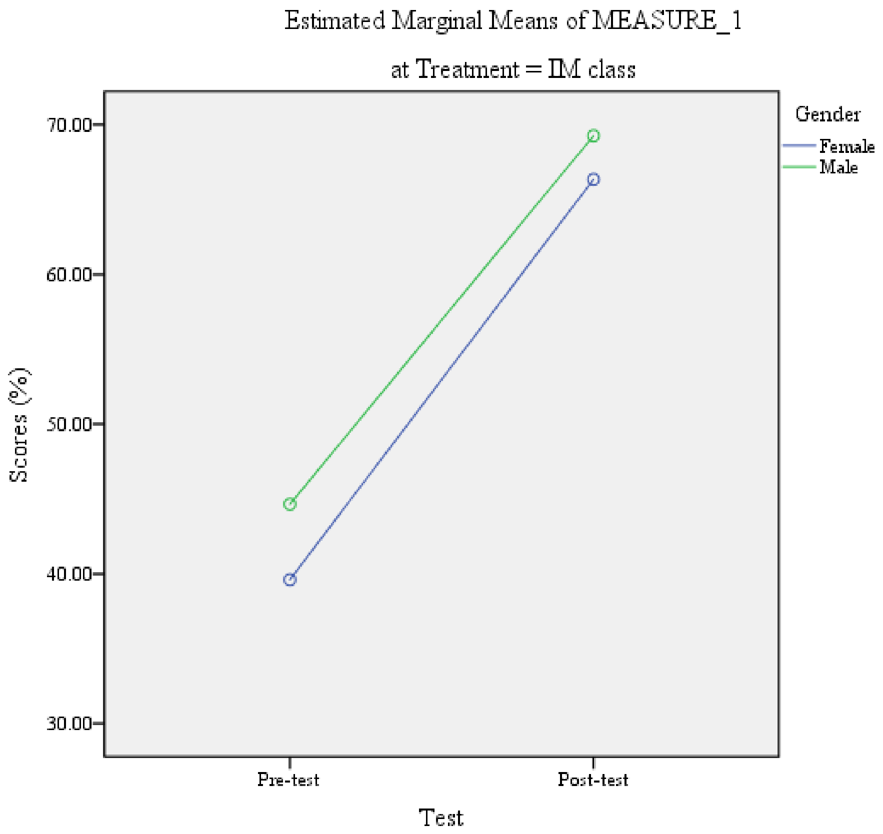

Figure 7. Interaction between Tests, treatment, and gender in IM class

From the above figures, one can descriptively depict information related to school and gender factors. Table 3 presents inferential statistics. Using repeated measures ANOVA through the general linear model in SPSS, there was a statistically significant difference ($p<.05$) between public and private schools in both pre-and post-test scores despite the treatment offered (traditional method or IM software). However, such difference was not realized throughout the test provided and treatment offered.

Discussion

Summary of results

From the analysis of learners' scores, at the beginning of the treatment, the pre- test administered to both traditional and IM class groups generated no statistically significant difference ($p>.05$). Learners' knowledge from the treatment and control groups was found equivalent. However, results from the post-test generated a significant difference ($p<.01$, $f=.38$) in learning outcomes between the treatment and control group in favour of IM software. This is consistent with Beri and Sharma, (2021)'s study findings about the role of ICT in improving conducive learning environment. Therefore, our study results showed that the teaching of mathematics with IM software as a teaching and learning technology support might promote a conducive learning environment and influence learners' academic achievement. Comparing performances, IM-assisted class learners performed better than learners who studied the same content in traditional clas settings. In addition, statistical analysis found learners learning gain to be higher in IM-assisted mathematics classes than in traditional mathematics class teaching and learning. Although learners performed better in the post-test than in the pre- test for both traditional and IM assisted classes, more learners who scored above 50% were found in IM assisted classes than in traditional classes. Considering the school statuses, the study found that although private school performance was higher than public in traditional and IM assisted classes in pre-test and the post- test, the public school showed a greater improvement in the post-test than in private. By analysing learners' scores by gender, boys outperformed girls in both traditional and IM teaching. However, girls in IM-supported teaching manifested a greater improvement in performance than the boys' by comparing their pre-test and post-test scores.

The Role of Smart Teaching Using Interactive Mathematics Software on Learners' Performance

According to Orodho et al. (2016), administering a pre-test to the experimental group and control group is likely a means to measure the groups' equivalence of knowledge. From our study's findings, learners in both traditional and IM classes showed no statistically significant difference ($p>.05$, effect size (f) =-19) in the pre- test (before learning), while such significance was found to be highly significant ($p<.01$, f=.38) after learning (in post-test) in favour of IM software. Therefore, the pre-test results showed the equivalence of knowledge in the two groups, while the post-test results showed an improvement in learners' performance due to IM use in teaching and learning. Our study' results are in line with findings that hold the view that innovation through technology is one of the ways developing environments is necessary for effective learning (Delen, & Bulut, 2011). This argument was based on the findings of OECD countries in international mathematics competitions, which ranked Japan and Singapore among the best mathematics performers resulting in their use of computer technologies in mathematics classrooms (Delen, & Bulut, 2011). Therefore, using IM in teaching and learning mathematics at the primary level may be a good start on the journey of optimizing learning and improving the quality of mathematics education from early level of education. This confirms De Witte and Rogge, (2014)'s study results which found a correlation between access to technology and learner achievement. Considering differences in classroom environments, this study is in line with Rutz, et al. (2003)'s study which found that learners' performance improved in instructional technology methods more than in traditional teaching methods. In quest of reaching learners' different learning abilities, the use of IM may be a good means to help both slow learners and fast learners based on its potentials to attract learners' attention and to boost their learning interest. According to

Jena (2013), a smart class learning setting is better for teaching both slow and fast learners than in traditional classes. In our study, this was confirmed by the results of IM class compared to control classes.

According to Yang (2015), when learners are presented with interesting teaching strategies, they develop positive attitudes toward mathematics, which is likely to contribute to quality learning resulting in good performance. These strategies may include the using technological tools, like IM used in our study, or applying mathematics learning models like the one used by Dafid Slamet et al., (2021)'s study. Factors of performance in mathematics include learners' ability to think critically and solve problems. Dafid Slamet et al.'s (2021) study found that junior high school learners' critical thinking abilities developed after using a mathematical learning model and that dissatisfactory performance results from learners' low critical thinking abilities. Effective teaching should not only promote critical thinking skills but also creative thinking skills. Purwoko et al., (2019) explained that a comprehensive implementation of PCK model can improve learners' creative thinking skills more optimally. Therefore, improved learners performance may be an indicator of their improved critical thinking abilities. Henceforth, considering that learners' performance improved thanks to IM use in mathematics class, IM software can be ranged among the strategies to promote learners' critical thinking skills. This is obvious based on IM settings and features of feedback whereby the right answer is accompanied by an audio and written positive reinforcement while a wrong answer is accompanied by a negative reinforcement. The latter triggers learners thinking critically to dig up to finding the right answer. We can infer that if IM is used repeatedly and effectively, teachers' TPACK knowledge would improve and learners may move from being critical thinkers to becoming creative thinkers (Purwoko et al., 2019).

Although some studies found that learners working with computer-assisted instruction are more likely to be low achievers compared to their classmates in traditional classes (Drigas, & Papanastasiou, 2014), other studies highlighted the potential of ICT to make learning enjoyable and to help learners improve their performance. For example, Gachinu, (2014)'s study explains that when ICT components are applied in concretizing abstract mathematics concepts such as 3D geometry, it may serve as a means to improve performance or test scores. Likewise, the findings of our study revealed that learners' scores from the post- test improved after learning in IM supported class.

Drawing on our study results, the improvement of performance by IM can be interpreted as resulting in learners' and teachers' positive attitudes towards mathematics and IM software. Therefore, these results seem to be in line with the UTAUT model with its performance expectancy construct on the outcomes of technology use in educational settings (Momani, 2020). In addition, the results may have depended on the teachers' ability to effectively integrate IM in teaching and learning as recommended by the curriculum. Our findings confirmed that the effective use of IM in teaching and learning might result from teachers' perception and acceptance of that technology as stipulated by the UTAUT model based on the performance expectation. This results in the development or improvement of teachers' TPACK level, which leads to the effective use of technology as an instructional tool. During this study, teachers' TPACK level manifested during IM assisted lesson through experimentation period when teaching activities were integrated with ICT skills. From lesson planning stage to IM supported teaching activities, teachers' pedagogy was IM enhanced and the content was delivered using IM enhanced instruction. Teachers themselves were the ones to set the projector, the computer, wireless mouse and use them to teach or engage learners in using them to learn. IM content was organised into semi-concrete, quick exercises and evaluation levels. Teachers managed to take learners through all these levels using a wireless mouse. In addition to mathematics knowledge, teachers helped learners to develop, for the first time and for almost all learners, basic ICT skills including clicking, cautiously moving the mouse and the curser. During evaluation, questions were projected for learners to work on them, while the teacher was moving around to check learners' working. Using IM software, evaluation was given in plenary and a specific sound accompanied each right or wrong answer for reinforcement or correction. The software presented also checking options which were very interesting to learners. Teachers managed to use all these IM features to make the lesson understandable and enjoyable to learners. IM features including ease of use and its motivational features including different forms of sound, colours and movement influenced teachers' acceptance of the tool and their flexibility to integrate it in lessons. Therefore, drawing on TPACK theory and technology acceptance model, our study confirmed that technology use in mathematics class can promote effective learning (Delen, & Bulut, 2011) and improve learners' performance.

The Role of Interactive Mathematics Software on Public and Private School Learners' Performance

From the analysis of the variables with repeated measures ANOVA in general linear models, private school (N=78) showed a higher level of performance both before and after learning than public schools (N=116). However, the public schools showed a slight improvement from the intervention offered more than private schools. Therefore, the use of IM in mathematics teaching influenced learners' performance more in public schools than in private schools. This led us to confirm our argument that the use of IM in public primary schools teaching promote the learning environment of overpopulated classes resulting in learners' increase in performance. On the one hand, our results align with Khun-Inkeere's (2016) study, which found a difference in private and public school performance in favour of private schools. This was confirmed by the results, which showed that private schools' performance was higher than public schools' one in both the pre- test and the post-test. This is obvious as private schools present a conducive learning environment due to factors including a manageable number of learners per teacher. In addition, private schools host learners from able families, mostly educated and having enough financial means and technological tools to help learners learn effectively both in class and outside class (Khun-Inkeeree, 2016). For example in Rwanda, it was reported that while one public school teacher struggles to teach an average of 62 learners, a teacher in a private school teaches only 35 learners (MINEDUC, 2018).

On the other hand, our findings show that public school learners' performance can improve by IM use in class. These findings are in line with Chenoby's (2014) study, which found the existence of a relationship between access to technology and learner achievement. Gachinu's (2014) study explains that when ICT components are applied in concretizing abstract mathematical concepts such as 3D geometry, it may serve as a means to improve performance or test scores and to address the teachers' and learners' challenges caused by exposure to ICT in class.

The use of IM influenced teachers' TPACK level in teaching mathematics, which also resulted in IM software ease of use and acceptable by teachers. The findings show public school performance increased in post-test more than private schools did. We can say that public school teachers perceived IM as easy to be used in teaching and manifested acceptance towards it. Therefore, this resulted in better teaching and learners’ performance. This can be understood using Akturk et al.'s (2019) study, which explained that TPACK framed lessons have a positive impact on learning outcomes. In addition, it was found that teachers’ TPACK levels influence academic achievement (Akturk et al., 2019), especially with appropriate ICT tools. Our study used IM software developed in accordance with the CBC framework, which is under its implementation. Therefore, IM is an appropriate ICT tool to teach mathematics in primary level. It can therefore influence learners’ performance as it influences the development or improvement of teachers’ TPACK levels. Besides, the way teachers perceived IM as easy to be used and their acceptance to use it while expecting performance, influenced their ability to integrate it in teaching and learning resulting into learners’ performance. Therefore, the use of IM in public schools in Rwanda can be a means to overcome hindrances to achieving quality education which includes poor teaching, crowded classrooms and teacher heavy load as mentioned by Nizeyimana et al., (2021). This would result in improving performance in public schools as it was realised from our study findings. If quality education is to be achieved in public schools of 9YBE and 12YBE statutes, which present many hindrances to quality education compared to private ones, the learning environment conducive to effective learning should be set out primarily. Therefore, IM software is an important ICT tool for primary level schools that should be considered when designing classroom environments for effective learning (Delen, & Bulut, 2011) and that can contribute to the development of TPACK knowledge of primary level school teachers.

According to Akturk et al. (2019), TPACK is appropriate for educational settings of the 21st century for learners and teachers of grade and secondary to support the development of basic skills, interests, and confidence in learners learning, which are necessary for lifelong learning. IM software manifested the potentials to develop teachers’ TPACK knowledge necessary to influence learners’ performance. In addition, teachers’ perception of IM ease of use and its potential to influence performance affect public school teachers’ TPACK levels. This was evidenced by the improvement of learners’ performance in the post-test by IM.

The Role of Interactive Mathematics Software on Male and Female Learners' Performance

Mathematics education in Rwanda has long been characterized by gender disparities in enrolment and in performance mostly in favour of males. From the findings, the use of IM in teaching improved female and male learners' performance. Although males' performance remained higher than females', the latter showed a will to descriptively improve in post-test. Studies on gender and performance highlighted many hindrances to girls' performance in mathematics. These include low confidence in learning mathematics (Uwineza et al., 2018) and external factors to learning, including the learning environment (Dev, 2016).

Based on the findings, IM use in mathematics class manifested potential to create a learning environment suitable to improve both females' and males' performance

(Khun-Inkeere (2016). Therefore, this study agrees with Dev's (2016) study, which found that girls learning and performance depend more on external factors and less on learning abilities, while boys depend on internal factors. Therefore, the use of IM in teaching mathematics created a suitable learning environment for all learners which, however, benefited female's learning and improved their performance. It was found that ICT adoption in conservative environments where females and males learn separately improved the performance of female learners more than male learners (Basri et al., 2018). However, our study was conducted in mixed gender learning environments whereby one classroom hosts females and males who learn together. Therefore, our results are not in line with Basri et al., (2018)'s findings as we conducted our study in mixed gender classroom and that IM benefited both males and females in the same way. Rwanda education system focuses on education for all (EFA) which promote equality, equity and inclusive education. Therefore, public schools (of 9YBE and 12YBE statutes) learning environments in Rwanda are all non-conservatives and promote equal, equitable and inclusive learning for all learners. However, some secondary private schools' learning environments are still conservatives. The focus of our study was in primary school level of public and private schools whose learning environments were non-conservative. Therefore, IM improved male and female learners' performance in non-conservative learning environments. As it is pointed out by Uwineza et al. (2018), teachers play an important role in widening the gap between male and female learners' performance. A study about teachers' TPACK level in teaching biology and chemistry found no difference between male and female teachers' TPACK level (Akturk et al., 2019). Therefore, these findings together with this study finding are supportive to the fact that the integration of technology in class activities can benefit both female and male learners. In addition, as mentioned by Akturk et al.'s, (2019) study that found no difference in males and females TPACK level, IM influences male and female teachers' TPACK knowledge in the same way. It follows that IM use in mathematics class can contribute to promoting gender equity and equality in class based on our findings. It can therefore be used to support teachers' to promote learners' gender balance in the learning of mathematics.

Conclusion

In quest of improving quality implementation of the CBC and addressing issues hindering the achievement of quality education in Rwanda, IM software was developed to support the effective teaching and learning of mathematics at the primary level. This study focused on the effect of IM supported teaching on grade-5 learners' performance. From our findings, IM software used as instructional tool manifested the potential to design the classroom environment for effective teaching and learning and to improve learners' performance. Therefore, IM software would be more beneficial to public schools in Rwanda to address issues related to quality education delivery in overpopulated classes. However, this would depend on teachers' perception and acceptance of IM software ease of use with reference to teachers' and learners' performance expectations. Teachers should be able to make a good judgment about IM use in mathematics lessons so that they can effectively and meaningfully use it in pedagogy. This is in line with the Ministry of education's policy that stresses the role of the teacher in the appropriate pedagogical use of ICT in class to transform teaching and learning and improve the quality of learning outcomes.

It is worth noting that this study faced different constraints. Some participant teachers and learners were having very low basic ICT skills at the time of experimentation. Therefore, they were assisted in some ICT activities like clicking and projecting content, which was sometimes interrupting the smooth and effective teaching flow. Since this study was purely quantitative involving learners, a similar study focusing on the qualitative aspect of IM in mathematics class and/or teachers' lived experience in using IM software would bring more information about the features of IM in quality mathematics teaching and learning.

Acknowledgements

We acknowledge the support provided by the African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science (ACEITLMS), the University of Rwanda-College of Education, and the grant provided by the UR- SIDA Programme.

Declaration

Author contribution:

Innocente Uwineza: Conceptualisation, Writing- Original Draft, Methodology, Formal Analysis, Editing and Visualization;

Prof. Alphonse Uworwabayeho (Ph.D.): Review, & Editing, Validation and Supervision;

Kenya Yokoyama: Methodology, Software Developer and Trainer

Funding Statement: The University of Rwanda- SIDA Programme and the African Centre of Excellence in Innovative Teaching and Learning Mathematics and Sciences funded this research.

Conflict of Interest: No conflict of interest.

Additional information: No additional information available

Public Interest Statement

This article presents a comparative analysis of learners' performance in traditional teaching and technology-enhanced teaching in mathematics classes. It focused on primary-5 learners' performance using Interactive Mathematics (IM) software as an instructional tool. IM as a new technological tool under its piloting phase was developed to support the effective implementation of the Competence Based Curriculum (CBC) in mathematics at the primary school level in the Rwandan education system. Considering that the quality of mathematics education faces hindrances especially in public schools, this study explored the comparative effects of IM software in public and private schools with a glimpse into gender issues. It then explained the importance of IM in addressing quality mathematics education issues at primary school level in Rwanda.

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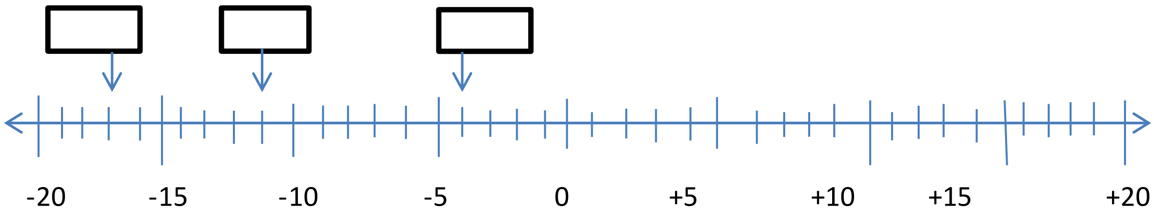
Appendix 1. The test provided to grade-5 learners

Test for P5

Pupils' name:……………………………………………………………………

Pupil's number:…………..…. Gender: Female: ☐ Male : ☐

1. Fill in the box below with number.



Match the right and the left by drawing the line

Negative numbers . .+20, +11,+8, +15

Zero . .+17, -9, +25, -31

Positive numbers . .-8, -17, -25, -14

Integers. .0

Fill in the box with "less" or "greater".

+14 is ☐ than -18

-15 is ☐ than -5

4. Fill in the box with the sign (< or >)

- ☐ 11 +9

- ☐ 12 -23

Write the numbers from smaller to greater in ascending order.

-12, +15, -6, +9, -18

Answer: ____ ____ ____ ____ ____

Write the numbers from greater to smaller in descending order.

-12, +15, -16, 0, +9

Answer: ____ ____ ____ ____ ____

Calculate the following:

(-6) + (+3) = (+5) – (-5) =

(-2) – (-6) = (-3) + (-7) =

Fill in the box below with number

(-13) + ☐ = 0

☐ +(+18)=0

Fill in the box below with number

The inverse of +5 is ☐

The inverse of -8 is ☐

2.3. Effect of IM-supported teaching on conceptual understanding

2.3.1. Detailed account of the paper (next page):

European Journal of Educational Research

Volume 12, Issue 2, 759 - 774.

ISSN: 2165-8714

https://www.eu-jer.com/

Grade-3 Learners' Performance and Conceptual Understanding Development in Technology-Enhanced Teaching With InteractiveMathematics Software*

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Received: July 26, 2022 ▪ Revised: December 1, 2022 ▪ Accepted: March 2, 2023

Abstract: This study presented the effect of interactive mathematics (IM) software assisted-teaching on primary three learners' conceptual understanding and performance. The cognitive theory of multimedia learning (CTML) supported the quasi-experimental design of this study drawing on IM software features that fit a multimedia tool for effective learning. This study used a sample of 138 lower primary learners. Learners' test scores and examples of their work provided data to be analyzed. Learners' conceptual understanding was measured using the percentage of learners who performed a particular item and analyzed using sample learners' work while the overall performance was measured using the mean class scores. From the data analysis, IM-assisted teaching influenced conceptual understanding and performance based on a .05 p-value, the effect size of significance, and learning gains. The analysis of learners' workings revealed different errors in addition, subtraction, division, and multiplication, which were remarkably reduced in the post-test by IM-supported teaching. This evidenced conceptual understanding development by IM- supported teaching. The study suggested the integration of IM in the Rwandan Competence-Based curriculum and its use as an instructional tool in teaching and learning mathematics at the primary level. Besides, it was recommended that Rwanda Education Board support teachers in developing basic computer skills to effectively create and monitor a multimedia learning environment for effective learning. Furthermore, further similar research would improve the literature about interactive technologies in supporting quality mathematics delivery and outcomes.

Keywords: *Conceptual understanding, interactive mathematics software, lower primary school, mathematics education, Rwanda.*

To cite this article: Uwineza, I., Uworwabayeho, A.,, & Yokoyama, K. (2023). Grade-3 learners' performance and conceptual understanding development in technology-enhanced teaching with interactive mathematics software. *European Journal of Educational Research*, *12*(2), 759-774. https://doi.org/10.12973/eu-jer.12.2.759

Introduction

Mathematics education occupies a core place at the center of quality education worldwide for its generic competencies and application to other areas. Since the last decades, education systems prioritized mathematics education and allocated bigger teaching time to mathematics subjects compared to other subjects. This shows the weight and importance mathematics is attributed in education. However, there exist disparities in mathematics achievement between countries around the world. Data from the trends in international mathematics and science study (TIMSS) revealed that performance in mathematics appears to be highly dominated by learners from developed countries and high-flying countries of East Asia, while African countries are poorly represented (Bethell, 2016). Although a high level of global competition dominates the current educational era, there exist challenges to quality mathematics education attainment worldwide and especially in sub-Saharan African countries (Bethell, 2016). Those challenges include poor pedagogies, poor teacher qualification, widespread mathematics anxiety, and some teachers experiencing mathematics as a rather abstract subject imported from outside Africa resulting in poor mathematics public image (Madaki, 2021). Besides, both primary and secondary levels of mathematics education are weak in most sub-Saharan African countries. This results in a limited enrolment rate in mathematics-related fields at higher education levels with a reduced potential population of talented students (Madaki, 2021). Mathematics and science are essential for developing a highly skilled workforce (Dwyer et al., 2015). Therefore, achieving quality mathematics education in developing countries should be a priority to develop mathematical competencies to cope with the current global educational aspirations.

* This article is part of the first author's Ph.D. study

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In this era of rapid scientific and technological advancement, mathematics is one of the vital study areas necessary to foster development, especially for under-developed countries that aspire to industrialize (Njiku, 2019). Strategies for improving teaching and learning like technology adoption to help teachers gain access to ideas, models, materials, and tools and more importantly the use of self-learning technologies have been found useful supplements, particularly where adequate teaching is lacking (Bethell, 2016; Madaki, 2021). The incorporation of ICT in education and its use as an instructional tool may be necessary for the modernization of mathematics teaching methods (Pachemska et al., 2014). However, it had been pointed out in the past that the best technology-supported teaching approach had not yet been ascertained in most sub-Saharan African countries (Bethell, 2016). In addition, the use of information and communication technology (ICT) in teaching and learning mathematics in most African countries is still in its infancy despite policies and initiatives promoting technology use in education (Madaki, 2021). Therefore, inquiring about outcomes of technology-supported methods in mathematics class and the potential of technological tools to promote quality education should be a priority to support ICT in education policies and to pave the way to effectively integrate ICT in education.

Mathematics education in Rwanda has been characterized by teachers' long explanations and writings on the chalkboard with learners' fewer mathematics activities. These practices are still persistent in Rwandan mathematics classes, with a growing number of learners per teacher. In 2015, Rwanda's education system adopted a new competence-based curriculum (CBC) replacing a knowledge-based curriculum in a quest for quality education. The purpose was to achieve the country's mission of developing human capital for sustainable development (Ministry of Education, 2018) and to embrace the national and international job market requirements and job creation.

Along with the development of the CBC, the Rwandan education system endorsed policies and initiatives to improve learning outcomes, including the integration of ICT in teaching and learning activities (Mugiraneza, 2021). Different programs and initiatives promoting the use of ICT in education, like the 'one laptop per child campaign' (OLPC) achieved a lot. Namely, the distribution of computers, laptops, and XOs, also commonly called OLPC, by assimilation to the campaign that provided them. However, all these laptops and OLPCs have longtime been kept under lock and key for many years without being used in classroom activities. School administrators simply accommodated to make daily reports about the number and the state of these technological tools that kept on dampening day after day in school stores.

The interactive mathematics software for Rwanda is an ICT technology designed by Rwanda Education Board (REB) in partnership with a Japanese company that designs educational materials known as Sakura-Sha through Japan international cooperation agency (JICA). IM was developed to support the effective implementation of CBC using laptops and XOs (OLPCs) distributed to schools some time back. IM is believed to support basic mathematics teaching and to benefit mathematics education in Rwandan basic education. Given that more research in ICT-supported pedagogies is mostly found at high school levels, this study is among few conducted at the primary level. It is the first one in Rwanda to analyze the potential of IM in supporting effective teaching and learning. This study is believed to serve as a means for teachers and learners to experience teaching and learning activities in a smart classroom.

Drawing on this background, our study focused on exploring the role of technology (IM software) in mathematics performance and conceptual understanding development at the primary level. This was achieved by answering the following question: What is the effect of IM on primary 3 learners' performance and conceptual understanding of mathematics? Before discussing the methodology, the researchers reviewed the existing literature on conceptual mathematics understanding and the cognitive theory of multimedia learning (CTML) as a learning framework.

Literature Review

Conceptual Understanding in Mathematics

Ordinarily, the ultimate goal of teaching mathematics is not only about getting learners' best scores but more importantly, it is about developing their abilities to understand mathematical concepts (Kusumaningsih et al., 2019) and equipping them with a powerful tool to understand and change the world (Andamon, & Tan, 2018). Conceptual understanding development is one of the ultimate goals of quality mathematics teaching and learning. Conceptual knowledge in mathematics is the understanding of core mathematical principles and the relationships among them. Conceptual understanding results from teachers' practices involving learners to actively build new knowledge from experience, previous knowledge, and reflection on their thinking through explanations and problem-solving strategies (Dwyer et al., 2015). The development of conceptual understanding in mathematics is an important factor in building Kilpatrick's mathematical proficiency (Haji, & Yumiati, 2019). Some studies pointed out the existence of a relationship between learners' performance and their conceptual understanding (Mendezabal, & Tindowen, 2018; Psycharis et al., 2013). Therefore, the development of conceptual understanding may result from implementing strategies to improve performance. The development of conceptual understanding in mathematics is important to develop problem-solving skills and other mathematical-related competencies needed for the workforce.

Conceptual understanding is a variable that attracted different researches focus worldwide in the quest of improving quality mathematics education. Some of these studies focused on technology in mathematics education (Amit, & Amia, 2020; Mendezabal, & Tindowen, 2018; Mlotshwa et al., 2020; Psycharis et al., 2013; Zulnaidi, & Syed Zamri, 2017), while others focused on other strategies (Dwyer et al., 2015). It was found that technology plays an important role in developing learners' conceptual understanding (Haji, & Yumiati, 2019). According to Mendezabal and Tindowen (2018), mathematics teachers should integrate technology into mathematics instruction to provide a technology-based learning environment, diversify their teaching approach and make it more interactive, and engage students in meaningful learning.

However, while these studies concentrated on developing conceptual understanding at the high school level, the lower level education needs much more attention in matters related to quality learning and conceptual development. It was found that elementary learners experience difficulties in building conceptual understanding especially in arithmetic, geometry, and word problems (Haji, & Yumiati, 2019). According to Milton et al. (2019), elementary education learners need conceptual understanding to be well prepared to fit the upper educational level standards. Mathematics, like other sciences, should be developed earlier to ensure that learners leave schools technologically and mathematically literate to embrace the global competition in all aspects (Bethell, 2016). It is therefore important to start addressing conceptual understanding-related issues from the early educational stage to pave the way to upper educational levels to ensure sustainable meaningful learning and quality delivery.

Successful mathematics learning encompasses learning processes aimed at understanding the knowledge of the procedure and the concepts contained in the material being taught (Nahdi, & Jatisunda, 2019). According to Andamon and Tan (2018), understanding mathematics concepts refers to the knowledge that results from the understanding of basic concepts necessary to understand and perform mathematical algorithms. In Khan's (2018) terms, conceptual understanding is the understanding or mastery of a student's concepts, operations, and mathematical relationships. According to Dwyer et al. (2015), and Amit and Amia (2020), conceptual understanding development may be evidenced by learners' improvement in performance. For example, data from the TIMSS in 2007 were used to examine differences in instructional practices that support students' conceptual understanding development resulting in getting high mathematics test scores among high-performing countries (Dwyer et al., 2015). Therefore, evaluating conceptual understanding development may result from analyzing the percentage of correct answers in a test following the type of teaching practice implemented.

Various strategies influence the development of conceptual understanding in mathematics. Those include teaching practices with or without technological tool support. It was found that teachers in the U.S.A. focus on using repetitive exercise strategies in developing conceptual understanding of mathematics, while mathematics teachers in other high performing countries use intructional strategies emphasizing critical thinking and lesson structure (Dwyer et al., 2015). For Haji and Yumiati's (2019) study, conceptual understanding development may result from the application of national council of teachers of mathematics (NCTM) principles and standards consisting of 6 principles including teaching, learning, and technology. Therefore, conceptual development results from effective teaching when the teacher understands well mathematics knowledge, learners' abilities, and pedagogical strategies whereby understanding-based methods are promoted. In addition, technology supports effective teaching by visually and attractively presenting learning in a streamlined manner which results in learners' engagement in activities promoting meaningful learning. Hence, through examining, representing, changing, solving, applying, proving, and communicating mathematical ideas, mathematics conceptual understanding may be developed (Haji, & Yumiati, 2019). Therefore, it is important to explore conceptual understanding development in primary education using technology as an instructional tool to ensure the development of mathematics skills required for the workforce at early learning stage.

Different studies explored the use of technology in developing learners' conceptual understanding. Psycharis et al. (2013) and Mlotshwa et al. (2020) explored the use of Moodle under the learning management system (LMS) as a pedagogical tool to teach and develop learners' conceptual understanding of physics and mathematics respectively. Zulnaidi and Syed Zamri (2017) investigated the effect of GeoGebra software on students' conceptual and procedural knowledge the achievement in mathematics particularly on the topic function while Mendezabal and Tindowen (2018) explored the role of Microsoft Mathematics to improve mathematics conceptual understanding in differential calculus. Another study conducted by Amit and Amia (2020) investigated the use of Quizizz which is an android-based quiz, with a case-based game learning (CBGL) strategy, to improve conceptual understanding in mathematics. The findings revealed improvement in performance and conceptual understanding development in technology-assisted teaching and learning environments more than in traditional teaching and learning environments (Mendezabal, & Tindowen, 2018; Mlotshwa et al., 2020; Zulnaidi, & Syed Zamri, 2017). In addition, learners' knowledge acquisition resulting from interacting with computers and mathematics content through Moodle under LMS improved their understanding of the function concept (Mlotshwa et al., 2020). Moreover, the use of Android-based quizzes (Quizizz) influenced learners' conceptual understanding development by understanding their mistakes because of direct feedback from assessing the work result quickly, right, and accurately (Amit, & Amia, 2020). Besides, learners developed positive attitudes toward blended learning (Psycharis et al., 2013). The IM used in this study is a new technological tool under the piloting phase intended to be used in primary mathematics education. Therefore, this study is among the first to tackle the potential of IM to boost quality mathematics education at the primary level and to add to the works of literature about interactive technologies in quality education at the primary level.

Our study draws from previous studies interested in the use of technology to support the development of conceptual understanding in mathematics subject. It follows Mendezabal and Tindowen's (2018) study which recommended mathematics educators continue examining current practices for teaching mathematics with technology to determine its effectiveness and to explore new ways to harness the potential that it brings as an instructional tool to develop different mathematical skills including conceptual understanding. In addition, this study draws on a study conducted at the primary level which found that elementary learners experience difficulties in building conceptual understanding especially in arithmetic, geometry, and word problems (Haji, & Yumiati, 2019). It also follows Loo and Said (2020) study conducted in primary school and grounded in the cognitive theory of multimedia learning to monitor learners' motivation, performance, and problem-solving skills development. Therefore, our study focused on primary education conceptual development and argued that the use of IM technology in primary mathematics education can improve learners' conceptual development and performance in arithmetic.

According to Ji and Barbara (2013), the development of a conceptual understanding of multiplication follows two models such as additive relationships that fit whole numbers and multiplicative relationships that fit non-whole numbers. The additive relationship is a process of adding equal-sized numbers repeatedly. This model consists of building a conceptual understanding of multiplication starting by using groups of discrete objects whereby learners count the number of objects and the number of the groups; and apply their addition skills to prove that the repeated addition gives the same result as multiplying (Ji, & Barbara, 2013). The effective use of repeated addition to developing a conceptual understanding of multiplication and multiplicative reasoning results not from the operational side of multiplication but from the emphasis on the discovery of 'the intermediate unit,' the creation of a new unit (the number of occurrences of the intermediate unit in repeated addition) and the ability to deal with two levels of units: from adding the same unit or intermediate unit several times to iterating the intermediate unit several times (Ji, & Barbara, 2013). For example, 3 + 3 + 3 + 3 = $3x4$ means adding 3 units to three four times is equal to iterating the unit 3 four times, and 3 is the intermediate unit while 4 is the new unit created from repeated addition.

However, a multiplicative relationship involves conceptualizing an intermediate unit or many intermediate units other than multiplication. For example, working on $\frac{1}{4}x\frac{1}{2}=\frac{1}{8}$ requires the understanding of the concept fraction, a bar of fraction, equal sign, numerator, and denominator in addition to multiplication itself. According to Ji and Barbara (2013), additive relationships measure multiplicative reasoning linked to natural numbers, while the multiplicative relationship model measures multiplicative reasoning, which is linked to fractions, slope, proportions, and rate also explained as complex topics. The comparative judgment model (CJ) explained by Ian et al. (2013) likely completes the multiplicative relationship model to develop multiplicative reasoning involving fractions. The understanding of fractions needs to develop the conceptual understanding of multiplication as the foundation for developing a more cohesive understanding of complex multiplicative reasoning (Ji, & Barbara, 2013). This study was conducted in lower primary on numeration and operation of whole numbers. Therefore, the researchers used the additive relationship model for the development of a conceptual understanding of multiplication and division (inverse of multiplication).

Cognitive Theory of Multimedia Learning

According to GebreYohannes et al. (2016), multimedia can be understood as computer-mediated software that presents concepts in a simultaneously integrates text, color, graphical images, animation, audio sound, and full motion video in a single application. The CTML is defined as learning that draws on auditory and visual stimuli, or learning from the combination of text and pictures (Mayer, 2014a, 2014b; Sorden, 2012). According to Mayer and Moreno (1998), there exist three principles of the CTML that influence learning. The acquisition of knowledge may go through separate processing channels for pictures and words (dual principle of learning), but the working memory's capacity for information processing limits knowledge to be acquired (limited capacity principle of learning). They need appropriate cognitive processing for meaningful learning (active processing principle), like paying attention, conceptual organization, and integration with prior knowledge. Multimedia learning environments may be static (using pictorial and auditory information) or dynamic (with animations), dealing with the transient nature of the dynamic information presented in these environments. According to Soewardini et al. (2018), the CTML is likely an effective ICT learning theory capable of helping learners learn effectively and efficiently through instructional multimedia (Mayer, 2014b). In classroom situations, CTML is learner-centered and influences active and meaningful learning observable through learners' performance on a task or a test (Sorden, 2012).

CTML benefits teaching in different areas and levels. The interventionist study conducted using game-based learning applications in primary school using Mayer's (2014b) CTML framework found that the intervention can enhance learners' achievement with significant mean differences (Loo, & Said, 2020). In Rwanda, Ndihokubwayo, Uwamahoro and Ndayambaje (2020) found that CTML is effective in promoting quality education. Moreover, Uwurukundo et al. (2022) found that GeoGebra supported the teaching of geometry and improved problem-solving abilities more than the use of chalk and talk. For CTML to be as successful in dynamic classroom situations as it is in controlled experimental situations, learners' cognitive capacity should be taken into consideration to avoid cognitive load (Mayer, 2014b). Therefore, the use of technology in education should be advantageous compared to traditional teaching in facilitating the teaching of mathematics in multiple representations and in lessening learners' cognitive load. According to Bethell (2016), the availability of appropriate educational technologies influences achievement and performance in mathematics.

The Interactive Mathematics (IM) Software for Rwanda

This study used IM software as a multimedia tool in primary three mathematics teaching and learning. Adapted from the IM software used in Japan and developed under the primary three-mathematics CBC framework for Rwanda, the IM- assisted teaching goes through 3 levels consisting of understanding, quick exercises, and evaluation. At the understanding level, learners are engaged in exploring unknown relationships by manipulating semi-concrete mathematical objects presented as attractive pictures associated with particular sounds, movements, and text. This level triggers learners' questions like 'what kind of mechanism is it'? By undertaking several repeated activities using different exercises at the understanding level, learners manage to figure out and progressively grasp clear relationships. After understanding relationships, learners are taken to the next level, where mathematics objects are presented in an abstract way to practice multiple times. Sometimes, they switch back to an understanding level whenever they forget the relationship and return to quick exercises. At the evaluation stage of IM content, the software allows learners to perform several exercises, to check the answer, and to get rewards for a correct or a wrong answer. All these IM characteristics explained above can be understood as fitting the multimedia features explained by GebreYohannes et al. (2016). Therefore, we can argue that IM software features fit the multimedia instructional tool that can boost learners' conceptual understanding and performance in a primary mathematics class in Rwanda.

Conceptual Framework

Some studies found a positive correlation between conceptual understanding, procedural fluency, and problem-solving (Ho, 2020). Mathematics expertise and conceptual understanding cannot be separated from one another, and they serve as the best predictors of learners' performance. In this study, the teaching and learning activities were performed on numeration and operation in the set of natural numbers. Therefore, the additive relationship model was used to analyze learners' conceptual understanding of multiplication. This was visualized by analyzing the potential development of learners' conceptual understanding through some of their workings. Thus, the analysis of learners' conceptual understanding started with the analysis of their problem-solving skills, and their performance as evidenced by a sample of scriptural work. In this study, IM software will be used as an ICT tool that fits the characteristic of a multimedia tool to frame the cognitive theory of multimedia learning. The teaching slightly focused on addition and subtraction of multi- digit numbers and focus more on simple multiplication and multiplication of multidigit numbers and less on division.

Therefore, the additive relationship helped to develop learners' conceptual understanding of multiplication and to develop multiplication reasoning. The relationship between the variables can be best visualized in Figure 1 below:

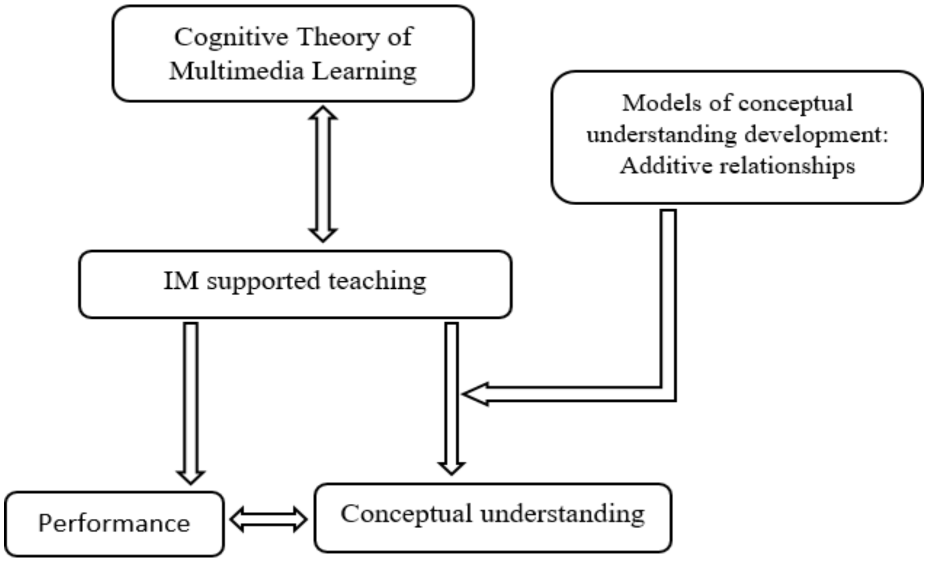

Figure 1. Conceptual Understanding Development Model by IM Multimedia Learning (Source: authors' drawing)

Methodology

Research Design and Sampling Issues

This study was quasi-experimentally designed and used control and experimental groups. It used a sample of 138 lower primary learners from private schools and public schools of Nine Years Basic Education (9YBE) status in an urban area, Kigali. The urban area attracted our focus because of the availability of primary-level private schools and public schools well equipped with ICT facilities. In addition, this area presents more transport facilities to move from one school to another. Therefore, after identifying public and private schools that are ICT equipped, we conveniently selected sample schools and focused on primary-3 learners to participate in this study. The experimental group consisted of a group of learners who were taught mathematics with IM software as a supportive tool for teaching and learning, while the control group was the group of learners who were taught the same content as experimental the group using the traditional method of chalk and talk.

At the beginning of our study, primary three teachers who participated in this study and the researchers with a group of Japanese experts conducted a short seminar about the effective use of IM in teaching. They agreed on the content and the lesson plans that are IM-integrated, and they practiced the microteaching before the actual teaching activities. Together, they developed items for the pre-test and the post-test referring to the Rwandan mathematics syllabus of P3 (REB, 2015) and to the planned scheme of work to support the actual school's classroom activities calendar effectively. An invigilated pre-test was given to control and experimental group learners. The purpose was to ensure equivalence in learning for all learners. Learners used 30 minutes in maximum to work on the test by answering using the place provided in front of each question. After the pre-test, the first author collected all answers with question papers and kept them confidential to avoid learners' familiarity with the questions. Then, a pre-test was followed by IM-supported teaching in the experimental group and the chalk and talk teaching in the control class. In IM-supported classes, teachers started by setting the computer with the projector, opening the IM software, and the IM lesson while also giving learners instruction to sit properly. The teacher presented the teaching by projecting mathematics content on the screen using a projector connected to a computer. Learners followed the teaching under the teachers' guidance and work on exercises projected in front of them. Teachers and learners interacted with the content using a wireless mouse. Learners' work was done in two ways: they sometimes worked by clicking using the wireless mouse or by writing on a piece of paper with a pen. While the teacher was teaching, the first author was collecting some observations (used in another article waiting for publication) and sometimes assisting the teacher with some IM technical issues. The teaching was conducted during the first term of the 2019 school year for 40 minutes per period and 6 teaching periods per week.

Research Tools and Data Collection

The content taught consisted of addition and subtraction of numbers with sum or difference less than 2000, multiplication tables of 7, 8, and 9, multiplication with digit number and multiplication with a two-digit number, and long division of numbers less than 2000 by a one-digit number. The teaching of multiplication occupied nearly 73% of the teaching time while the remaining content occupied 27% of the teaching time. Therefore, the tests consisted of eleven items out of fifteen items about multiplication, two items about addition and subtraction and two items about division. Addition and division items were used to serve as pre-requisites knowledge while items about division (inverse of multiplication) were included to develop higher order thinking out of a conceptual understanding of multiplication. The integration of division topics with the multiplication ones was guided by the argument that it is important to choose models that embody the meaning of a multiplicative relationship as compared to an additive relationship at the early stage of instruction of multiplication (Ji, & Barbara, 2013). Referring to the CBC framework, the language of instruction in the lower primary was Kinyarwanda by the time of the study. Therefore, the test was administered in English and translated into the local language (Kinyarwanda).

This study used quantitative data collected using pre-tests and post-tests. After the pre-test results, the schools which got fewer scores were assigned to experimental group in One-Group Pre-test-Post-test Design (Fraenkel et al., 2012). Learners' scores from the pre-test and post-test have been collected using question items developed out of the content used in the experimentation. The same items grouped into five questions were used in pre-test and post-test (see appendix 1). The purpose was to measure learners' consistency in their understanding. To limit learners' familiarity with the test items, pre-test feedback, and marks of pre-test and post-test were given two days after the post-test was done. The numbering and order of the test items in pre-test was changed in the post-test and items formulations slightly changed but the constructs to be measured remained the same. In addition, teachers and researchers managed to collect all question papers after the pre-test and ensured that learners were not exposed to test items during the intervention period.

Data Analysis

Researchers used MS Excel 2016 to analyze the data and marked the test with fifteen items under five questions. Each item got one score and all scores were then summed up to the total score each pupil got. Then the average was computed on a percentage score. A paired t-test was used to measure the effect between pre- and post-test learners. Again, the number of learners who successfully performed each item was calculated and averaged on percentage. Graphs were drawn to represent learners who performed the questions well visually. The statistical measures and the effect size and learning gains of significance were measured using formulae (Ndihokubwayo et al., 2021). The effect size was measured by taking the difference between post-test and pre-test average scores and dividing this by the average standard deviation. The learning gain was measured by taking the difference between post-test and pre-test average scores and dividing this by the difference between the highest post-test and pre-test scores. The control group was used to ensure equivalence in knowledge. This study started with two groups of learners consisting of 64 learners in one group and 74 learners in another group. We then started by checking parametric test assumptions. The sample was enough (>30) and equal variance was assumed (Levene's test revealed a $p>.05$). The Kolmogorov-Smirnov test of normality revealed no statistically significant difference in the two groups with $p>.05$ (.382 in the control group and .531 in the experimental group). In addition, the skewness (an indicator of lack of symmetry) for the two groups was normal (.327 for the group of 74 and -2.855 for the group of 63). However, the Kurtosis (which determines the heaviness of the distribution tails) of

-1.921 was found in the group of 74, and high Kurtosis of 6.348 was found in the group of 63. Therefore, we conveniently chose to utilize a group of 64 learners as an experimental group and one of 74 learners as a control group. When we left the pre-testing stage for testing equivalence in knowledge, we continued with an experimental group with teaching intervention and post-test to check the level of IM effect on performance and conceptual developmen

Results

Primary Three Learners' Performance

Table 1 shows the results of a t-Test analysis of two samples of means assuming equal variances. These are results from two groups, control (those learners who only did the pre-test) and experimental (those learners who did both pre and post-test or who experienced a teaching intervention). Based on these findings, it can be said that treatment and control group learners are likely, not different from each other in terms of performance, and their mean scores are almost the same (p=0.056; p>.05, df=136, Mean pre-test [only]=38.558 and Mean pre-test [both]= 31.354) before learning. Therefore, before the intervention, the treatment group and the control group were equivalent in knowledge about the content of experimentation based on the p-value or significance.

Table 1. t-Test of Two-Samples of Means From Pre-test [only] and Pre-test [both] Groups Assuming Equal Variances

	Pre-test [only]	**Pre-test [both]**
Mean	38.55856	31.35417
Variance	466.6913	802.3699
Observations	74	64
Pooled Variance	622.1895	
Hypothesized Mean Difference	0	
Df	136	
t Stat	1.692008	
P(T<=t) one-tail	0.056467	
t Critical one-tail	1.656135	
P(T<=t) two-tail	0.092934	
t Critical two-tail	1.977561	

Table 2 shows the results of the analysis of a t-Test of paired two samples of means of the treatment (experimental) group in pre-and post-test. Results revealed that the difference in performance before the treatment and after the treatment is significantly based on the mean differences, the degree of freedom, and the one-tail P-value (p=3.05E-18, *p*<.001; df=63; Mean pre-test [both]= 31.354; Mean post-test [both]= 62.916).

Table 2. t-Test of Paired Two Sample for Means From Pre-test and Post-test [Both] Groups

	Pre-test [both]	**Post-test [both]**
Mean	31.35417	62.9667
Variance	802.3699	682.716
Observations	64	64
Pearson Correlation	0.704689	
Hypothesized Mean Difference	0	
Df	63	
t Stat	-12.0107	
P(T<=t) one-tail	3.05E-18	
t Critical one-tail	1.669402	
P(T<=t) two-tail	6.1E-18	
t Critical two-tail	1.998341	

Table 3 presents descriptive and inferential statistics in testing (pre-and post-test). The results of the pre-test show learners' equivalence in knowledge. While the control class got a *Mean* = *38.55* and the experimental class got a *Mean*=*31.35* the difference was not significant as $p>.05$.

The experimental group post-test results show that IM descriptively improved learners' performance based on the significance ($p<.001$), effect size ($f=1.07$), and learning gain ($g=1.57$). Therefore, before the intervention, the two groups' knowledge was equivalent. After the intervention, learners' performance improved by IM software based on the significance of mean differences, learning gain, and effect size.

Table 3. Descriptive and Inferential Statistics in Testing (pre-and post-test)

Treatment	**Test**	**Sample**	**Mean (%)**	**Std. Dev (%)**	**p-value**	**f (Test)**	**G**
Control class	Pre-test	74	38.55	21.60	>.05		
IM class	Pre-test	64	31.35	28.32	<.001	1.07	1.57
	Post-test		62.91	25.04			

Primary Three Learners' Difference in Performance on Test Items

Before the intervention, only question numbers #1, #2, #5, and #9 out of 15 sub-questions were likely understood and performed by more than 50% of learners from the pre-test [only] group (control group) and the pre-test [both] group (experimental group). The other 11 sub-questions were poorly understood by learners from the two groups and were generally performed by less than 50% of learners, with question no #15 that was not performed by any learner from the experimental group (see Figure 2). Therefore, comparing the control and treatment groups, results show equivalence between the two groups in conceptual understanding before intervention.

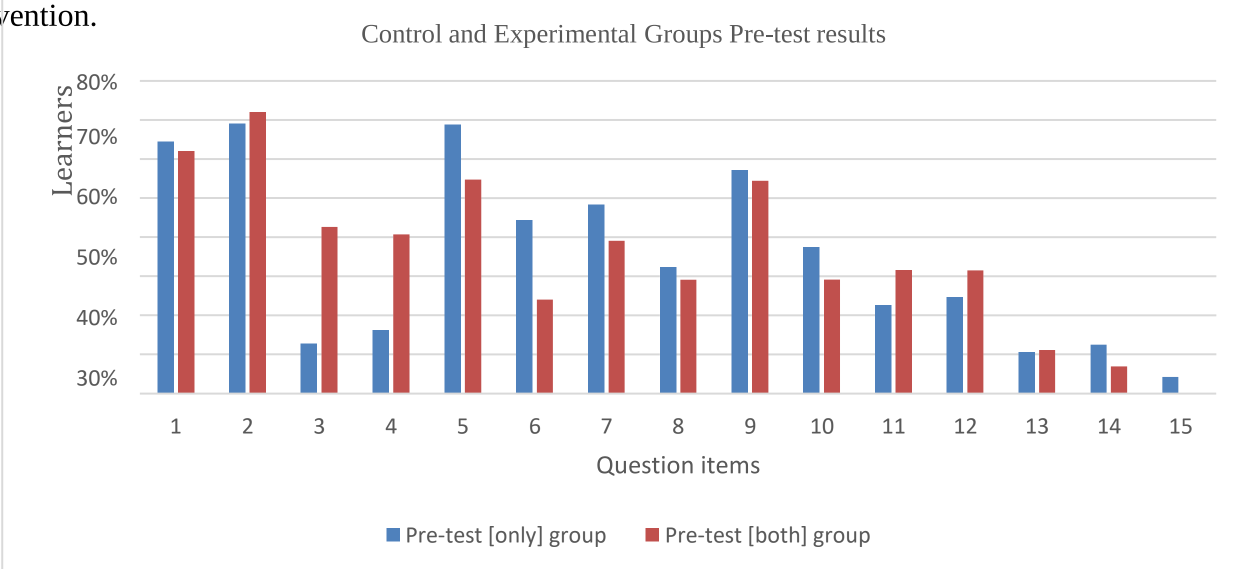

Figure 2. Conceptual Understanding of Control and Experimental Group Before Intervention

Figure 3 shows the result of the pre-test and post-test for the experimental group post-test. In the pre-test, only items no #1, #2, #5 and #9 were each performed by 50% of learners at least item no #15 was not performed by any learner. In the post-test, all items were performed by more than 50% of learners except items no #13, #14, and #15 whose performance was less than 50% of learners each. A remarkable improvement was realized on item no #15 which was not understood by any learner in the pre-test but performed by a remarkable percentage of learners (37%) in the post- test. Therefore, the results post-test show that after the intervention, IM improved the performance of the experimental group.

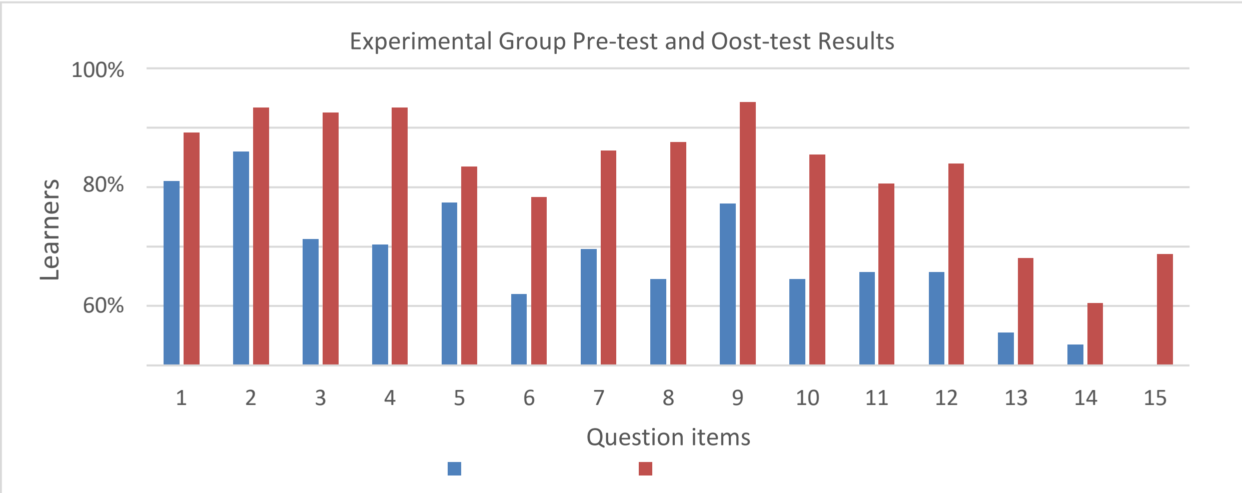

Figure 3. Conceptual Understanding of Experimental Group Before and After Intervention

Figure 4 shows a comparison between the control and experimental group's pre-test and experimental group' post-test results. Results show that the experimental group improved conceptual understanding after intervention and question no #15 which was not understood by any learner was performed by a remarkable percentage of learners.

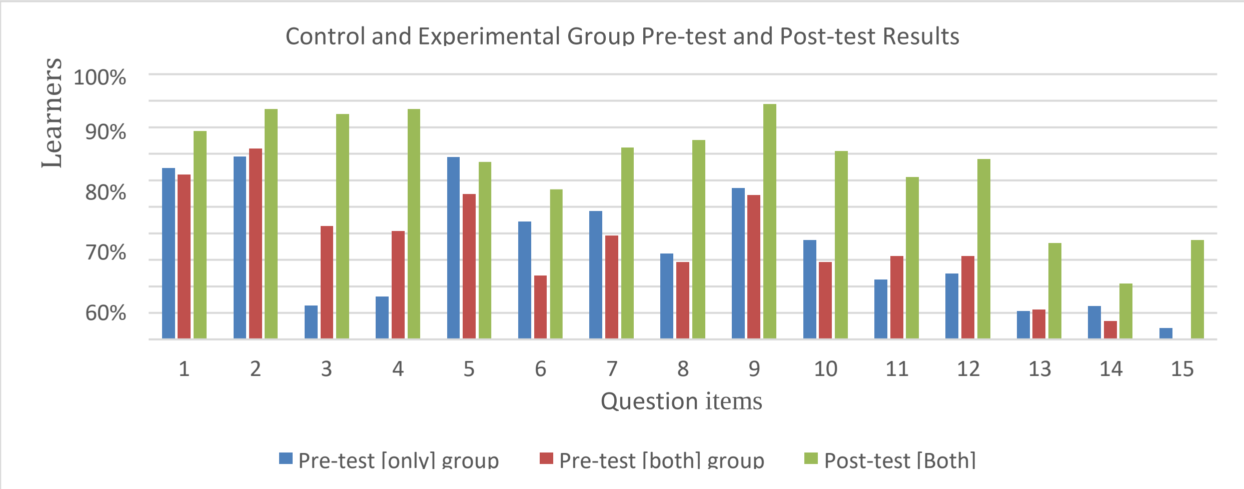

Figure 4. Conceptual Understanding of Control and Experimental Group Before and After Intervention

By looking at individual learner workings which led to a performance in the pre-test and the post-test, learners' difficulties encountered in tests were analyzed (see figure 5). In the pre-test, learners manifested errors in performing addition and subtraction of multidigits numbers, interpreting repeated addition as multiplication, performing simple multiplication and division as well as performing long division. However, these errors were reduced remarkably in the post-test because of the intervention.

From figure 5, learners' post-test scores improved by 73% (from 0 to 11 out of 15). The analysis of learner's post-test scriptural work shows learners' poor performance on the two items of question #1 consisting of the addition of two multi-digit numbers with carrying and simple subtraction of two multi-digit numbers. However, these operations are very basic to multiplication and division which were the focus of this study's intervention. Besides, expressing repeated addition as multiplication, multiplication table of 8 and simple division by 7 (inverse multiplication table of 7), which are very basic to perform complex multiplication (2 items of question #5) and long division (last item of question #5) were difficult for learner 1 to perform. In the post-test, learner 1 managed to increase the performance from 0 out of 15 items in the pre-test to 11 out of 15 items. Learner 1 manifested the understanding of addition with carrying and simple subtraction (question #1), expressing repeated addition of 7 as multiplication by 7, and working out simple multiplication exercises. Therefore, many items involving addition, subtraction, and multiplication that were likely, not comprehensible in the pre-test were well performed in the post-test after IM-supported teaching.

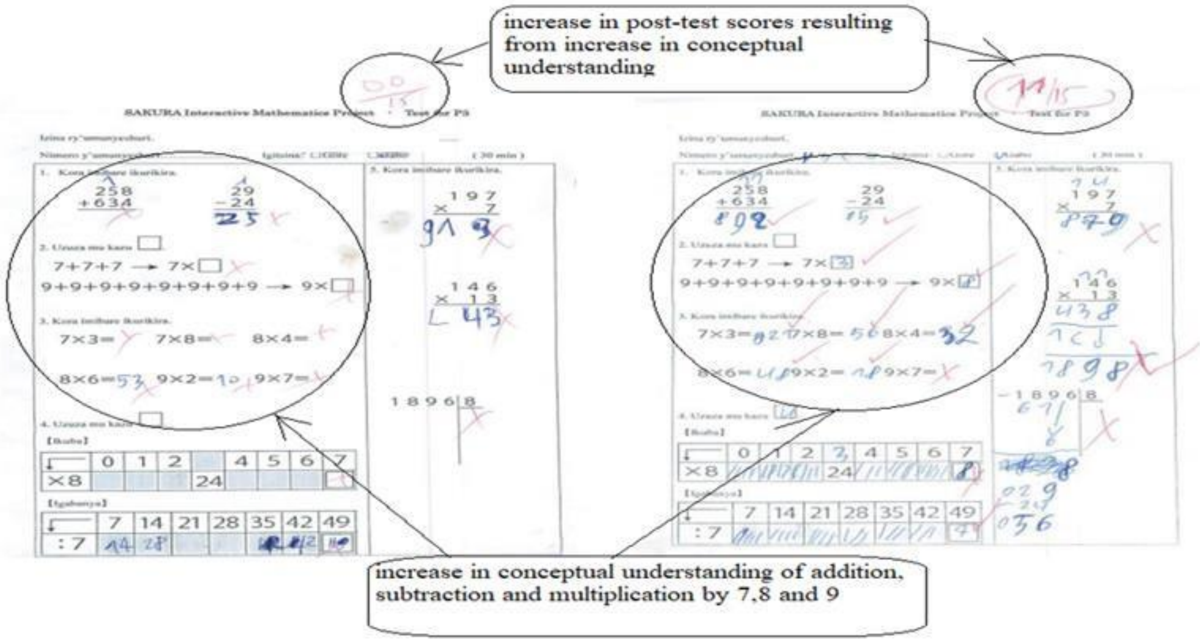

Figure 5. Learner 1's Scriptural Work of Pre-test and Post-test, Field Study, 2019

From figure 6, learners' post-test scores improved by 66.7% (from 4 to 14 out of 15). In the pre-test, learner 2 struggled to find mechanisms behind relationships between repeated addition and multiplication, relied on drawings, and drafted a multiplication table of 3 to help recalling the mechanisms to find the answers. Curiously, figure shows that the learners were not mastering the multiplication table of 3 or the content of primary 2 though it is a pre-requisite to learning multiplication by 7, 8, and 9 or the content of primary 3 (REB, 2015). In addition, the multiplication of multidigit numbers with one digit numbers or two-digit numbers was also so difficult that the learner failed to work out $17x7$ or $146x3$. In the post-test, learner 2 demonstrated abilities to smartly perform multiplication of $197x7$ or $146x3$ but did not grasp the mechanism of organizing vertical addition of digits from multiplication which led to failing to find $146x3$. On division (inverse of multiplication), the learner showed difficulties in performing simple division by seven and long division of 1896 by 8 . The long division of 11896 involves the understanding of groups of the number to be divided and the systematic mechanism to continue the process, including multiplication, subtractions, and movement of digits (lowering) up to the answer. Figure 6 shows no evidence of the understanding of these mechanisms by learner 2 during the pre-test. However, after IM-supported learning, learner 2 understood the mechanism of long division and all mechanisms involved in the process to find the final answer.

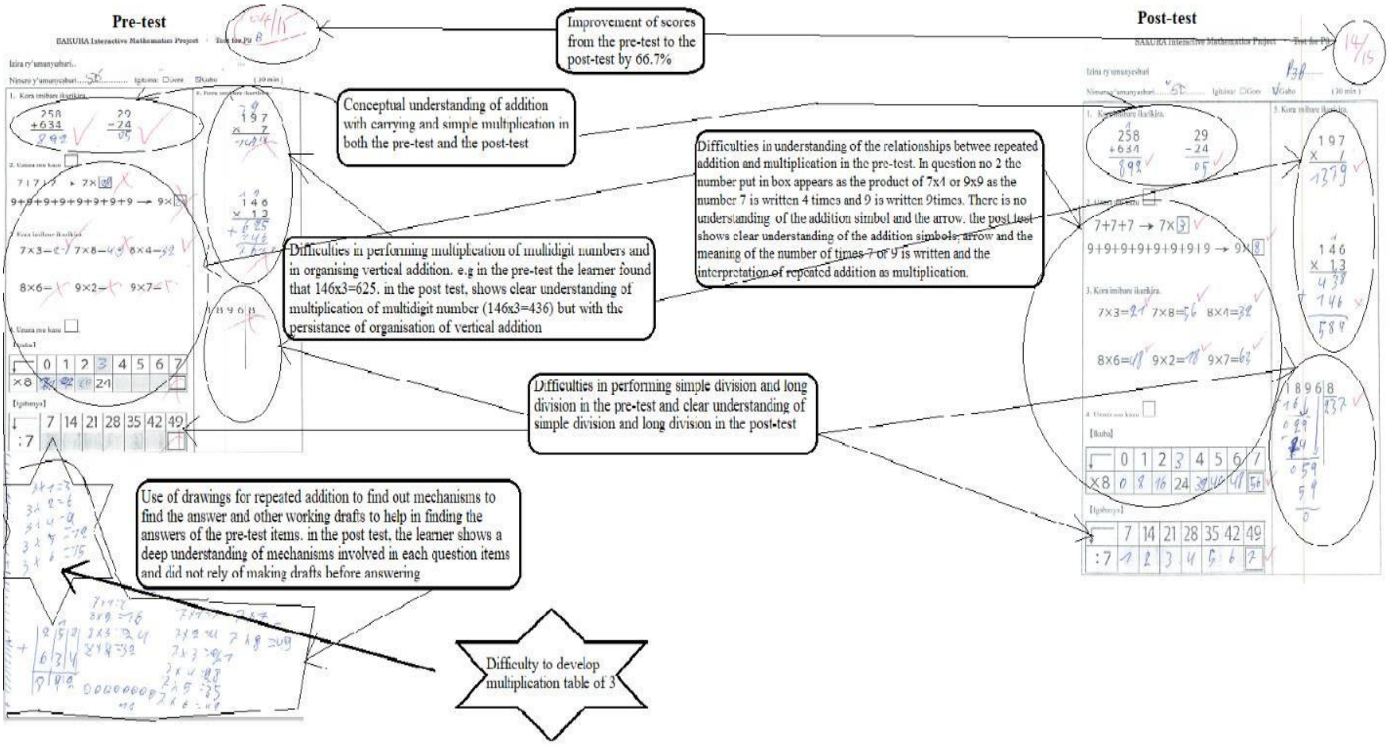

Figure 6. Learner 2's Scriptural Work of Pre-test and Post-test, Field Study, 2019.

According to the analysis of the different multiplication errors made in the pre-test, many students either did not comprehend the question or were unable to find the answer. Therefore, they left the answer space unfilled. Many other learners understood the repeated addition but failed to interpret it in a corresponding multiplication. As a result, they substituted the additional terms for the multiplication terms. Other learners did not understand the role of the arrow between the repeated addition expression and the corresponding multiplication expression. They simply added all present terms regardless of the presence of the arrow and wrote the resulting sum as the requested multiplication term. Other few learners wrote answers which do not show any link either with the terms or with the operation. This explains the root of learners' low conceptual understanding in the pre-test as it appears in figure 7 below:

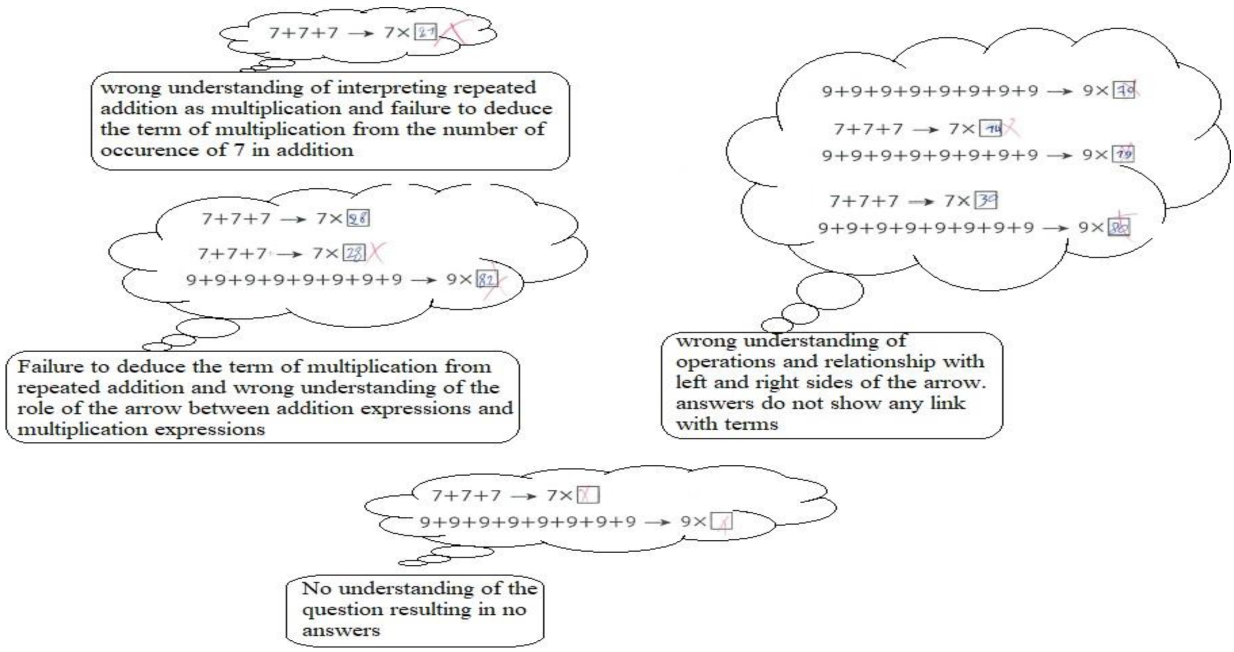

Figure 7. Types of Errors of Multiplication Committed in the Pre-test, 2019

Discussion

Considering the post-test results in a one-group pre-test-post-test design (Fraenkel et al., 2012), our findings show that there is a significant difference between learners' pre-test and post-test scores based on statistical significance. While the control group mean was *38.55,* the experimental group mean was *31.35*. After the intervention, the experimental group mean improved from *31.35* to *62.91* with $p<.05$ ($p=3.05E-18$, $p<.001$). Therefore, IM-supported teaching improved experimental group learners' performance. Our findings support Zulnaidi and Syed Zamri's (2017) finding that GeoGebra software can raise students' achievement levels compared to learning in a typical mathematics class. Our results are also consistent with a primary school study by Pachemska et al. (2014) that discovered that technology-enhanced classes improved mathematics teaching strategies, which led to learners' improved achievement more than their counterparts who concurrently attended traditional mathematics class. Furthermore, our findings confirm that effective implementation of technology-enhanced teaching based on Mayer's (2014b) cognitive theory of multimedia learning generates a positive effect on primary school learners' learning and performance (Loo, & Said, 2020).

By analyzing learners' conceptual understanding, we found that few items were performed by at least 50% of learners and that the percentage of learners who performed an item was almost the same during the pre-test. Therefore, the two groups were having the same conceptual understanding or equivalence in knowledge before intervention. After the post- test however, results revealed an increase in items performed by at least 50% of learners and an increase in the percentage of learners who performed an item in the experimental group. Therefore, comparing the control and treatment groups, results show equivalence between the two groups in conceptual understanding before intervention and an increase in conceptual understanding for the experimental group after intervention. The analysis of conceptual understanding from learners' performance was drawn from Sorden's (2012) argument stating that learners' performance on a test visualizes their meaningful learning or conceptual understanding. Therefore, our findings show that IM improved experimental group learners' conceptual understanding. These results are in line with Zulnaidi and Syed Zamri's (2017) study which found that technology-assisted teaching promotes conceptual understanding of mathematics.

The improvement of learners' scores and the development of conceptual understanding by IM software resulted from factors including mathematics content and lesson presentation in IM software which show that IM software fits a multimedia tool for effective learning. GebreYohannes et al. (2016), explain a multimedia tool as a computer-mediated software that presents concepts a simultaneously integrates text, color, graphical images, animation, audio sound, and full motion video in a single application. IM content is organized into levels consisting of understanding, quick exercises, and evaluation. At the understanding level, the IM content is presented in semi-concrete objects (contents and processes) using different colors and accompanied by some movements. This may be best understood using an example of a lesson about the long division of 1099 by 7 and another about multiplication by 7 annotated in Figure 8 below:

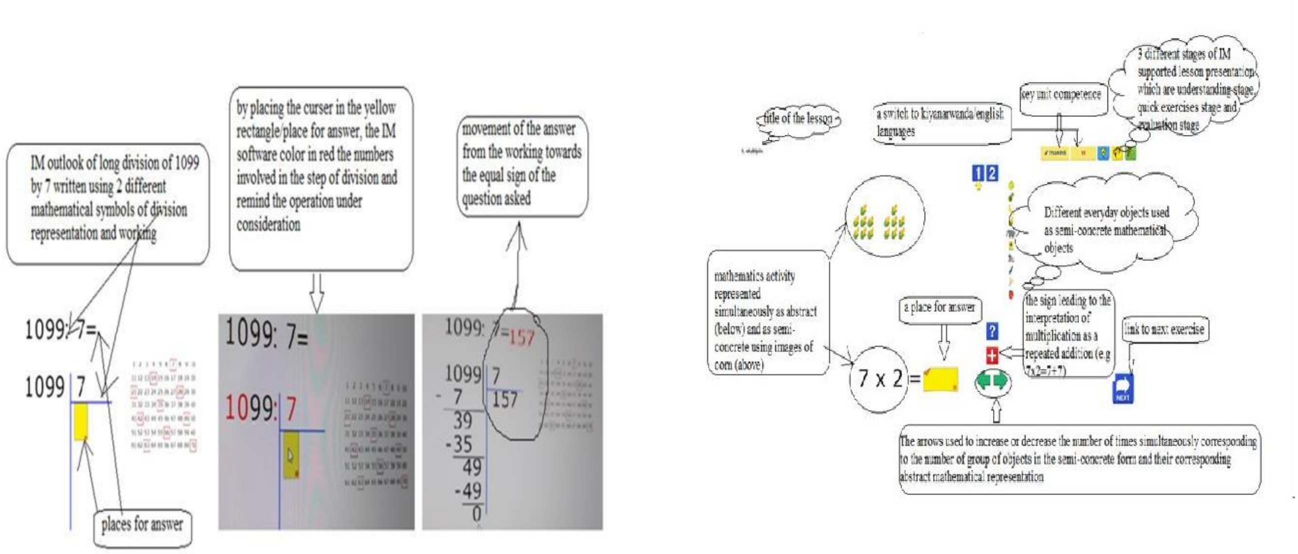

Figure 8. Annotated IM Outlook of the Long Division of a Multi-digit Number by one digit Number (Left) and Multiplicationby 7 (Right)

This example shows that IM software presents contents and processes associated with long division or multiplication in multiple and integrated ways. This allowed learners to develop conceptual understanding by linking and using different representations of the same concept. The results were realized through the improvement of performance (Sorden, 2012). For example, the simultaneous presentation of two symbols of division enhanced learners' building conceptual understanding of division at the level of division symbols (see Figure 8, left). In addition, the simultaneous presentation of two sets of seven in semi-concrete objects (images of corns) with its abstract presentation in mathematical expression helped learners' easy building of conceptual understanding of multiplication.

The IM assisted-teaching started by connecting the prerequisites with the new lesson at the IM software understanding level, where mathematics content was attractively presented as words and pictures of different colors. It went through multiple representations of the content simultaneously in semi-concrete and abstract with words or sounds and movements of objects (process and content). This helped learners to grasp auditory and visual information (dual principle) through a colorful presentation of mathematical objects accompanied by mathematical movements of objects and soundly mathematical processes. This allowed learners to pay attention, conceptually organize their learning, and easily integrate new knowledge with prior knowledge while also minimizing their cognitive load. They, therefore, managed to actively engage in the lesson. This is in line with Shamim (2018) arguments stating that multimedia learning environments allow learners to become more focused and attentive and that they manage to organize new knowledge building on prerequisite knowledge. This fitted with the active processing principle of the CTML (Mayer, 2014a; Mayer, & Moreno, 1998) which is important for meaningful learning and building conceptual understanding (Mendezabal, & Tindowen, 2018). In addition, manipulation of mathematics objects was accompanied by a characteristic sound and movements associated with a wrong or right process or answer. This confirms GebreYohannes et al.'s (2016) study which found that multimedia-assisted lesson was more organized and understandable, resulting in an improvement in learners' performance in the modules of calculus and numerical methods. The organization of these levels allows an individual learner to engage in meaningful learning throughout IM-enhanced lessons. This conforms with the CTML principle which stipulates that successful learning considers individual differences in learning (Mayer, & Moreno, 1998). Drawing on all the above, IM software has got features to make mathematics fun and enjoyable for learning leading to reducing its abstract nature (Ernest et al., 2016), which is likely to influence successful learning, improved performance, andconceptual understanding.

In addition, the analysis of learners' works revealed types of errors in working on pre-test items which were reduced after intervention in the post-test (see figure 7). From the analysis of errors, many learners failed to understand the different roles of the same term in repeated addition and in multiplication (intermediate unit) which translates that their understanding of the link between addition and multiplication was very poor by the time of the pre-test. However, these errors were reduced remarkably in the post-test by observing their overall performance and the analysis of their work. Therefore, our results are in line with arguments stating that learners develop a better conceptual understanding of multiplication and multiplicative reasoning when the repeated addition model is used while simultaneously emphasizing the intermediate unit concept differently from focusing on the operational side of multiplication (Ji, & Barbara, 2013).

Therefore, the results of our study are in line with other studies grounded in the CTML which found that the use of technology in primary level teaching and learning improves learners' motivation, performance, and problem-solving abilities after intervention (Loo, & Said, 2020). The IM-supported multimedia learning environment stimulated meaningful and successful learning based on Mayer and Moreno (1998) interpretation of multimedia learning outcomes.

Conclusion

Drawing on the CTML, this study sought to investigate primary-3 learners' conceptual understanding. In light of the studies grounded in the CTML like Ndihokubwayo et al. (2020), and Uwurukundo et al. (2022) which were conducted in high school and Loo and Said (2020), which was conducted in primary school, this study confirmed that IM-supported teaching promotes the development of conceptual understanding observable through learners' performance in a test (Sorden, 2012). Data collected from a group of 64 learners' primary three through a pre-test and post-test were compared before and after learning IM at the beginning of 2019. The use of IM in teaching mathematics affected the conceptual understanding and learners' performance. In addition, teachers and learners developed basic computer skills and experience for the first time in teaching and learning activities in a smart classroom. Notably, teachers and school administration managed to build awareness about using computers in classroom activities instead of using them in administrative activities only. Although the conceptual understanding improved throughout the concepts examined, a low understanding of some concepts related to multiplication and division of three digits persisted. Besides, the one group pre-test post-test design used in our study limited the findings to the experimental group only. The results of our study should have been different if the post-test was administered to the control group too. Therefore, this aspect should be considered in further similar studies using the same or different methodologies for the generalizability of findings.

Recommendations

In light of the findings, the Ministry of Education could provide basic computer training for primary school teachers through Rwanda Basic Education Board. As a result, especially in the beginning levels of mathematics education, they would be able to actively construct and supervise effective multimedia learning environments and effective multimedia learning principles. Also, the timeline for the policies controlling the inclusion of IM as a teaching tool in Rwanda's competence-based curriculum framework needs to be accelerated in order to formally endorse its usage in mathematics instruction. This would promote the successful implementation of the CBC in primary school mathematics that nearly all public schools in Rwanda considering that nearly all public primary schools in Rwanda are equipped with XOs Laptops distributed during the OLPC campaign. Therefore, the IM software would be installed and used in XOs. It would be also a means to manage educational resources as those XOs are simply kept in school stores and almost unused. Lastly more technology-oriented research in mathematics education should be conducted at the primary school level in Rwanda to improve the quality of mathematics education from the early education level.

Limitations

This study encountered some constraints. Those included teachers' and learners' lack of basic computer skills which occasionally interrupted the flow of productive instructional activities and sometimes impaired the time management of planned lessons.

Acknowledgment

The researchers would like to express their appreciation to Japan International Cooperation Agency (JICA) through Sakura-Sha K.K. and to the teachers and the schools that participated in this study.

Funding

This study was financially supported by Sakura-Sha, K.K., the University of Rwanda-Sweden Programme, and the African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science (ACEITLMS) based at the University of Rwanda-College of Education.

Authorship Contribution Statement

Uwineza: Conceptualization, design, analysis, drafting of the manuscript, and writing. Uworwabayeho: Supervising, reviewing, editing. Yokoyama: Software designer and trainer.

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Appendix

The Test Provided to P3 Learners

Workout the following (Kora imibare ikurikira) 258 29

+634 -24

Fill in the box (Uzuza mu kazu) 7+7+7 → ☐ → 7x

9+9+9+9+9+9+9+9 9 x ☐

Work out the following (kora imibare ikurikira) 7x3= 7x8= 8x4=

8x6= 9x2= 9x7=

	0	1	2		4	5	6	7
X 8				24				

Fill in the box (Uzuza mu kazu)[Multiplication] (Ikuba)

Division (igabanya)

	7	14	21	28	35	42	49
: 7				24			

5. Workout the following (Kora imibare ikurikira)

197
x 7

146
x 13

1896 | 6

Chapter III. Comparative effects of IM-supported teaching on learners' learning outcomes between lower and upper primary levels

3.1. Introduction

The information in this chapter pertains to comparative analysis of IM-supported effects on learning outcomes between lower and upper primary educational levels. It addresses the second objective. Detailed information about learners' conceptual understanding development in IM-supported class can be accesses via the paper next posted.

3.2. Detailed account of the paper (Next page)

Education and Information Technologies

https://doi.org/10.1007/s10639-023-11860-z

Lower and upper primary learners' difference in performance and conceptual understanding: Support of Interactive Mathematics Software for Rwanda

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Received: 21 August 2022 / Accepted: 25 April 2023

Abstract

The use of technology to enhance classroom practices draws attention from numerous educational systems and scientific studies. Rwanda's educational system prioritized ICT-integrated instruction in primary schools in order to enhance the provision of high-quality education from early years. Therefore, this study was undertaken at both public and private schools in Kigali City. It sought to find out the impact of Interactive Mathematics software (IM) on conceptual understanding and performance in lower and upper elementary mathematics learners. Designed as quasi-experimental, it involved 253 learners from Primary 2 and Primary 4, conveniently assigned to controls and experimental groups. A sample of learners' test works was used to collect data before and after the treatment. Learners' test scores were collected and analyzed using Excel and SPSS v.23 software. The results showed that P2 and P4 treatment groups' mean scores differed significantly from each other. The effect was more noticeable at both levels in public schools than in private ones. Based on the significance of mean differ-ence and performance on an item, there was no discernible difference in the impact of Interactive Mathematics aided teaching on lower and upper primary mathematics per- formance. The study's conclusion included some recommendations for Rwanda Basic Education Board and called for additional, more thorough research on the qualitative facets of IM-supported teaching.

Keywords: Information and Communication Technology (ICT)-Interactive Mathematics software-Conceptual understanding-Performance-Rwanda

Introduction

To stay competitive in the worldwide market for high-quality education, educational systems are investing more than ever in the integration of ICT into class- room practices. Lee et al. (2012) assert that ICT integration in education is appropriate for curricula that aim at globalization, connectedness, and lifelong learning. Mathematics education and technology integration in

Extended author information available on the last page of the article

Published online: 23 May 2023

Education and Information Technologies

https://doi.org/10.1007/s10639-023-11860-z

mathematics are two educational fields that are mutually interdependent and highly prioritized in educational systems worldwide. According to Yogyakarta et al. (2021), mathematics is an important area to develop because it plays an important role in the current technological advances. It was claimed before that mathematics is a basic substance for each technology, and that technology supports mathematics teaching (Joshi, 2019). Investigating how technology affects effective mathematics teaching, learning, and outcomes are crucial.

The government of Rwanda (GoR) strives to meet sustainable development goals four (SDG4), focusing on quality education that is inclusive, equitable, and that promotes lifelong education for all (MINEDUC, 2018). The use of ICT-enhanced classroom practices is thought to contribute to the accomplishment of the 2030 Vision through enhancing smart learning environment and technological tools to assist the successful operationalization of the new competence-based curriculum (CBC) (Ndihokubwayo, & Habiyaremye, 2018; The Republic of Rwanda, 2017). That curriculum was adopted and implemented in basic education in Rwanda since 2015. Thus, the Interactive Mathematics (IM) software was developed by Japan international cooperation agency (JICA) through Sakura-Sha K.K. in partnership with Rwanda basic education board (REB) to aid in the efficient use of the elementary CBC in arithmetic.

Despite efforts spent in mathematics basic education in Rwanda, adequate performance of the CBC and quality attainment at primary level record major pedagogical deficiencies. For example teaching in a crowded classroom, where one teacher may instruct nearly 100 students in two classes per day, especially in public institutions, poses a challenge to quality mathematics delivery and outcomes for primary school mathematics teachers. The study of Ukobizaba et al., (2021) discovered that inability of students to understand the importance of mathematics in daily life and how mathematics is taught are among the determinants of their failure to learn mathematics, and it concluded that mathematics teachings should be connected to real-world situations.

While using the same curriculum, the school statuses in Rwanda have various features when it comes to providing high-quality education. For instance, it was noted that lower and upper

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Published online: 23 May 2023

https://doi.org/10.1007/s10639-023-11860-z

primary mathematics proficiency in government-aided and private schools is higher than that of lower and upper primary mathematics proficiency in public schools (MINEDUC, 2018). Besides, primary school teachers struggle to properly implement various teaching strategies, such as multiple representations of mathematics concepts to ensure that students develop conceptual understanding (Dorimana et al., 2021). Likewise, the use of lecture-driven rather than student-centered pedagogy that incorporates ICT in Rwanda's elementary schools is still prevalent. According to Lee, et al. (2012), the effective integration and use of ICT as instructional tool in primary school level entails specific pedagogies. Throughout the past few decades, ICT in education policies and research in mathematics education have been heavily influenced by the difficulties described above and many others. Nonetheless, secondary school level received more attention than primary level. Quality elementary mathematics instruction should be a foundation for quality upper-level mathematics instruction. In this regard, the IM-supported CBC implementation may serve as a good strategy. From the beginning of 2019 up to 2022, IM software was piloted in normal classroom context. Since students were accustomed to traditional teaching methods, we found it important to examine how IM-supported teaching affected the quality of mathematics learning by concentrating on student performance and the conceptual understanding development

Drawing on the above background, our study intended to determine the differences in primary school learners' performance and relational understanding and to find out remedies to following questions: a) what is the effect of IM-supported teaching on lower and upper primary learners' conceptual understanding and performance? b) What is the difference between lower and upper primary learners' performance and conceptual understanding by IM-supported teaching? We hypothesized that there is no difference in IM effects on learners' performance and conceptual understanding between lower and upper primary levels. This study drew on the cognitive theory of multimedia learning (CTML). The CTML is a cognitivism-based learning theory that Mayer and Moreno created in 1998 and is related to learning in a multimedia context. It also includes theories of learning with ICT and learning from ICT suggested by Ringstaff and Kelly (2002) which look into students' learning level (Lee et al., 2012).

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https://doi.org/10.1007/s10639-023-11860-z

2. Literature review

2.1. Theoretical framework: The Cognitive Theory of Multimedia Learning and Theories of Learning 'with' ICT and learning 'from' ICT

Multimedia, as defined by Milovanovic et al. (2016), is the presentation of educational content using written or spoken words, graphics, or photographs in a static or dynamic presentation. The CTML is a cognitivism-based learning theory that Mayer and Moreno created in 1998 and is related to learning in a multimedia context. Therefore, the underlying principle in multimedia environment is that effective learning results from presenting the topic in words and pictures combined rather than using words only (Milovanovic et al. 2016, Bhatti et al. 2017, Rudolph 2017). However, that presentation should exclude the extra text and images or "the superflu" and provide the textual and visual step-by-step explanation of the supplied knowledge (Milovanovic et al., 2016).

Three presumptions serve as the foundation for the CTML namely the 'limited capacity principle', 'the active processing principle' and the 'dual channel principle' (Kirschner et al., 2017). These principles stipulate that the human working memory has a finite capacity for processing information (limited capacity) and that meaningful learning should come about as a result of learners actively processing information through selection, organization, and integration (Kirschner et al., 2017). With their respective limitations, the auditory and visual channels (dual channels) process verbal information and visual information, respectively (Kirschner et al., 2017). As a result, while targeting meaningful learning and quality outcomes, encouraging perceptual memory and promoting information organization and integration should lead to successful active processing of information. To achieve the best learning results possible through multimedia, it is important to consider both the educational level or cycle and each student' learning styles and abilities.

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In order to recognize each learner's individuality and to encourage cognitive development in youngsters, successful teaching at these levels entails using a variety of representational strategies for a concept (Ojose, 2008). It was stated that one of technology's most effective applications in education is to adapt lessons to each student's unique learning requirements (Ringstaff, & Kelley, 2002). Contemporary multimedia approach to learning, include a wide range of varied possibilities suitable in mathematics lectures at various levels of education and with varying degrees of involvement (Milovanovic et al., 2016). Therefore, multimedia approach may be applicable at primary school level, as it had been applied in upper educational levels for quality education achievement. Our study intended to apply multimedia-supported classroom practices at primary school level.

In multimedia learning environment, computer-supported learning encompasses computer-based and computer-assisted instruction methods and learners may learn directly from ICT or learn with ICT (Ringstaff, & Kelley, 2002). Learning with ICT and learning from ICT are theories that look into students' level of learning and that are rooted in the behaviorist, constructivist, and socio-constructivist paradigms (Lee et al., 2012). Ringstaff and Kelley (2002) defined learning from ICT as using ICT to tutor learners about fundamental skills through contextualized, real-world problems. The term learning with ICT refers to the use of ICT as a teaching instrument for concept development, problem-solving, reasoning, and critical thinking wherein students and the teacher have control over the curriculum and instruction (Ringstaff, & Kelley, 2002). Whereas learning from ICT is linked to the behavioral philosophy of learning and the direct instruction method of teaching, allowing students to passively acquire knowledge and develop lower-order thinking skills (Ringstaff, & Kelley, 2002) like reading and listening. Learning with ICT is associated with socio-constructivism and constructivism as well as dialogical pedagogy. While learning with ICT, students engage with the material, their peers, and the teacher to build knowledge and cultivate higher-order thinking abilities (Ringstaff, & Kelley, 2002). Multimedia in mathematics learning combines both traditional mode of teaching using chalk and blackboard with computer-based educational materials like graphs and animation (Milovanovic et al., 2016) using selivery media like a computer and a projector (Bhatti et al., 2017). In accordance with Milovanovic et al., (2016), our study focused more on learning mathematics with ICT in a multimedia environment while also using a chalk and blackboard method.

In Rwanda, primary 2 and primary 4 learners are respectively aged between 7-8 years and 9-10 years. In accordance with Piaget's theory of cognitive development, these ages represent the concrete operational stage and the start of the formal operational stage, respectively. As a result, this learning level implies the choice of successful pedagogies that are tailored to learners' needs. As a result, the use of IM in lower and upper primary mathematics teaching and learning allows for the deployment of successful pedagogy based on elements of IM-content presentation and its relevancy to learners' learning levels. With the use of mathematical movement and particular sounds, IM software conveys mathematics material in a semi-concrete and abstract manner with quick and slow exercises options. As a result, IM software is a useful ICT tool for fostering and supporting multimedia learning environments based on its features of concurrently stimulating learners' hearing and visual senses. We might contend that the CTML together with computer-assisted learning using IM software promotes learner-centered teaching practices, which in turn leads to learners' increased performance and conceptual grasp of mathematics in an IM multimedia-enhanced environment.

2.2. Empirical review: The role of ICT tools in mathematics conceptual understanding and performance

Conceptual understanding and performance are desired outcomes of any teaching and learning activities. Conceptual understanding has been defined as a relational understanding of mathematical relationships (Salim Nahdi, & Gilar Jatisunda, 2020). According to Salim Nahdi and Gilar Jatisunda (2020), conceptual understanding is necessary for learners' mathematical expertise and performance. According to Lessani et al. (2017), appropriate teaching and learning strategies are essential for success and learners' academic performance and conceptual understanding. According to Ndihokubwayo et al. (2021), conceptual understanding in physics subject may be analyzed from learners' change in pre-test and post-test performance. Accordingly, an item performed by few learners despite the intervention provided can be evidence of low conceptual understanding about it while an item performed by many students after intervention testify learners' improvement in conceptual understanding development. This method can also be applied to analyze conceptual understanding improvement in primary

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learners' mathematics after implementing ICT-enhanced instruction. According to Haji and Yumiati, (2019), conceptual understanding development may result from solving, applying and communication mathematics ideas. According to Sorden (2012), the way test takers perform illustrates how much they have actually learned or how well they understand a material. Through multiple representations of mathematics ideas and engagement in problem solving of many mathematics exercises, learners improve their fluency and understanding of a concept (Phuong, 2020). Conceptual understanding is necessary for early elementary education to allow learners to complete advanced mathematics requirements in late elementary school (Milton et al., 2019).

ICT tools like GeoGebra software have longtime widely attracted educational research focused on mathematics classroom activities (Uwurukundo et al., 2022; Mushipe, 2016; Eyyam, & Yaratan, 2014; Moses et al., 2012). Instruction that use GeoGebra are probably in favor of new teaching philosophy backed by ICT adoption over the conventional teaching paradigm with chalk and speak observance (Uwurukundo et al., 2022). According to Lessani et al. (2017), the traditional teaching approach or teaching by telling, which is also classified as a poor teaching method, emphasizes the teacher's role of knowledge provider. It was discovered that students in typical teaching settings struggle to comprehend mathematics concepts and experience anxiety during exams and throughout class activities (Lessani et al., 2017). Furthermore, Ukobizaba et al. (2021) contended that poor teaching practices have been demonstrated to cause pupils to lose interest in learning mathematics.

Literature shows that learning geometry using the GeoGebra software improved learners' achievement more than learning geometry using conventional mode of teaching (Eyyam, & Yaratan, 2014; Moses et al., 2012). The same software was used to analyse relational understanding and achievement by Akgül (2014), Naidoo and Govender (2014), Zulnaidi and Zamri (2017). They found that learning mathematics using GeoGebra improved learners' conceptual understanding compared to conventional methods (Zulnaidi, & Zamri, 2017). However, Geogebra software's effective use requires the user to have prior programming experience to insert some commands in the input bar. According to Putrawangsa, & Hasanah

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(2020), there is still a lack of information about making and employing a digital learning tool to promote conceptual learning.

Moreover, ICT is typically only used in today's classrooms as a means of preparation for instruction rather than as an integral element of the teaching process (Zenki-Dalipi, 2019). So the role of the teacher in adopting ICT-supported methodologies is of paramount importance. Besides, the teacher's role in selecting effective methodologies should be put first if effective conceptual development is the focus of teaching. In our education system, most primary school teachers hold a high school certificate in teaching from TTCs with moderate or no ICT skills that can allow the effective use of GeoGebra. Therefore, this software is mostly used in high school-focused research where almost all mathematics teachers' ICT skills are advanced compared to primary school teachers.

2.3. The Interactive Mathematics (IM) software for Rwanda

IM software for Rwanda was drawn from the Japanese education system and developed according to the Rwandan syllabus and textbooks to suit learners' needs. From the beginning of 2019 up to 2022, IM software was piloted in normal classroom context. Since students were accustomed to traditional teaching methods, we found it important to examine how IM-supported teaching affected the quality of mathematics learning by concentrating on student performance and the conceptual understanding development.

Unlike GeoGebra software, whose effective use requires the user's experience in basic programming skills, IM software use encompasses basic ICT skills like switching on and off a computer, using a mouse and navigating the IM content. The features of IM lay in the presentation of mathematics concepts as words and pictures accompanied by specific sounds and movements to attract learners' attention. Along with developing this software following the Rwandan competence-based curriculum, there was a pilot study done to test IM software in bootcamps-like settings in 2017 and 2018. This activity shown some potential educational impact of IM on performance like mathematics fluency, as shown in the diagram below:

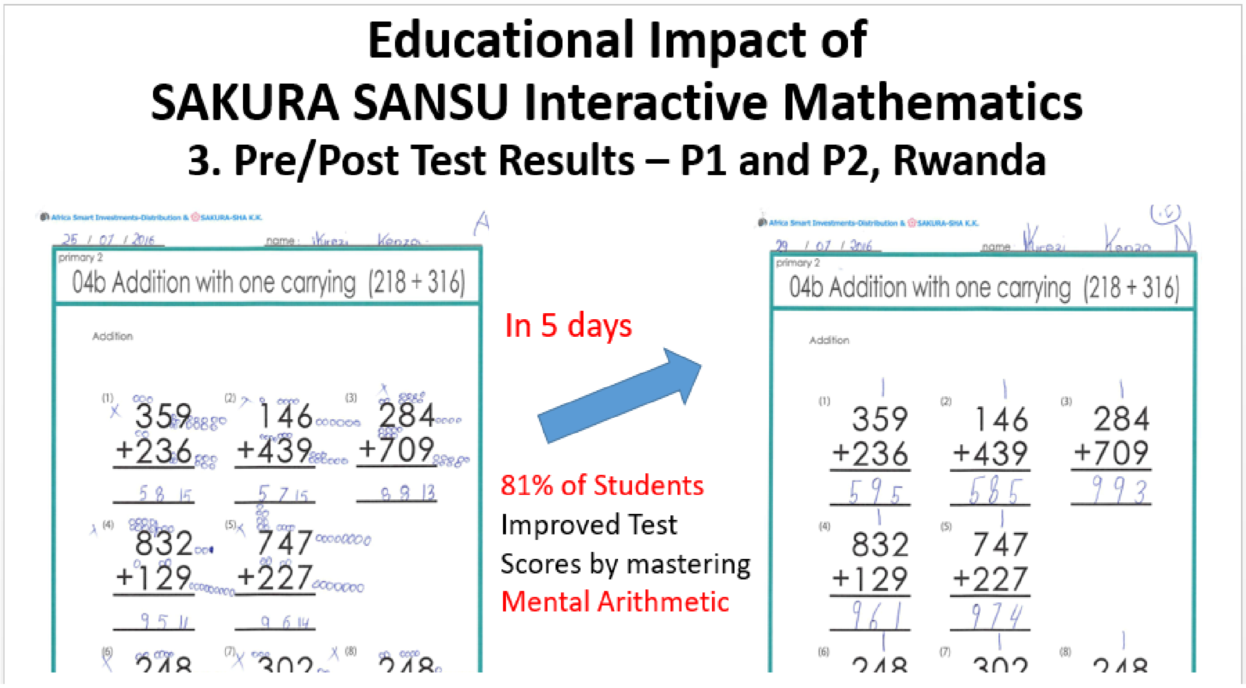

Figure 1. Pilot study results. Source: field data, 2017

This activity created a big educational positive impact where both teachers and learners found IM software to enhance mathematics classroom practice. Learners managed to perform many mathematics activities quickly, and apply them to solve further mathematical problems. However, a broad pilot study was planned to take place later in real learning settings to look into how IM affects the standards of mathematics instruction in Rwanda.

Methodology

Research design and sampling issues

Quasi-experimental design was used to create this study (Fraenkel et al., 2012). The purpose was to explore differences in academic achievement among lower and upper primary school learners in IM-supported teaching and learning environment to boost learning in Rwanda. Schools that participated in this study were conveniently selected from Kigali, an urban area, depending on whether they are available to take part in the study (Uzer, 2016) (Uzer, 2016)and the availability of infrastructures and ICT facilities and their free consent to participate. The city

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setting attracted our research focus because of the availability of private primary schools, which cannot be easily found in rural areas. Furthermore, this setting presents transport means to go from one school to another, and schools are closely located to one another. After primary three and primary five classes participated in other studies separately, primary two (P2) and primary four (P4) classes were selected to represent lower and upper primary levels while analyzing the differences in IM effects on the two levels. The sample of participants consisted of 293 learners, including 145 from primary 2 and 148 from primary 4. Participants from each level were tasked with the intervention group and control group. In the treatment group, mathematics content was presented with a computer and projector support. The teacher manipulated the interactive mathematics software projected on the classroom wall and engaged the learners in the classroom practices. Learners were given a wireless mouse to interact with the content, and sometimes, they switched on using pens or pencils for class activities. In parallel to IM-supported teaching, the same lessons were given to the control group in the normal way of teaching with a piece of chalk and the teacher's talk while learners followed and worked with their pens or pencils on a piece of paper. To effectively conduct IM-supported teaching activities, two days-training was given to teachers by SAKURASHA agents together with the researcher to draw common understandings of the effective IM-supported mathematics pedagogy. The training consisted of activities including manipulation of IM software, lesson preparations, and microteaching.

Research instruments

At the beginning of the intervention, a test was given to the two groups to check learners' equivalence in learning. After the pre-test, the researcher collected the answers and all the questions to avoid learners' familiarity with the pre-test questions. Next, the IM teaching followed. During experimentation, the teacher installed the computer and the projector and prepared the wireless mouse to be used in the teaching. The teacher presented the lesson and used the IM to engage learners, explore, elaborate and evaluate the concepts. The wireless mouse was used by the instructor and students to engage with the content. In parallel to IM-supported teaching, the same content was delivered in the non-experimental group employing the standard traditional mode of teaching. After the IM-supported teaching, the post-test was given to learners

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from both groups. The tests items were designed based on mathematics topics of P2 and P4 that served in IM-supported teaching and chalk-and-talk teaching. The test items were developed by teachers concerning their levels of teaching and based on the topics subject to research. The topic covered in P2 consisted of Numbers from 0 to 500, Finding the missing numbers from 0 to 500, Hundreds of tens ones (0-500), Comparing numbers using >, <, =, (0-500), Arranging numbers in ascending or descending order (0-500), Addition with or without carrying (0-500), Subtraction with or without borrowing (0-500). The topic covered in P4 was the following: number line (from -10 to +10), the inverse of an integer, the inverse property of an integer, the distance between two integers, comparing integers, arranging the numbers [integers] in ascending or descending order. In P2, the test consists of six questions divided into ten sub-questions (see appendix 1), while in P4, the test consists of 6 questions and 15 sub questions (see appendix 2).

Data collection procedures

Our research was performed in government schools of Nine Years Basic Education (9YBE) status and in private schools. The selection of schools two folded: first all, from Rwanda Education Board datasets, schools with ICT infrastructures and facilities were identified. Secondly, the researcher used an ethical clearance from the postgraduate office of the URCE to conveniently select available schools and to request their permission freely get involved in our study. In P2, the sample consisted of 145 learners, while in P4, the sample consisted of 148 learners making a total sample of 293 participants from lower and upper primary levels. The first author of this study together with a P2 and a P4 mathematics teacher and IM expert conducted a two days seminar on how IM can be effectively used to support teaching. Teachers manipulated IM several times, developed IM-supported lesson plans, and tried out the implementation of IM in microteaching of 15 minutes each. Areas of improvement in teachers' technological and pedagogical content knowledge were raised and discussed for their improvements. The researcher played a collaborative role all along the experimentation period. The experiment began with testing of the two groups after the experiment themes were decided upon and potential relevant difficulties were discussed. The experimentation was conducted for 40

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minutes and six weekly periods for three months of the first term in 2019 for P2 and in 2020 for P4.

Data analysis procedures

After data collection, we entered data in excel sheets. We eliminated students who completed one test only. We computed the average percentage of each learner across all the test items. We analyzed each of P2 and P4 data in two dimensions. However, we did not compare P2 and P4 results because of the different levels, different tests and different school years. The first dimension was to analyze learners' performance. We used SPSS v.23 by taking learners' average scores from excel spreadsheets and putting them in SPSS. We first checked the assumptions for using parametric tests via analyzing and exploring in SPSS and plotting histograms of score distributions in pre-tests. Next, we calculated the difference between the test scores for each of the two groups. The conceptual knowledge of the pupils as it related to each exam item was the second dimension. We averaged the number or percentages of students who performed each item well and plotted graphs in excel spreadsheets. We also analyzed a sample of learners' work and compared the pre-test work to the post-test work to identify learners' improvement in working that resulted in IM-supported teaching. The dataset for assessing Rwanda's conceptual comprehension of optics include more methodical techniques (Ndihokubwayo et al., 2021).

Results

Primary-2 (P2) academic achievement by IM software

We started with two groups of students, a group of 80 and a group of 65 learners. The first step was to check parametric test assumptions. The sample was quite enough (>30), and equal variances were assumed (Levene's test revealed a $p>.05$). Although the Kurtosis and skewness were in range; however, the Kolmogorov-Smirnov test of normality revealed a difference that is statistically significant ($p<.05$) in a group of 80 learners. Skewness (an indicator of lack of symmetry) must fall between − 10 to + 10, and Kurtosis (which determines the heaviness of the distribution tails) has an appropriate range of − 3 and + 3. The skewness of .603 and Kartosis of -.209 was found in a group of 80 learners, while the skewness of -.043 and Kartosis of -1.023 was

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found in a group of 65 learners. Therefore, we chose to utilize a group of 65 learners as an experimental group and one of 80 learners as a control group. Thus, since the data distribution in the control group was not normal, we left it at the pre-testing stage, and we continued with an experimental group with teaching intervention and post-test to check the level of impact of IM software. This led us to use the one-group pre-test-post-test method (Uzer, 2016) for statistical analysis of P2 data.

The two tests results for the P2 treatment group were analysed using a paired sample t-Test (see table 1). The findings revealed a very high significant difference in learners' performance by IM (M_{pre}=42.62%, M_{post}=50.46, df=64, p<.001). Therefore, IM-supported teaching improved P2 learners' performance based on the significance of differences.

Table 1. Paired samples statistics for the experimental group

Pair	Mean	N	Std. Deviation	Correlation	T	df	p
Pre_test	42.62	65	25.389	.796	-3.848	64	<.001
Post_test	50.46	65	26.067				

The comparative analysis of the frequencies or number of learners per score interval was conducted on both tests to identify the effect of the intervention on performance frequencies (see Figure 1). Results show that learners' score range in the pre-test varied from 0 to 90% and many learners fell in the 50% score range while some others fell in the 0% score range. In the post-test, learners' score range varied from 0% to 90% like in the pre-test. However, the frequency distribution of score intervals changed. Comparing the post-test score intervals frequency distribution to the pre-test, the number of learners who fell in the 20% (and below) score range reduced while those who fell in the 30% (and beyond) score range increased except in the 60% and the 80% score range. Particularly, a significant increase in frequency distribution was remarkable in the 90% score range.

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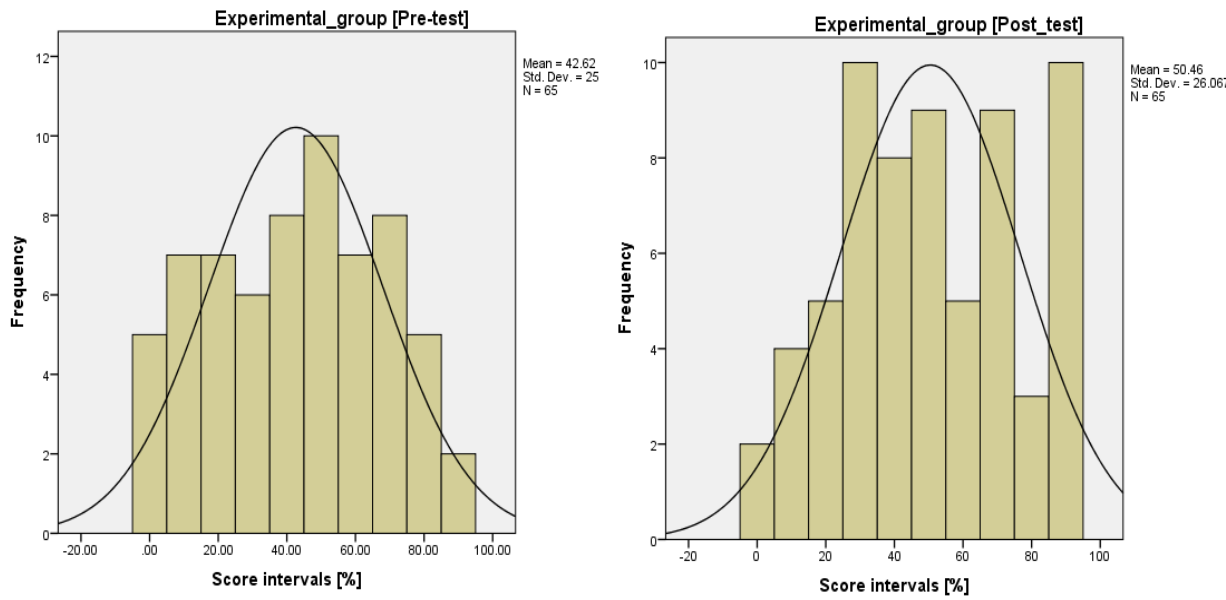

Figure 2: P2 learners' score intervals distribution in pre-test and post-test

After looking into the tests results of the intervention group learners, we used a general linear model (GLM) to perform multivariate analysis of variance (MANOVA) to determine whether the school status (public or private) could reveal a statistically significant difference due to IM software during teaching and learning mathematics. Table 2 shows that between subjects-factors displayed, 41 public school learners and 24 private school learners obtained a pre-test mean score of 42.50 %, and 44.58% respectively. In the post-test, both public and private school learners' performance improved [Mean=49.00% for public school and Mean=54.58% for private school]. Therefore, these results show that the general academic performance improved in the post-test by IM-supported teaching. In addition, though the private school academic performance was found to be higher compared to public schools, IM-supported teaching improved the academic performance of both public and private schools but more improvement was realized in public schools.

Table 2. Descriptive statistics

	Type	Mean	Std. Deviation	N

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Pre_test	Public	42.50	26.77	41
	Private	44.58	22.25	24
	Total	43.28	25.01	65
Post_test	Public	49.00	25.70	41
	Private	54.58	26.04	24
	Total	51.09	25.76	65

Table 3 shows that before the pre-test and after the intervention, the schools were not different (sig.>.05).

Table 3. Tests of performance Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Type of school	Pre_test	.274	1	.274	.000	.983	.000
	Post_test	396.224	1	396.224	.576	.451	.010

Primary-2 (P2) conceptual understanding by IM software

After analyzing performance, we analyzed conceptual understanding development by IM-supported teaching among P2 learners. Figure 3 shows the comparison between the number of public and private schools number of learners who performed each test item before the teaching intervention. It can be seen that, before the intervention, private school learners had a good understanding than public school learners in almost all test items, except item #3, item #5, item #6, and item #10, which were performed by a very low number of learners (<10%).

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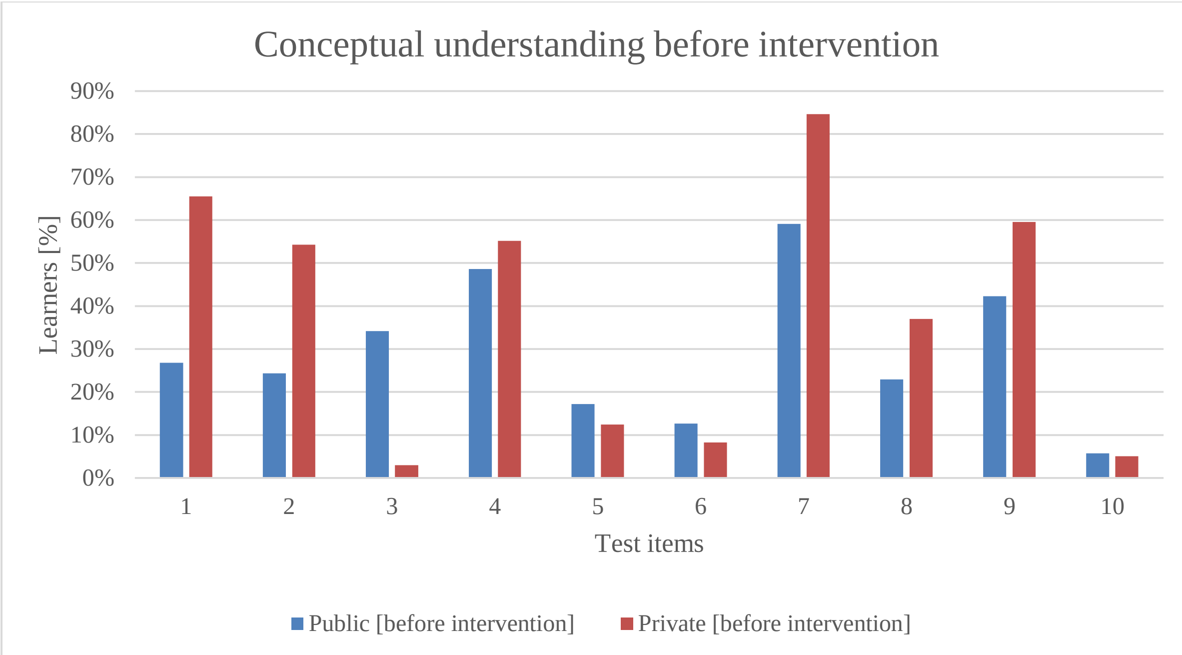

Figure 3: Public and private schools P2 learners [%] who correctly answered the test items before teaching intervention

Figure 4 displays the public and private schools' percentage of learners from the experimental group [both groups] who answered the test items correctly after the teaching intervention. The results indicated that private school learners' understanding improved more than the public school learners in items #1, #2, #5, #6, #7, #8, and #9. However, the public school learners manifested more understanding of item #3 than private school learners. Therefore, IM improved more conceptual understanding for private school learners than for public school learners.

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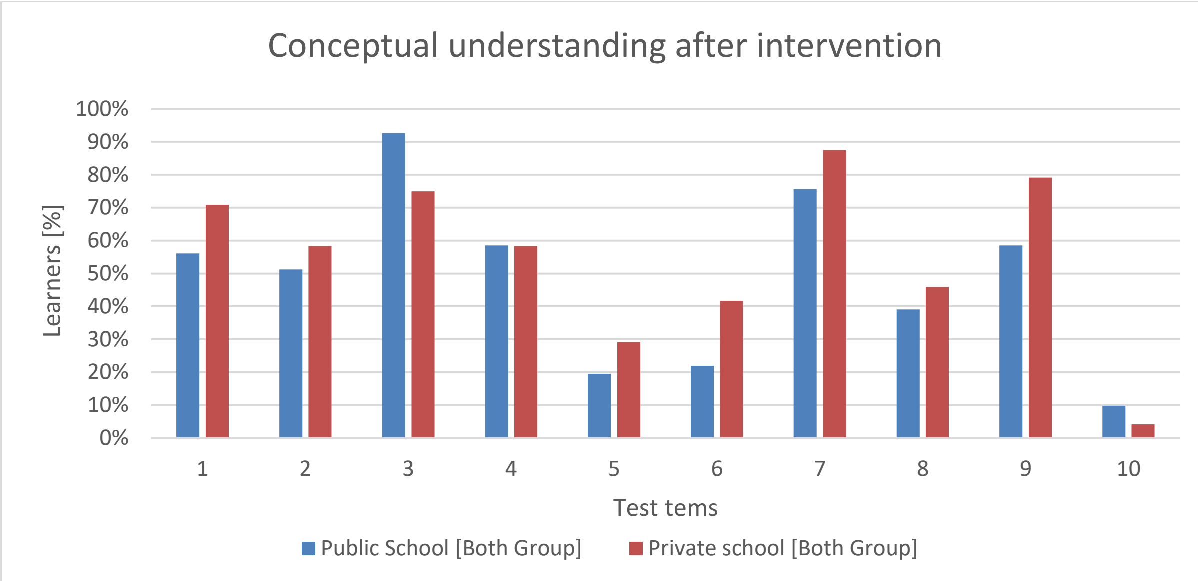

Figure 4: Public and private schools P2 learners [%] who correctly answered the test items after teaching intervention

Figure 5 displays the percentage of learners from the control [only group] and intervention group [both groups] who answered the test items correctly before and after the teaching intervention. The results show that before the intervention, the private school learners' understanding was higher than public school learners except on items #3, #5, #6, and #10. After the intervention, the result shows an overall improvement in conceptual understanding of public and private schools. However, the private school learners' conceptual understanding remained higher than public school learners except on items #3, and #10 where public school learners' understanding remained better than private school learners as it was before intervention.

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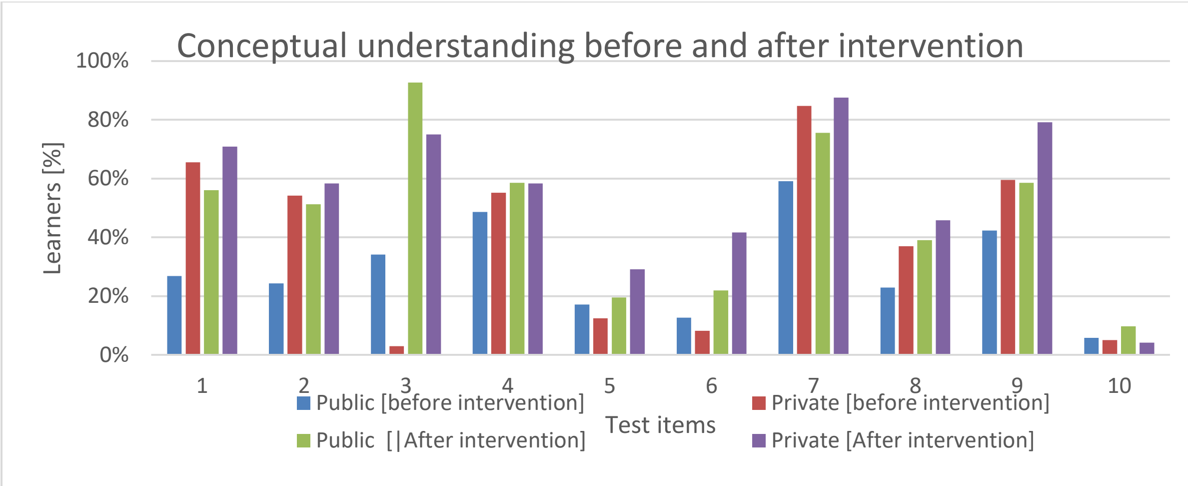

Figure 5: Public and private schools P2 learners [%] who correctly answered the test items before and after teaching intervention

Therefore, based on the results, IM-supported teaching improved P2 learners' performance and conceptual understanding based on the significance of difference and the percentage of learners who answered the test items correctly. Such improvement was highly achieved in private schools more than in public schools. Therefore, IM-supported teaching improved the academic performance and conceptual understanding of both public and private schools P2 learners, but more improvement was realized in public schools P2 learners.

Primary-4 (P4) academic achievement by IM software

As we did for primary-2, to measure P4 learners' academic achievement, we analyzed their performance and conceptual understanding. However, before that, we checked assumptions to use parametric tests. The first assumption of enough sample (>30) was achieved, as seen in Table 4.

Table 4. Between-Subjects Factors sample

		Value Label	N
Group of intervention	1	Control	68
	2	Experimental	80
Type of school	1	Public	97
	2	Private	51

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The second assumption of the normality test was also valid as the Kurtosis and skewness fell in the appropriate ranges, and Kolmogorov-Siminov generated a non-significant probability value in both control and experimental groups before teaching intervention. However, the third assumption of the equality of variance was not valid as Levene's test revealed a statistically significant difference (p=.030) among control (N=68, M=19.31%, SD=12.57%) and experimental (N=80, M=14.08%, SD=10.06%) group. Thus, equal variances were not assumed before the teaching and learning process. Figure 6 of the boxplot visualizes such a difference.

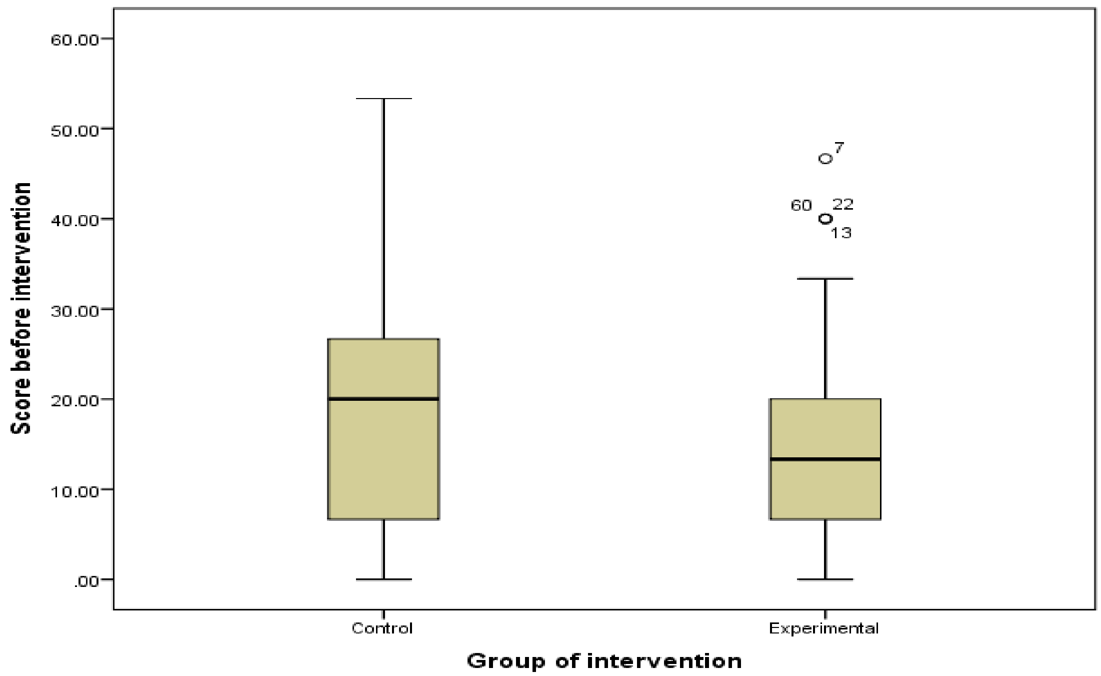

Figure 6. Boxplot of difference between control and experimental group

Therefore, although a parametric test would be appropriate, the analysis of variance was not valid. Thus, we opted to use analysis of co-variances (ANCOVA) to remediate differences in groups before giving them intervention. After checking the assumption and placing an appropriate test, we measured the impact of the teaching intervention delivered to both groups. Univariate analysis of variance was used where the pre-test scores were fixed and revealed the impact of post-test scores.

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Table 5 presents descriptive statistics between the two groups, between public and private schools. The results show that IM-supported teaching improved the overall academic performance of public and private school learners from 57.9412% mean scores in the pre-test to 60% mean scores in the post-test (see table 5). Considering the individual school status, IM-supported teaching improved the performance from 40.4651% mean scores in the pre-test to 46.0494% mean score in the post-test in public school, while in private schools, the mean scores improved from 88.00% in the pre-test to 88.97% in the post-test. The findings showed that academic learning outcomes were more influenced by IM-supported instruction in public than in private institutions.

Table 5. Descriptive statistics. Dependent variable: Score after intervention

Group of intervention	Type of school	Mean	Std. Deviation	N
Control	Public	40.4651	20.59410	43
	Private	88.0000	12.01850	25
	Total	57.9412	29.16772	68
Experimental	Public	46.0494	21.09253	54
	Private	88.9744	9.78749	26
	Total	60.0000	27.16828	80

The two study groups did not vary statistically significantly following the intervention, as indicated by the intercept in Table 6 (F=7.56, p=.220) even though the effect size was large (η=.882). It can be inferred that the intervention group improved in comparison to the non-experimental group after learning because the control group's level prior to the intervention was greater than that of the experimental group.

Table 6. Tests of performance Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	151271.394	1	151271.394	7.560	.220	.882
Pre-test	502.285	1	502.285	1.540	.217	.011
Group	547.519	1	.	.	.	.
School	64239.888	1	.	.	.	.
Group * School	383.743	1	383.743	.476	.615	.321

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However, the descriptive differences can be visualized in Figure 7. Figure 7 displays the estimated marginal mean scores after teaching intervention among P4 public and private school learners. It can be seen that private school learners achieved more than public schools learners across both groups under control and under experimentation. However, although the number of private school learners was lower than public schools ones, public school learners that were taught by IM software (experimental group) increased their level against those who received their education through the conventional manner (non-experimental group).

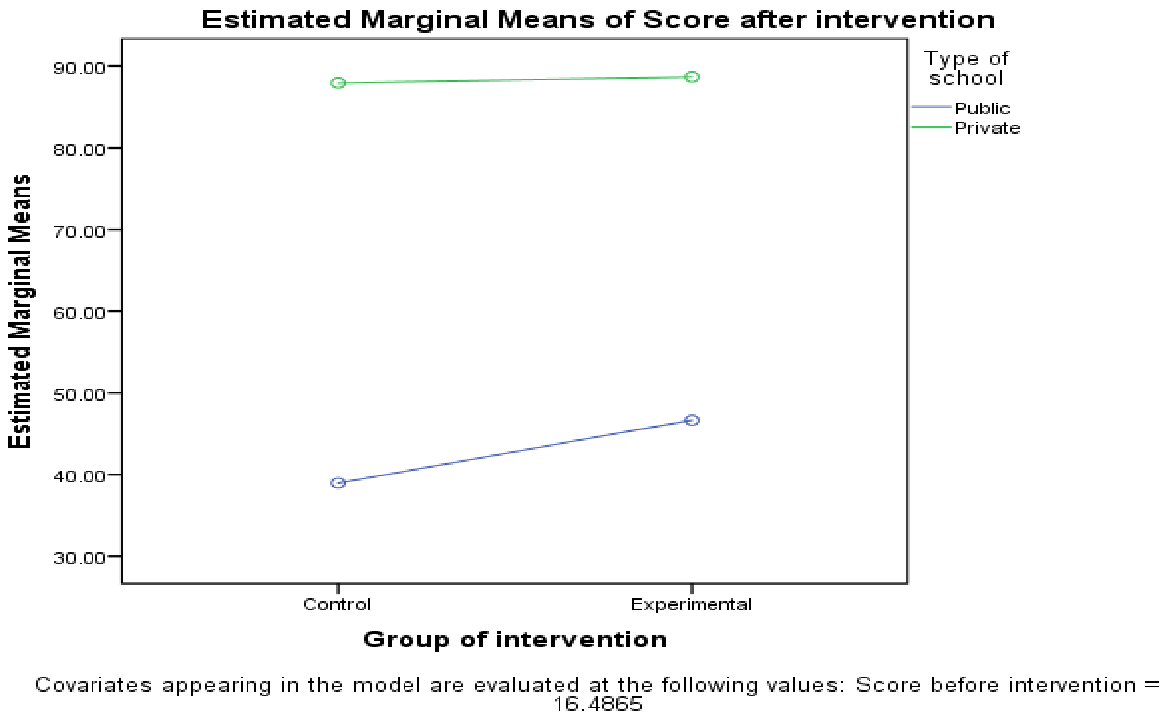

Figure 7. Visual representation of estimated marginal means of public and private in control and experimental group

Primary-4 (P4) conceptual understanding by IM software

After measuring the performance of P4 learners, we also analyzed their conceptual understanding before and after teaching the same content using traditional and IM-supported teaching.

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Figure 8 displays the percentage of public and private school learners in control and experimental groups before intervention (pre-test-results). There is no clear trend in the results. All items show a low performance, except item #7, public school learners in the experimental and control group were able to answer it correctly. Likewise, item #11 was correctly answered by private school learners [experimental] and public school learners [control]. Besides, results show that private and public schools [experimental] failed to correctly answer items #1, #14, and #15.

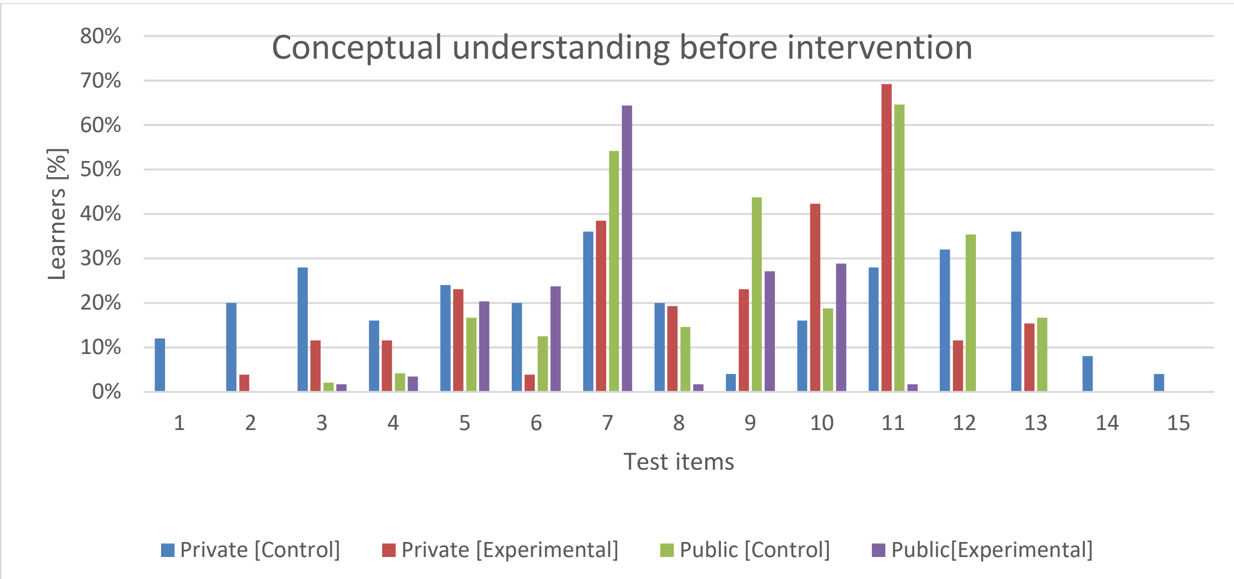

Figure 8. Percentage of P4 learners who correctly answered each item before teaching intervention

Figure 9 displays the percentage of learners from public and private schools in both groups after learning (post-test results). There is a clear trend in the results. All items show a high performance among most groups, except in public schools. Both control and experimental groups showed a high but similar increase despite the teaching intervention provided. In items #4, #5, #6, and #8, the control group improved conceptual understanding better than the experimental group. However, the experimental group demonstrated an increase in learners who performed well in most of the questions, except for some items (from item #4 to item #8) in public schools.

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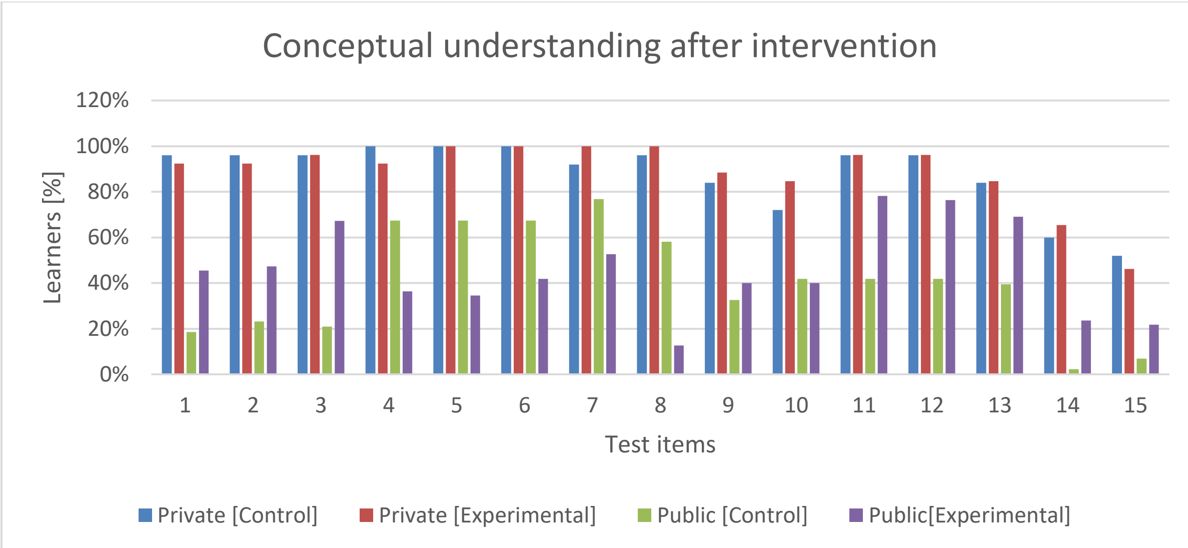

Figure 9. Percentage of P4 learners who correctly answered each item after teaching intervention

The analysis of a P4 public school [experimental] learner's sample work from the pre-test and post-test revealed an improvement in performance by 73.3% (from 1 to 12 marks out of 15). Before the intervention, the learner's work revealed a very low or no understanding of the concepts of the position of an integer on a number line, comparison of integers, ordering integers in ascending or descending order as well as the distance between two integers was not existent based on the items well performed in the pre-test. Even in the concept addition of integers, the learner got 1 item correct out of 3, but the post-test results showed that the development of conceptual understanding is still lacking as the learner did not get any item correct out of 3 items given. However, the post-test results show that the learner correctly identified a number on a number line, found the distance between two integers, compared integers, and organized them in ascending and descending order. Therefore, the learner got all items correct except those on the addition of integers. Based on the result of the post-test, the results show that learners' conceptual understanding of the concept of integers improved by 73.3% based on correct answers got and the learner's work.

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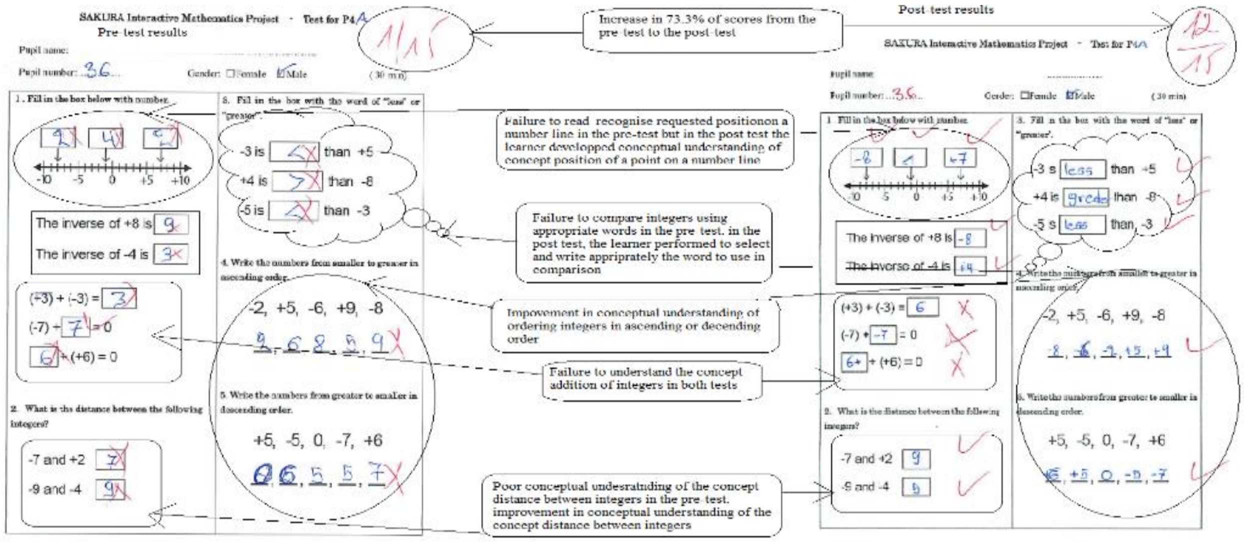

Figure 10: A Public school, P4 learner's comparative analysis of pre-test and post-test works (Source: field study, 2020).

Discussion of results

What are the effects of IM-supported teaching on Lower and Upper Primary Performance?

The P2 and P4 results demonstrated that learners' scores improved from the pre-intervention test and the post-intervention test and that the treatment group's mean scores differed significantly from the control group's mean scores on both tests. It follows that IM-supported teaching improved lower and upper primary mathematics learners' performance similarly based on P2 (Table 2) and P4 (Table 5) post-test mean scores and the significance of their differences.

These findings support Uwurukundo et al.'s (2022) study, which discovered that students who used GeoGebra in their learning manifested greater success than kids who did not use GeoGebra. Accordingly, students who learn by observation and manipulation might comprehend concepts that they previously thought were abstract when blackboards and chalk were the only teaching tools accessible. According to Ringstaff and Kelley' (2002) study, algebra students who learned using a computer outperformed students in traditional classes and learning with ICT promoted learner-centred pedagogy, leading to increased student motivation and improved self-concept.

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Hence, IM efficiently tackles the difficulties of traditional chalk-and-talk instruction while also enhancing students' academic performance. These results assure the feasibility of implementation of the policies promoting the use of technology in education in Rwanda (MINEDUC, 2016).

Furthermore, these results show that IM-supported teaching can serve as an answer to learners negative attitudes towards mathematics. As explained earlier, learners' low marks on test and exam as well as their failure to see the connection between mathematics and everyday life context results in developing negative attitudes towards learning mathematics (Ukobizaba et al., 2021; (Nzaramyimana et al., 2021). Therefore, the two studies suggested ICT-supported teaching at primary school level to improve learners' positive attitudes and performance. It can be understood that learners got motivated while learning with IM because mathematics content was effectively attractively presented, simplified, and visualized in accordance to Milovanovic et al.' (2016) multimedia- supported learning explanation. The cognitive theory of multimedia learning supported these findings in the way that IM-supported teaching engaged learners in learning by using graphics consisting of colored semi-concrete mathematics objects, animated mathematics objects, and spoken texts which can be combined into one piece or used separately (Rudolph, 2017). Lower and upper primary learners therefore learned by using audio-visual stimuli (Moreno, 2002) by using IM software.

From the multivariate analysis of variance (MANOVA) through a general linear model (GLM) in P2 (Table 2) and descriptive statistics in P4 (Table 5), results demonstrated that in the two groups, learners' performance in private schools was higher than in public schools with a smaller standard deviation. However, while the difference in performance between the two schools was not significant (sig.>.05) before and after intervention in P2 (Table 3), public school scores after intervention improved exceptionally in P4 (Figure7). Public schools mostly serve students with diverse learning capacities from low-income and uneducated households, while private schools primarily serve students from wealthy and educated families that have the resources to ensure individualized and successful learning. The variety of ways that math knowledge was represented (Ojose, 2008) in IM software probably encouraged the teaching tailored to the cognitive level and learning capabilities of each individual learner. Our findings give rise to

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optimism that quality education may be provided in public schools using IM software despite their constant increase in rate of student per one teacher. These results confirm findings from previous studies which found there was a slight difference when teachers in public and private schools who used YouTube videos and interactive simulations during learning optics (Ndihokubwayo et al., 2020). Public schools in Rwanda are highly overcrowded with learners, and teachers experience the challenge of individualization of learning. In our study, between 50 to 60 students per teacher were present in participating public schools, compared to an average of 25 students per teacher in private schools. Therefore, the use of IM software improved the teachers' competence to individualize learning, to arouse learners' interest, and to concretize abstract mathematics (Ringstaff, & Kelley, 2002; Ojose, 2008; Loo, & Mohd, 2020) which resulted in important performance effects particularly in overpopulated public mathematics classes.

5.2. What are the effects of IM-supported teaching on Lower and Upper primary learners' conceptual understanding?

According to Ndihokubwayo et al. (2021), measurement of conceptual understanding development may be analysed from learners' change in pre-test and post-test performance on a test item. Accordingly, a task completed by a small number of students despite the intervention offered can be evidence of a lack of conceptual understanding about it, whereas a task completed by a large number of students following the intervention attests to the development of conceptual understanding among the learners (Ndihokubwayo et al., 2021). This approach was also be used to examine how conceptual understanding has improved in the mathematics of elementary learners after using IM-enhanced lessons.

By calculating the percentage of learners who correctly answered test items in P2 (Figure 5) and in P4 (Figure 10) our resuts revealed that learners' overall performance increased from the pre-test to the post test thanks to IM-supported intervention. Therefore, this evidenced the improvement in conceptual understanding during IM-supported teaching process that resulted into improvement in performance. Although private schools understanding was the most improved, public schools moderately improved understanding after intervention in both P2

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(Figure 4) and P4 (Figure 9). The analysis of a sample of a P4 learner's pre-test and post-test work (Figure 10) revealed that IM-supported teaching allowed the learner to develop an understanding of concepts including the position of an integer on a number line, the comparison of integers, the addition of integers, and the distance between integers which as very poor from the pre-test work.

Our results are in confirmation with different arguments which stipulated that mathematical problem-solving can lead to the development of conceptual knowledge (Haji, & Yumiati, 2019) and that test-takers' performance demonstrates how much or how well they have truly learnt or understood a subject (Sorden, 2012). Furthermore, our study findings confirm Zulnaidi and Zamri's (2017)'s arguments which stipulated that the utilization of GeoGebra software supported instruction may result in learners' gaining a deeper comprehension of concepts, which has a substantial positive impact on their academic performance. It follows that IM software-supported teaching can enhance learners' conceptual understanding development resulting in their mathematical achievements.

This may result from the IM software features which may facilitate learners' understanding of mathematics concepts and relationships. The IM-supported teaching follows three levels of IM mathematics content presentation: a) the understanding level rich in semi-concrete eye-catching images and graphs with animated processes and corresponding sounds, b) the quick exercise level where learners engage in working with abstract mathematics content and processes and c) evaluation level with checking and rewarding features. Therefore, mathematics content presentation in IM software ease learners' selection, organization, and integration (Kirschner et al., 2017) of mathematical knowledge while building relations across mathematics notions and concepts or conceptual understanding development. Therefore, our study confirmed that multimedia environment foster meaningful learning (Kirschner et al., 2017). Conceptual understanding development resulted from IM direct instruction (like indicating where to put the answer, where to click for checking the answer etc.) and IM-supported instruction from the teacher. Therefore, our findings resulted from learning with IM and learning from IM in conformity with Ringstaff's and Kelley's, (2002) theory and (Lee, Y.T. et al., 2012) arguments

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about ICT use in teaching and learning mathematics at primary level. The CTML supported out study as IM software stimulated learners' auditory and visual memories while learning.

From the results, some items in the experimental groups were better understood in the pre-intervention test than in the post-intervention test (Figure 5, item #10; figure 8 and figure 9, item #7). This might have resulted from teachers' lack of experience in using IM software and generally in using ICT in teaching. IM software features are suitable for learners' conceptual understanding, but the teachers should have enough skills to effectively teach using IM software to maximize the benefits of IM-supported learning.

5.3. What are the differences in IM-supported teaching effects between Lower and Upper Primary Performance and conceptual understanding?

From our results, it was realized that IM-supported teaching significantly improved P2 and P4 learners' post-test scores similarly. Thus, we continue to believe that there is no difference between the effects of IM-enhanced instruction on mathematics achievement and conceptual understanding between lower primary and upper primary. According to our study, private schools performed better than public schools at both levels in terms of improving learners' test results before and after intervention in P2 (Table 2), just as it did in P4 (Table 5). In addition, the conceptual understanding developed in the post-test in P2 (Figure 4), like in P4 (Figure 9), more in private schools than in government schools of both levels. However, public schools learners manifested interesting improvement in performance and understanding especially in P4 (Figure 7) despite the challenging learning environment they present compared to private schools. Therefore, our study confirmed that contemporary multimedia approach to learning may suit various levels of education and with varying degrees of involvement (Milovanovic et al., 2016). Besides, our study confirmed the existence of a relationship between teaching and learning resources and academic performance (Ondieki, & Orodho, 2015). Hence, the use of IM improved the teaching quality, leading to improvement in performance and conceptual understanding. The fact that IM-supported teaching influenced lower and upper primary levels similarly indicates that this software is effective in preparing learners to upper levels of education and lifelong learning supported by an ICT tool. This falls in Zenki-Dalipi, (2019)

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findings which stipulated that technology makes it easier to understand mathematical ideas while also allowing for more sustained learning.

Conclusion and recommendations

This study intended to explore differences in academic performance and conceptual understanding among lower and upper primary school learners in Rwanda's IM-supported teaching and learning environments. The findings revealed that IM-supported teaching improved learners' academic performance and conceptual understanding in lower and upper primary in the same way. From our results, the use of IM-enhanced teaching proven achievement of quality learning in government schools despite the challenges which reigns there. IM software proven its potentials to improve the quality of mathematics outputs and knowledge at the primary level as stipulated by policies advocating the use of ICT as a teaching tool. Our study faced limitations about the analysis of our results due to different levels (lower and upper levels) and different tests. In addition, the use of one-group-pre-test-post-test method and design for lower primary limited the use of pre-test and post-test results for control and experimental groups. We recommend carrying out additional broader qualitative and quantitative studies using similar or different methodologies to provide valuable additional information on the potential of IM software to facilitate the successful delivery of mathematics following the CBC standards.

Based on the findings, we recommend Rwanda Basic Education Board (REB) and the Ministry of Education (MINEDUC), which are educational institutions in charge of curriculum development and teacher management, to allow the official use of IM as an instructional tool by all public primary schools in Rwanda. This should be done in conjunction with teacher training to improve their ICT basic skills and their abilities to create and manage an effective multimedia teaching and learning environment. Furthermore, teachers' planning abilities should be raised to the effective integration of ICT in lesson plans and adjust it to the teaching period recommended by the CBC. In addition, MINEDUC, through REB, should ensure the availability of technological infrastructure in all schools in Rwanda.

Appendix 1. The test provided to P2 learners

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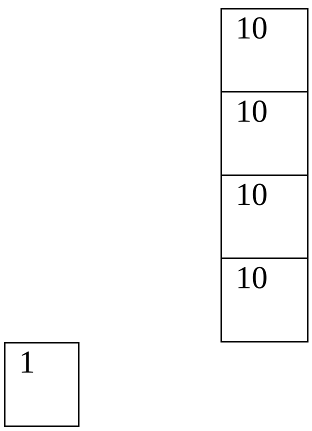
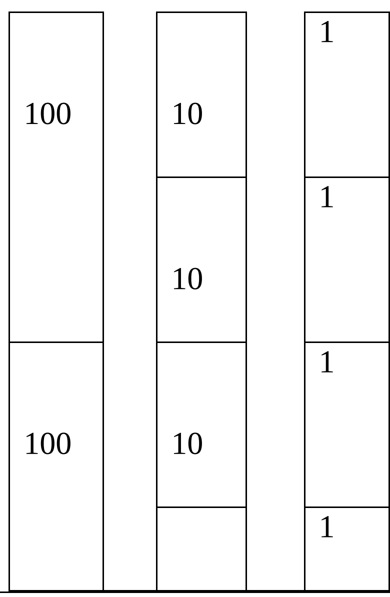
Uzuza mu mwanya urimo ubusa (Fill the missing number in the box):

435, 436, ☐ , 438

240, 250, ☐ , 270

Bara kandi wandike umubare mu mwanya urimo ubusa (Count and write the missing number in the empty box):





Uzuza mu mwanya ukurikira ukoresheje ikimenyetso gikwiye (Fill with an appropriate symbol in the place provided):

271 ☐ 259

Tondeka imibare uhereye ku muto ujya ku munini (arrange numbers in ascending order):

371, 348, 427

Tondeka imibare uhereye ku munini ujya ku muto (arrange numbers in descending order):

398, 447, 412

Kora imibare ikurikira (workout):

164 +232	318 +165
297 -154	351 - 291

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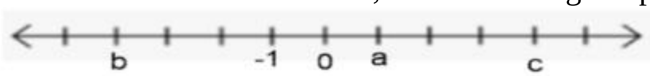
		10				
100		10				

Appendix 2. Test provided to P4 learners

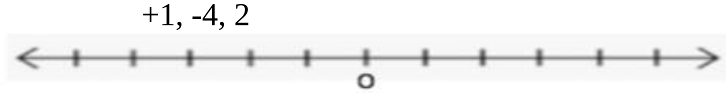
From the number line below, write the integer represented by the letter:



a=……..
b=……..
c=……..

Locate the following integers on the number line below:

+1, -4, 2



What is the distance between the following integers on a number line?

-2 and +3 …………………..
-3 and -5 …………………..
0 and 6 ………………….

Using a ruler or your estimation, indicate integers showing the following expressions

2 steps backward: 

3 steps forward: 

Compare the following integers using <, > and =

-3…..0
-2….-4

6. Arrange in ascending order: -3, +2, 0, -2, 4
   Arrange in descending order: +3, -2, -1, 6, 0

Acknowledgements We acknowledge the support provided by the African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science (ACEITLMS), the University of Rwanda College of Education, and the grant provided by the University of Rwanda-Sweden Programme.

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Published online: 23 May 2023

Data availability statement: Datasets generated and analyzed during the current study can be accessed via the following links: https://drive.google.com/drive/folders/1aOHvM6urp5vX1rywZfL3VdRc_Zq9wPWF?usp=sharing and https://drive.google.com/drive/folders/1lg3d2O93AQ3dAdXnkpr8rUe2sJTGUwIj?usp=sharing and the software's link is http://sakura-m.ver2.asia/.

Declarations

Conflict of interest No conflict of interest.

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Published online: 23 May 2023

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Published online: 23 May 2023

Chapter IV. Teachers' perceptions of using IM in teaching and learning activities

4.1. Introduction

The third objective of the study, which was to find out how teachers felt about using IM to enhance their instruction, is addressed in this chapter. The article that is posted after this one contains information regarding teachers' experiences using IM to aid in the teaching and learning of mathematics.

4.2. Detailed account of the paper (next page)

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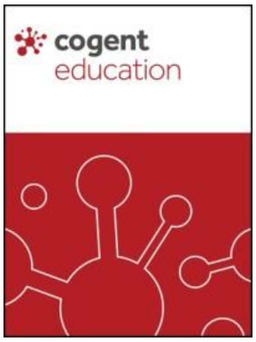

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oaed20

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To cite this article: Innocente Uwineza, Alphonse Uworwabayeho, & Kenya Yokohama (2023) Perceptions of using interactive mathematics software among Rwandan primary school teachers, Cogent Education, 10:1, 2170113, DOI: 10.1080/2331186X.2023.2170113

To link to this article: https://doi.org/10.1080/2331186X.2023.2170113

Published online: 16 Feb 2023.

Extended author information available on the last page of the article

Published online: 23 May 2023

Springer

Extended author information available on the last page of the article

Published online: 23 May 2023

Reviewing editor:

Li Zhao, School of Education Science, Nanjing Normal University, Nanjing, China

Additional information is available at the end of the article

Received: 29 October 2022

Accepted: 15 January 2023

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INFORMATION, & COMMUNICATIONS TECHNOLOGY IN EDUCATION | RESEARCH ARTICLE

Perceptions of using interactive mathematics software among Rwandan primary school teachers

Innocente Uwineza[1]*, Alphonse Uworwabayeho[1] and Kenya Yokohama[2]

Abstract: This study aimed to explore primary school teachers' perception of using Interactive Mathematics (IM) software in teaching and learning activities using qualitative interpretive phenomenology. It involved seven teachers non-randomly selected from the lower and upper primary with different gender and teaching experiences who participated in a semi-structured interview which took around

30 minutes on average for each interviewed teacher after the experimentation period. Data were collected by recording and writing in a notebook some key information using both English and Kinyarwanda languages to capture the max- imum perception of teachers. Translation of Kinyarwanda answers to English and transcription followed by respecting the main interview questions. Three themes emerged: (1) the disadvantages of traditional teaching and learning of mathe- matics, (2) the benefits of aspects of ICT and interactive mathematics software, and the challenges of using ICT and interactive mathematics software. Based on the findings, suggestions, and recommendations about the effective utilization of IM in classroom activities, as well as its integration into the curriculum, were discussed.

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PUBLIC INTEREST STATEMENT

Teachers' attitudes and perceptions about teaching and learning practices have an impor- tant role in quality education achievement. This article presents a qualitative study on Rwandan teachers' perception of teaching mathematics in the smart classroom using Interactive Mathematics software (IM). IM is a new techno- logical tool developed to support the effective implementation of the Competence Based Curriculum (CBC) in mathematics at the primary school level in Rwanda. From interviews, tea- chers explained their experience with teaching with ICT, their awareness of IM software, their lived experience in IM-supported teaching and learning, and how they perceived IM's potential to boost quality mathematics education while considering that, for many teachers, this was a new teaching experience. From the results, tea- chers believe that IM-supported teaching increases understanding and interest to learn which cannot be achieved effectively through traditional teaching methods. They also formu- lated their wishes for the future of IM in quality mathematics education in Rwanda.

Subjects: Mathematics Education; Primary/Elementary Education; Teaching, & Learning

Keywords: benefits and challenges of teaching with ICT; interactive software; mathematics software; Rwandan primary schools; teachers' perceptions

Introduction

Teacher teaching experience in Rwanda

ICT integration in education was considered as a key strategic tool expected to contribute to the country's economic transformation (MINEDUC, 2018). In this context, the education sector as a whole has been experiencing a more general pattern shift with the advent of technology (Perienen, 2020). It is why Rwanda opted to equip both primary and secondary students with ICT tools and allow them to interact with these tools guided by their teachers to enhance quality education (Das, 2019).

In 2015, Rwanda revised its curriculum by shifting from a teacher-centered to a learner-centered approach, whereby teachers engage learners in active learning and in constructing their knowl- edge. Through this learning approach, less lecturing and more engaging teaching methods are expected to dominate classroom activities (Ndihokubwayo, & Habiyaremye, 2018). Therefore, ICT use in teaching and learning activities was prioritized to support the effective implementation of the new Competence-Based Curriculum (CBC) which is in its early phases of implementation in Rwanda since 2015. In fact, newer technologies under development brought many pedagogical benefits including the removal of the concern about teachers being anchored in front of classes, and instead the promotion of more interactivity and participation in a learner-centered teaching environment Beauchamp, G. (2004). Therefore, the use of ICT in classroom practices is importantto shift from traditional role of the teacher as a "sage on the stage," which promotes passive learning and less engagement of learners. With ICT use as an instructional tool, teachers are freeto move about the class checking on learners' engagement and activities as well as responding tolearners' needs.

Challenges of the traditional teaching of mathematics

Mathematics, like other subjects used to be taught by a teacher using a chalk-and-talk approach,whereby students learned just by listening to what the teacher was saying (Sharndama, 2013). For instance, in Mathematics, several students said that their teachers went too fast and could not explain mathematics concepts clearly (Swan, 2000). Similarly, Ukobizaba et al. (2021) argued thatteachers giving poor marks and being harsh and careless are some factors contributing to students feeling demotivated to learn mathematics in Rwandan primary and secondary schools. The fact that teachers do not take time to interact with students by discussing mathematics concepts results in rote learning; students simply memorize formulas without understanding where those formulas are derived from, and why and when those formulas are to be used (Ishartono et al., 2019). Consequently, teaching students to recall formulas does not provide students with oppor- tunities to develop their central mathematical competencies, such as problem-solving ability, reasoning ability, and mathematics conceptual understanding (Lithner, 2012). However, Ukobizaba et al. (2021) suggested that teachers should show the relevance of Mathematics in everyday situations, give them lots of work examples, and provide exercises and home works, to enhance students' performance in mathematics. Therefore, teachers need to shift from the tradi- tional way of teaching and adopt a new interactive teaching and learning style, which is key to enhancing students' performance and skills development through interactive ICT tools (Beauchamp, 2004).

The goodness of teaching with ICT and interactive mathematics software

A significant increase in ICT integration in teaching and learning mathematics was recorded worldwide in the past ten years (Das, 2019; Perraton, 2000). With the development of technology, educationists and researchers were interested in finding which appropriate teaching method and effective educational technology to teach mathematics. The technology used should support mathematics teaching and learning (Radović et al., 2020). To this end, integrating ICT tools suchas interactive mathematics (IM) in primary schools may be a vital tool due to its role in improvingstudents' performance in mathematics and its potential to enhance students' skills as they interact with technological tools (Das, 2019). In addition, teachers' perceptions towards the IM should affect students' performance in mathematics since it was found that the Primary Six (P6) learners who performed highly in mathematics in the Rwandan national examinations are those taught byteachers who had positive attitudes toward teaching resources used that engage students' activelearning (Gichuru, & Ongus, 2016).

Benefits of learning aspects with ICT and mathematics software

ICT not only facilitates teachers in their teaching practice but also plays a key role in enhancing students' performance and lifelong learning (Munyengabe et al., 2017). ICT can afford to monitor students' achievement through regular assessments (Golzar et al., 2022), which inform teachers about students' progress to make the appropriate decision and effective educational manage- ment. Also, ICT helps students to make self-reflection about their learning progress. Furthermore, ICT contributes to strengthening teacher professional development and improving the quality of education (Ministry of Education, 2016). In mathematics, ICT enables students to make calcula-tions, draw graphs, and solve problems. For instance, an IM spreadsheet can help students make graphs and calculations and solve mathematical problems (Das, 2019). It is why, Jalinus and Alim (2019) argued that teaching mathematics to elementary kids using IM is important since it enhances students' creativity, active learning, and independent learning. Therefore, using ICT tools such as IM is expected to improve the quality of mathematics being taught as it is adaptive to students' age, making them perform and enjoy the lesson (Jalinus, & Alim, 2019).

Role of ICT in teaching big classes and time management

ICTs influence interactive and collaborative learning environments in place of traditional teaching and learning, which was dominated by teacher-talking and student listening. With this affordance brought by ICT tools, multimedia devices and internet technologies are used to facilitate teaching large classes

(Sharndama, 2013). In addition, ICT was found to enhance students' self-regulation as a fundamental element that enhances the awareness of time management for planned learning and submission of the given activities by respecting the deadline (Yamada et al., 2016). In addition, research about learners' emotions and control in the multimedia environment found that using ICT in teaching and learning may help learners benefit from negative emotions when control strategies are implemented in the multimedia environment (Chen et al., 2021).

Challenges of using ICT and mathematics software

Although the integration of ICT has the potential to concretize mathematical concepts (Beauchamp, 2004; Jalinus, & Alim, 2019), Mathematics remains viewed as a challenging subject even in normal circumstances (Rozgonjuk et al., 2020). For instance, Mazur et al. (2021) argued that there are challenges connected with learning mathematics using ICT, whereby hands-on activities and practical experiments are also required. Similarly, Bentata (2020) argued that students struggle with typing mathematics expressions. In addition, the lack of internet and electricity in remote areas, the high cost of ICT equipment, and students' and teachers' insufficient skills to use ICT tools were challenges for effective ICT integration in teaching and learning (Rajan,& Manyala, 2021). It is why Naidoo (2020) suggested that teachers and students should be provided with resources that are easy to use, readily available, and cost-effective.

Problem statement and AIM of the study

Although Rwanda has set policies and invested much in ICT integration within the educational system from primary to higher learning institutions, there are still gaps in implementing those strategies and policies. For instance, most pre-and in-service teachers teach without sufficient knowledge about ICT tools, which may affect quality education (Mugiraneza, 2021). Although many students are enrolled in primary schools, there is a need to link enrollment with the quality of education received by students (Ministry of Education, 2016). In this context, there is a need to explore primary teachers' perceptions of IM since there is a link between teachers' perceptions of their teaching practices and students' performance (Gichuru, & Ongus, 2016). In addition, there is a need to investigate primary teachers' perceptions and attitudes about how they teach mathe- matics through the integration of ICT since the awareness of teachers' practices leads to changing pedagogy and making adequate educational policies to improve teaching and learning (Zakaria, &Daud, 2013).

Rwanda Basic Education Board (REB), in partnership with a Japanese private company (SAKURA- SHA), created software commonly known as Interactive Mathematics (IM) software to support the implementation of basic mathematics in primary schools. Thus, teachers should fully understand the relevance of IM and its use in teaching mathematics since IM software has the potential to develop students' acquisition of primary mathematics topics as developed in the Competence- based Curriculum (CBC) being used in Rwanda (Ndihokubwayo, & Habiyaremye, 2018)... The IM software has been in the piloting phase since 2018, which is expected to last for three years. Thus, the present study explores Rwandan primary teachers' perception of IM since it is piloted in primary schools in Rwanda. It specifically wants to explore (a) the disadvantages of the traditional teaching of mathematics, (b) the benefits of teaching and learning aspects with ICT and interactive mathematics software, and (c) the challenges of using ICT and mathematics software. The findings from the study will inform Rwanda Education Board (REB) about the extent to which teachers appreciate the IM software in promoting quality mathematics teaching and learning in primary schools of Rwanda to make adequate decisions regarding this newly introduced technology.

Methodology

Research design

This research used a qualitative approach guided by phenomenology interpretivism philosophy. According to Tuffour (2017), qualitative research appreciates the meanings people attribute to their experiences. According to Sundler et al. (2019), the philosophy of phenomenology refers tothe study of a phenomenon, something as it is experienced or lived by a human being, or how things appear in our experiences. This study aimed at collecting teachers' perceptions about lived experiences in their teaching practices supported by the IM.

Participants and sample

This study focused on primary school teachers of mathematics who taught mathematics using Interactive Mathematics software. Seven (7) teachers from elementary school who have taught in treatment classes were non-randomly selected to participate in a semi-structured interview about their perception of the potential of Interactive Mathematics supported teaching to boost quality mathematics education in primary schools. Participants were female and male teachers of differ- ent teaching experiences in teaching mathematics in primary school from primary two, primary three, primary 4, and primary 5 which were the levels of our research focus. However, a primary-1 teacher who also contributed to the piloting of IM in primary-1 was interviewed to gain insight intothe experience lived at that level. The table below shows the sample of teachers by teaching experiences, gender, and level of teaching.

The study involved female and male mathematics teachers with teaching experience ranging from 4 years to 32 years of teaching experience in lower or upper levels from three public and two private schools.

Research instrument description

A semi-structured interview was designed to collect data from 7 teachers of elementary school who participated in this study. The researchers focused on teachers' perceptions about the potential of IM to support quality education in basic mathematics. During this study, a semi- structured interview was developed and used. A pen and paper, together with a digital recorder, were used. The researcher recorded the information from interviews to preserve the entire infor- mation for future analysis. The interview was designed in Kinyarwanda and English to facilitate the respondents' choice of language of communication. However, respondents were free to switch from one language to another while elaborating on their opinions. Using a recorder was better than direct writing for collecting the entire information in terms of words in such a way that it was very easy for the researcher to playback while transcribing and interpreting the data.

Teaching intervention (IM software) description

The IM-supported teaching took place in experimental groups selected from public and private schools from primary-2, primary-3, primary-4, and primary-5, which were the target group of our study during 2019 and 2020 research activities. However, considering that the piloting of IM also involved primary 1 in 2019, we included one teacher of primary one in our interview to hear about her lived experience in teaching primary 1 learners with IM. Before the teaching intervention, teachers underwent a two-day training about the manipulation of IM and its integration into the teaching of mathematics. Lesson preparation drafts followed by microteaching sessions were conducted during the training to find an effective way of teaching using IM. The teaching inter- vention consisted of 2 types. Type-A intervention consisted of IM-supported teaching using a projector and a computer manipulated by a teacher, and a wireless mouse which was used by both the teacher and learners. Learners' activities consisted of following the teacher's presentation on the screen and engaging in interactive mathematics activities using a wireless mouse under the teacher's invitation or working on projected exercises using an exercise book and a pen. The teacher used to move around the class, monitoring learners' work and correcting them. For each projected exercise, a learner was invited to correct it in front of the class using a wireless mouse under the teacher's and other learners' guidance, and all learners managed to compare their work to the projected correction. As the software cannot project different exercises at once, one activity was projected and given time to work on and correct it before embarking on the next activity. The role of the teacher was to facilitate learners' activities, manage the classroom environment, check on the time, correct the work of an individual learner, invite a learner to correct in plenary, and give the next activity. Type-A experimentation was used in primary-1, primary-2, primary-3, primary-4, and primary-5 during the 2019 and 2020 research activities.

In 2019, one public school accommodated type-B intervention, with enough rooms for smart teaching and enough XO computers for all primary-4 and primary-5 learners. This consisted of the teacher teaching with a computer and a projector while learners followed and worked on exercises and other activities using their individual XO computers. Like in type-A, the teacher used to switchon working on a blackboard with a piece of chalk and to engage learners in working in their exercise books using pens to develop their reasoning and conceptual understanding and exercisetheir motor skills.

This type of experimentation was not used in many schools, as it required teachers and learners with enough basic computer skills. In addition, many schools could not have enough learners' XOcomputers in good condition or infrastructure, allowing them to have a smart classroom to accommodate the teaching. Besides, some XO computer versions were not compatible with IM software. In addition, while policies governing the distribution of resources like computers in schools target public schools, private schools have to buy these resources as they are not under public governance. All these challenges influenced type-A experimentation in almost all schools except in primary 4 and primary 5 of one public school.

Data collection procedure

Data were collected from participants' interviews conducted by the researcher after research activities were concluded. During data collection, the participant was asked to provide his/her free consent to participate in the study after being communicated about the purpose and the importance of the interview and reassured about the anonymity of respondents during data analysis. The time favorable for the participant to spend nearly 30 minutes was agreed upon between the researcher and the participant. The interview started with questions related to challenges encountered in teaching mathematics traditionally, followed by the items for collecting teachers' lived experiences in IM-supported classes in quest of quality teaching and learning. Foreach item, a respondent expressed his or her understanding, opinions, and concerns, followed by the researchers probing questions, inspiring questions, and challenging ones to stimulate the respondents' deep thinking and provision enough explanations. However, the interviewer ensuredto stay connected to the core question or theme until the next question or theme was tackled. Atthe same time, the researcher recorded the respondent's voice while writing some new ideas orimportant points to consider in the interviews.

Ethical procedure

After getting ethical clearance, the researcher visited selected schools to obtain their free consent to participate in the study. The researchers have explained to the school administrative agents and teachers the research purpose, processes, and roles of the school administration, teachers, and researchers. Participants and school administrators were assured anonymity during data presen-tation, analysis, and interpretation. Therefore, during data collection and analysis, participants were referred to as teacher-1, teacher-2, teacher-3, etc.

Data analysis and results presentation

After collecting data, the first author transcribed the recording and translated the data provided in Kinyarwanda into English. Besides, some information collected by writing was also organized to be integrated into the transcripts. The first author arranged questions with their corresponding data to facilitate analysis. Data were analyzed thematically using the interpretive analysis following interpretive phenomenology. According to Tuffour (2017), interpretive phenomenological analysis (IPA) aims to look at how someone makes sense of a life experience and give a detailed inter- pretation of the account to understand the experience. Therefore, IPA represents a beneficial methodology in providing a rich and nuanced insight into the experiences of research participants(Tuffour, 2017). Data were analyzed data via *Taguette*, a free and open-source (https://www. taguette.org/) qualitative data analysis (QDA) software (Rampin, & Rampin, 2021). The analysis consisted of reading interview responses, identifying and highlighting the key idea from data, and creating a corresponding tag which later was analyzed as codes. *Taguette* software supported the coding method by importing the interview transcripts, reading over, tagging/coding, and comput- ing the frequencies of tags by exporting the Taguette project into the Excel codebook. Besides, a word document was opened to facilitate the caption of emerging themes, their categorization, and organization by related tags/codes. Specific direct quotes were selected from interview responses and directly used in the interviewee's term to discuss discrepancies to ensure that a consensus was reached or to support the explanation and demonstrate the robustness of each theme (Bouzo et al., 2022; Maghiar, & Brown, 2022). The author's first coding was given to the second author and an external researcher to evaluate the coding method concerning the meaning of codes concern-ing interview responses. This allowed the first author to correct potential coding method errors and reduce coding biases. Figure 1 serves as an example of a coding method and direct quoting.

From Table 1,Table 2 15 codes grouped into three themes provide data about teachers' percep-tions of using IM in teaching and learning mathematics. Data about the disadvantages of tradi- tional mathematics teaching were collected using three codes: teachers' heavy load, low understanding, and low motivation. The benefits of using ICT and mathematics software gener-ated nine codes, while two codes were generated from teachers' interviews to explain the challenges of using ICT and interactive mathematics software. These codes were identified directly or indirectly from teachers' interviews. From one teacher's interview, one code should appear once or several times while answering an interview question. In addition, one code should appear for one teacher but not for another one, as the interview questions asked were open questions. Each of the seven teachers' interviews was coded, and the frequency of occurrence was generated for every code. The total frequency for a code for all seven teachers was provided to allow a general-ized analysis of all teachers' perceptions.

From the findings, the disadvantages of traditional mathematics teaching were coded as Teacher Heavy Load, Low Understanding, and Low Motivation. Teacher Heavy Load was mentioned by Teacher 1 (T1) one time, Teacher 2 (T2) two times, and teacher 7 (T7) 2 times leading to a total of 5 times. However, during their interview, T2, T3, T4, and T6 did not mention it. Low Understanding of code was mentioned 16 times by all teachers. It was mentioned two times by T1 and T7, once by T2 and T6, three times by T3 and T4, and four times by T5. Low Motivation codewas mentioned once by T1, T6, and T7, twice by T4, and four times by T5. Considering all teachers, the Low Motivation code appeared nine times. From the findings, the disadvantage of traditional teaching is, in general, learners' low understanding considering the highest occurrence of Low Understanding of code compared to other codes.

The findings about the benefits of teaching and learning aspects with ICT and mathematics software tools show that Teacher Easy Load, Easy Lesson Plan, Easy to Teach Big Classes, Easy to Manage Distractions, Increase Understanding, Increase Learner Engagement, Increase Interest in learning, and Match with the CBC were the codes that emerged from teachers interview. Teacher Easy load was mentioned two times by T1, T2, and T7, while T3 mentioned it once, making a totalof 7 frequencies for all teachers. Easy Lesson Plan was coded nine times by all teachers, specifically two times by T1 and T5, by T2 and T3, and by three times by T7. Easy to Teach Big Classes was coded by T1 and T7 three times; T2, T3, and T4 two times; T5 and T6 once, which make a total frequency of 14. Easy to Manage Time was mentioned six times by T1, T3, and T5, who mentionedit once, and T5, who mentioned it three times during their interviews. Easy to Manage Distraction code appeared eight times from all teachers. T1, T2, and T4 mentioned it two times, while T3 andT5 mentioned it once. The increased understanding code was the highest coded of all codes, as itwas mentioned 38 times by all teachers. It was mentioned once by T1 and T4, eight times by T2,nine times by T3, ten times by T5, three times by 3, and 6 times by T7. An increase in Learners Engagement was mentioned by T1 and T3 once and seven times by T5, making a total frequency of 9. Increased Interest to Learn was mentioned once by T1, three times by T2 and T4, five times by

Figure 1. Example of coding

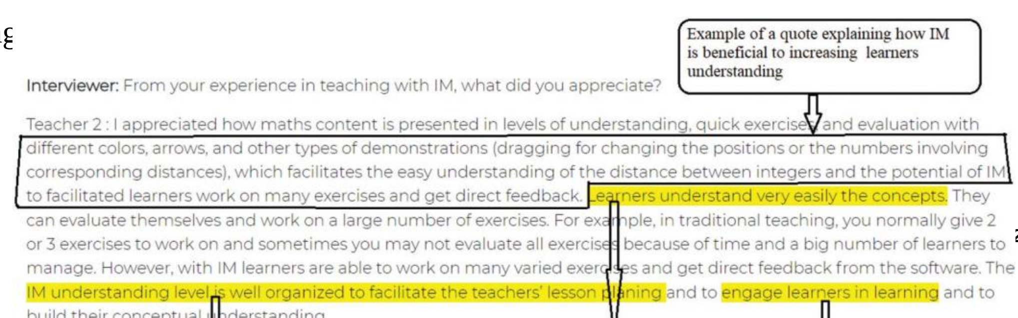


Table 1. Number of teachers by teaching experience, gender, and level of teaching

Teacher's code	Teaching experience	Type of school	Females	Males	Lower	Upper
Teacher 5 (T5)	4 years	Public	1		1	
Teacher 1 (T1)	5 years	Private		1		1
Teacher 3 (T3)	10 years	Private		1	1	1

Teacher 6 (T6)	18 years	Public	1			1
Teacher 4 (T4)	20 years	Public	1		1	
Teacher 2 (T2)	25 years	Public	1			1
Teacher 7 (T7)	32 years	Public	1		1	
	Total		5	2	4	4

Table 2. Distribution of codes among interviewed teachers

Themes	Codes	T1	T2	T3	T4	T5	T6	T7	Tot
Disadvantages of the traditional teaching of mathematics	Teacher heavyload	1	0	0	0	2	0	2	5
	Low understanding	2	1	3	3	4	1	2	16
	Low motivation	1	0	0	2	4	1	1	9
Benefits of teaching and learning aspects with ICT and interactive mathematics software	Teacher easyload	2	2	1	0	0	0	2	7
	Easy lesson plan	2	1	1	0	2	0	3	9
	Easy to teach big classes	3	2	2	2	1	1	3	14
	Easy to manage the time	1	0	1	0	3	1	0	6
	Increase understanding	1	8	9	1	10	3	6	38
	Easy to manage distraction	2	2	1	2	1	0	0	8
	Learners' engagement	1	0	1	0	7	0	0	9
	Increase interest in learning	1	3	5	3	9	0	2	23
	Matching with Rwandan CBC	0	0	3	0	0	0	0	3
Themes	Codes	T1	T2	T3	T4	T5	T6	T7	Tot
Challenges of using ICT and interactive mathematics software	Teaching various content	1	0	1	3	0	1	3	9
	Insufficiency of computers	1	1	0	2	0	1	0	5
	Training time and period	2	2	0	2	1	0	2	9
	Errors in terminologies	0	0	1	0	0	0	0	1

T3, and nine times by T5, totaling 23 times for all teachers. All teachers mentioned nine times during the interview that the IM content matches the Rwandan CBC. Considering all eight codes about this theme, all teachers mentioned that using ICT and Interactive Mathematics software is beneficial to teaching and learning aspects in many aspects but mostly in increasing learners understanding with 38 total frequencies.

The challenges of using ICT and Interactive Mathematics Software were coded as Teaching Various Contents, Insufficiency of Computers, and Errors in Terminologies. Many teachers, espe- cially in upper primary, mentioned nine times that the IM software content was developed on a few mathematics contents, which restricted the teaching to some mathematics contents. Besides, a few teachers mentioned other challenges, including errors in terminologies used in IM content which are different from the ones used normally, and insufficiency of computers as challenges faced during teaching with IM.

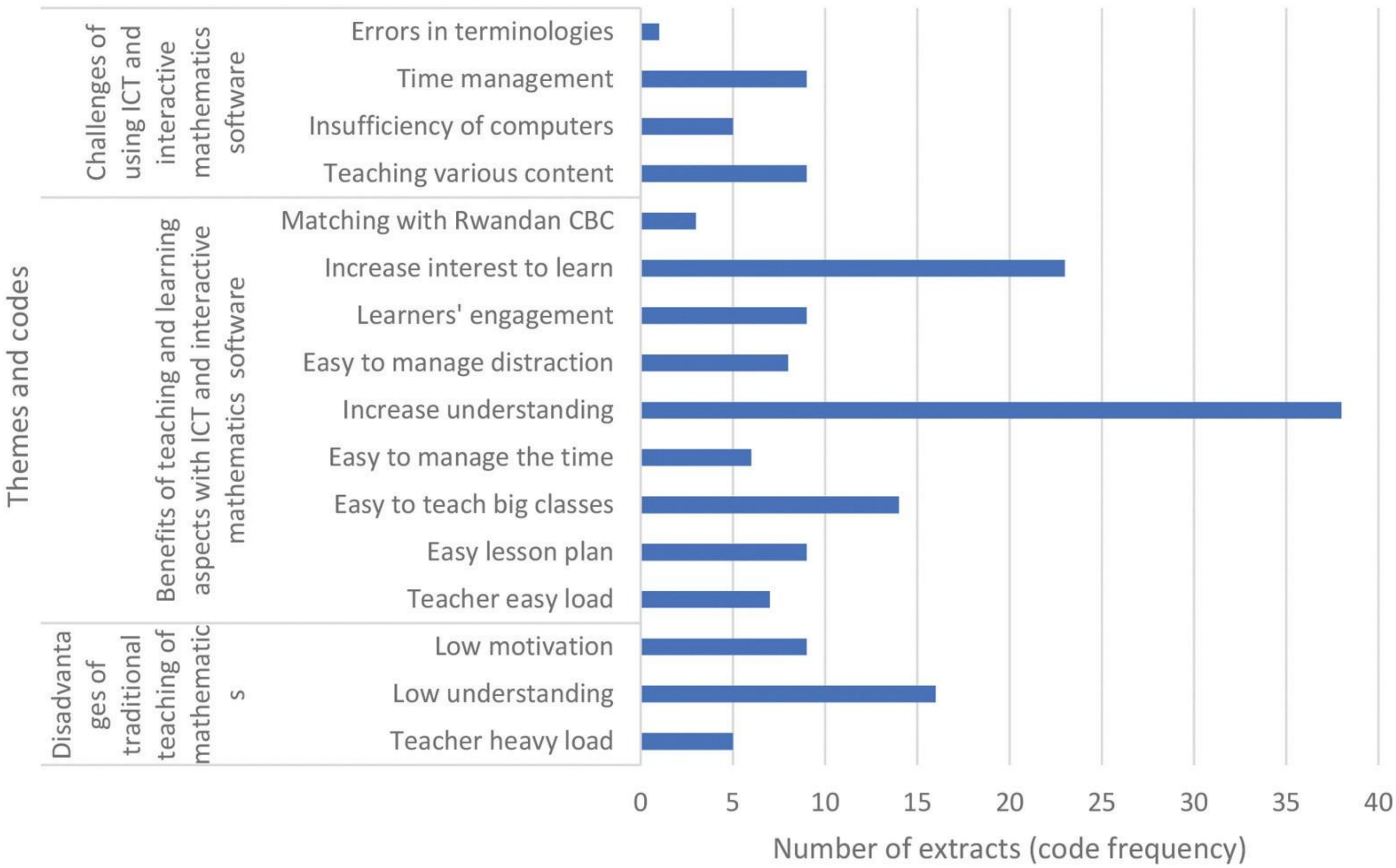
Major findings

Figure 2 below visualizes the cumulated codes from teachers about their perceptions of the challenges of traditional teaching methods and the benefits and challenges of using IM software in teaching and learning mathematics.

It was realized that many teachers' views about traditional teaching methods were that the latter bring about learners' low understanding of concepts, while other few mentioned learners' low motivation and teachers' heavy workload. On the benefits of teaching and learning aspects with ICT and mathematics software, teachers who participated in the interview mentioned that teachers' load, lesson planning, and learners' distraction management, as well as teaching big classes, get easier. In addition, learners' understanding, engagement, and learning interest likely increase. Considering all coded data, increased understanding, interest to learn, and easy teaching in the big class was respectively the most mentioned by teachers.

Among the disadvantages faced during IM-supported teaching, time management and teaching various content were the most mentioned as disadvantages. Therefore, from the findings, teachers believe that IM-supported teaching is highly beneficial to teaching and learning aspects and can remediate the challenges faced in traditional teaching methods, like learners' low understanding, despite some persisting challenges like an adaptation of IM content to management and teaching various mathematics content using IM software. Therefore, from the findings above, teaching using traditional methods is disadvantageous to learners' easy understanding. At the same time, the benefits of IM-supported teaching include easy understanding, increased learning interest, and easy teaching of big classes.

Figure 2. Cumulated codes from teachers



Discussion of findings

In this study, the researchers focused on investigating the teachers' perception of the potential of IM to support quality education in basic mathematics within primary schools in Rwanda. During data analysis, the theme describing the benefits of teaching and learning aspects with ICT and interactive mathematics software and the theme about the challenges of using ICT and interactive mathematics software dominated the discussion of the study findings. The findings are discussed thematically as follows:

Research objective #1 disadvantages of the traditional teaching of mathematics According to teachers, the traditional mode of teaching mathematics using chalk and talk is likely disadvantageous to achieving quality education. Many factors have been mentioned, like teachers' load, lack of adequate teaching aids, and lower or upper levels of basic education teachers' load in the primary is likely heavy, resulting in teachers' difficulties catering to the individual learner. According to one teacher, "*The teacher is at the same time busy to write on the blackboard and to engage individual learners in activities" (Teacher 1)*. This seems to be mostly realized in public schools, where the ratio of learners per teacher is higher than in private schools. Therefore, the teacher's time to cater to individual learners' needs is very reduced, and learners' opportunity to understand with the teacher's help is limited. In one interview, a teacher explained: *"You can understand that we teach using chalk and blackboard, but it is difficult for learners to understand because the teacher must help individual learners, which is also difficult given a large number of learners in class and means to motivate learners are not there" (Teacher 1).*

According to teachers, conceptual development in mathematics necessitates the use of teaching aids to concretize concepts. "*Manipulative helps learners to develop an understanding*" *(Teacher 6)*. Teachers explained the importance of teaching aids by using examples: *" ... if it is the teaching of fractions or shares is taught in the abstract, learners will not understand easily as there is nothing that shows how big the share is, they cannot understand it; it is necessary to use a concrete object like an avocado" (Teacher 3)*. However, the availability of teaching aids together with their adequacy seems to be the main challenge to the traditional teaching method. One teacher explained this as follows: "*Finding teaching aids are very difficult. Sometimes teaching aids are either not available or not sufficient, which affects concretization and conceptual understanding" (Teacher 1)*. When asked how they teach without teaching aids, a teacher said that "in such a case, *we try to use what we see around us, the environment in which we are, we also use drawings*" *(Teacher 3)*. Using locally available materials or improvisation seems to be one way to address the lack of teaching aids.

Although teaching mathematics in lower primary and upper primary schools need to be concretized to develop conceptual understanding. However, this is likely easier for experienced teachers but not new teachers regarding methodological use and accuracy. The use of drawings instead of physical objects may not be effective, especially in lower primary. On the availability of teaching aids, teachers explained comparatively that "*In lower primary, there is no problem of finding teaching aids (or improvisation), but when it comes to upper primary, there is a problem of lack of geometrical materials for the children; they do not bring tools for geometry and learn without engaging in practical work due to lack of learning aids" (Teacher 4)*. From their explanations, learners from low-income families or non-educated ones face the problem of bringing geometrical materials (mathematical set) because of socio-economic factors and some parents' mindsets that do not value education. "*Those children learn with difficulties because of lack of concretization and understanding*" *(Teacher 6).*

Research objective #2 benefits of teaching and learning aspects with ICT andinteractive mathematics software

Teachers were asked to explain their experience in teaching mathematics with ICT tools. They allsaid that they used the REB e-learning platform to simply download scripted lessons from the REBe-learning platform or sometimes to engage learners in a short observation of the concepts from e-learning platform lessons and continue with the traditional teaching and learning. Many teachers did not know interactive Mathematics software (IM) before it was introduced to them for the first time during the pilot study. Teachers' knowledge about ICT use in teaching and learningwas limited to the REB e-learning platform (Moodle), where they rarely download scripted lessonsto teach traditionally. Some of them are used to engage learners in observation of some concepts and processes on the platform but in a way that cannot be considered real teaching. Teachers were asked about the experience lived while using the IM in teaching and learning. Their answerswere grouped into benefits of IM on the teacher's side to the learners' side, the challenges faced, and recommendations about improving IM's potential for quality education.

Increase understanding

IM-supported teaching has been perceived as beneficial to quality teaching and learning by teachers because it likely manifested the potential to increase understanding and interest to learn, to ease teachers' load, to ease lesson planning, to facilitate time management and distraction, etc. While traditional teaching likely causes learners low understanding, teachers' perceptions about the benefits of IM-supported teaching include increasing understanding which has been coded 38 times from 7 interviews. From teachers' views, this may result from the IM software content and lesson presentation, which use "*different colors, arrows, and other types of demonstrations (dragging for changing the positions or the numbers involving corresponding distances), which facilitates the easy understanding of the distance between integers and the potential of IM to facilitated learners work on many exercises and get direct feedback*" *(Teacher 2).* Another teacher mentioned that "*the software is very helpful to learners as it has a very large number of exercisesthat they work on using their notebook and check the answers from the software. So, it speeds upthe availability of the exercise without the teacher writing on the backboard, which sometimes is dirty and requires to be cleaned before writing. Therefore it saves time and provides learners many exercises and quick feedback" (Teacher 1).*

A colorful presentation of IM content and movements of the process attract learners' attention and concentration to learning, improving learners' engagement. According to teacher 1, "*IM mayfacilitate* *the engagement and the focus of many learners more than the teacher can do in a traditional class*." This facilitates the teacher's task to engage learners and the struggle to make the lesson understandable as one teacher mentioned in the following terms: "*the way learners understand it is very easy without asking the teacher too much because they are seeing everything from the beginning of the lesson*" *(Teacher 3)*. These findings seem to confirm the result of a study conducted on the impact of multimedia on students' perception of the learning environment in mathematics class by Chipangura and Aldridge (2017), which revealed that the learning environ- ment in mathematics classes involved multimedia influenced student engagement. Therefore, the study recommended students' frequent exposure to multimedia in teaching and learning activities to promote positive learning environments and improve student engagement in mathematics. This should be planned and facilitated by the teacher during the teaching and learning activities for the safety of multimedia tools and the learners' maximum learning benefits.

By considering all eight codes about the first theme of our discussion, teachers declared that the use of ICT and IM software is beneficial to teaching and learning aspects in many aspects but mostly in increasing learners' understanding. It was similarly argued before that, new interactive teaching and learning style through Interactive White Board was a key to enhancing students' performance and skills development Beauchamp (2004). The newer technologies under develop- ment likely reduced the concern of teachers' chalk-and-talk approach and instead encouraged more teacher-learner interactivity through a learner-centered teaching approach (Alach, 2010; Ndihokubwayo, & Habiyaremye, 2018). Furthermore, Das (2019) and Radović et al. (2020) foundthat integrating ICT tools such as interactive mathematics (IM) software in primary schools is vital. They argue that ICT contribute to enhancing students' performance in mathematics and that it holds the potential to enhance student's skills development during their interaction with techno- logical tools. Thus, technology has the affordance to support the teaching and learning of mathematics even when applied in Rwandan primary schools.

According to some teachers, the teaching of integers is effectively achieved in IM-supported classes better than in traditional classes. "*I would give an example for integers; there are negative and positive numbers, and the child cannot easily understand why the number is either negative or positive. In traditional teaching mode, the teacher hardly manages to bring them to the under- standing that if you are below zero, the number should be negative, and if you are above zero, the number should be positive. Normally, understanding the concept of integers draws basically on understanding this mechanism. If you understand this mechanism immediately, it does not take anything else. Learning with IM and how it demonstrates the number line of integers facilitate learners to grasp this mechanism immediately because of the graphs, colors, movement, and dragging as well as sounds accompanying each process. Learners immediately know the location of the negative number and the positive number. You can ask them to compare them. They under- stand that the part below zero, although it is a number that appears to be large, is not large. For example, when asked to compare −5 and +2, they easily understand that +2 is bigger than −5 because of their location to concerning zero, which they know as a reference point*" *(Teacher 3).* Another teacher clarified how she experienced learners understanding of integers by using IM software as follows: "*learners who learned integers using IM (experimental) understood more than those who learned in traditional methods (control), either before experimentation, during, and after experimentation*" *(Teacher 7).*

In addition to integers, teachers explain that the teaching of place value is easily achieved thanks to the movements of mathematics objects in IM content: "*The software helped to teach the place values like ones, tens, and hundreds very easily. That is to say that when the child masters the learning of place value with a concrete object, he/she understands what the mechanism is and what is remaining is to show him or* *her how to demonstrate place values using a diagram. So, I found that the software can fit into the semi-concrete stage of teaching place values. It is easy to do it with the software because the drawings are automatically created by the software. And it helps to learn the place values of large numbers, which are difficult to do in traditional methods to manipulate concrete objects and semi-concrete objects of large numbers. The child cannot do it, but the software can help easily visualize large numbers' place values using diagrams. It was easy with the software to visibly organize the objects (in ones, tens, hundreds, etc.), which cannot be easy for the teacher to draw on the blackboard" (Teacher 4).*

Teaching with IM makes mathematics concepts more concrete. However, teachers claim that the use of IM could be effective if it follows the traditional mode of teaching to demonstrate the concepts using physical material. They explain that the IM software should traditionally reinforce what has been taught to boost learners' interest and motivation. One teacher explained it as follows: "*For example, the teacher may just show learners stones or bananas, learners manipulate them and use them in the activity (concrete stage), and then the teacher moves to use the software to show images of stones and bananas on the software, and the learner does with the software the same activities are done manually. Or the teacher may take 10 minutes to divide ten bananas among five learners; he/she shows them bananas (real ones) and divide them among five learners, then after that practical demonstration, the software comes in to show mathematical processes involved in dividing ten by 5"(Teacher 5).*

Increase interest in learning

Another benefit of IM-supported teaching, which teachers highly mentioned, is "Increase Interest in Learning," coded 23 times from 7 interviews. This was the second highly mentioned interest in IM-supported teaching after "Increase Understanding." Teachers explained it in the following terms: "*Teaching with IM is enjoyable for both the teacher and learners*" *(Teacher 3). For* another teacher, "*IM-supported teaching was interesting for learners who normally get easily bored learning mathematics because the software has graphs, images, sounds, and interactive content, which keep learners interested and engaged in learning it. Mathematics presentation in game-like settings attracts learners' attention and interest in learning*" *(Teacher 2)*. Therefore, these findings are likely in line with other findings of a study conducted in primary schools to explore learners' perceptions and experiences of self–regulated science learning in multimedia-supported e-learning environments (So et al., 2019). It was found that Multimedia-supported e-learning likely offers learners an enjoyable independent learning experience. Although its effectiveness in supporting self-regulated learning in science was inconclusive, the study suggested more opportunities for students' expo- sure to e-learning resources to ensure more effective self-regulated learning (So et al., 2019).

Teacher easy load

Some teachers' answers to the benefits of teaching mathematics using IM used to come back frequently to the teacher's easy load. One of them explained it in the following terms: "*IM is very beneficial to the teacher as it lightens the teacher's heavy load of teaching by writing on the blackboard and using books in teaching. For IM use, the teacher only has to know how to use the computer and the software because everything is prepared. It eases the teacher's job a lot. I found it very well developed as lessons are well organized and ordered from simple to complex. The lessons are well organized. It lessens teachers' heavy load of teaching while writing on the Blackboard (BB) and consulting books*" *(Teacher 1).*

Easy lesson plan

When teachers were asked how they perceived IM lessons and how they could help them make lesson plans, they all said that IM lesson presentations could facilitate teachers' planning of lessons. One claimed that "*IM content is well presented because lessons are ordered from simple to complex. Lessons are not mixed in disorder; they are well prepared and organized" (Teacher 1)*. It is known that a well-planned lesson is successfully taught because we teach the way we have planned. Therefore, a lesson planned with IM as an instructional tool is likely to be well taught and can potentially improve learners' understanding and performance according to teachers' lived experiences. This may result in other positive aspects of the classroom environment, like management of learners' behavior, and management of time, as learners' attention is fully directed to a well-planned and taught lesson. This can be realized from different teachers' speeches. "*IM-supported teaching helps in classroom management as every learner is busy. IM software cannot be a source of distraction to learners because learners have many activities to work on with the computer. And because of the audio characteristics of the IM, learners cannot be distracted as all their attention is on IM content. I found that IM can help to improve the performance of both girls and boys because it reduces their distractions" (Teacher 1).* Another teacher added that the IM supported teaching reduces learners' boredom com- pared to traditional one: "*because the content is presented with graphs and images, which allows learners to keep focusing on the lesson (concentrated and focused) when they are learning, which is different from learning traditionally because they easily get tired of learning" (Teacher 2).* Another benefit of IM supported teaching raised by the teacher is to ease the teaching in big classes. One teacher explained that "*it can help to manage the class by reducing learners' absent-mindedness and by attracting their attention to IM content. It helps in class- room management" (Teacher 1).*

The use of ICT through IM is expected to ease teachers' workload and increase students' interest in learning. For instance, the teachers who participated in the interview mentioned that teachers' load, lesson planning, and learners' distraction management, as well as teaching big classes, get easier. Our findings concur with Sharndama's (2013) findings that ICT tools such as multimedia devices and internet technologies facilitate teachers in teaching large classes. Similarly, the use of ICT facilitates teachers in classroom and time management, since through the use of ICT, students are self-regulated, they are aware of teaching and learning activities, and they know when to do the given activities as they also respect the submission deadline of the given activities (Yamada et al., 2016). Introducing IM in mathematics instruction increased students, understanding, and interest in learning. This learning approach is opposite to the traditional teaching approach, whereby teachers cannot take time to interact with students by discussing the results of mathe-matics concepts. Within this context, students had to memorize formulas without understanding the concepts (Ishartono et al., 2019). It is why Lithner (2012) informed that teaching students to recall formulas in mathematics does not provide them with opportunities to develop their problem-solving skills, reasoning ability, and conceptual understanding. However, through IM spread- sheets, students can easily make graphs, do calculations and solve some mathematical problems (Das, 2019). Thus, IM is suitable for elementary kids since it is adapted to their age and enhances their creativity, active learning, and independent learning (Jalinus, & Alim, 2019; Nyirahabimana etal., 2022).

Research objective #3 challenges of using ICT and mathematics software

Although IM-supported teaching manifested different benefits, some shortcomings were realized during experimentation. These challenges include insufficiency of the training period, insufficient computers for learners, limitation of IM-developed content, and errors in terminologies.

Training period

Before the experimentation period, all mathematics teachers were trained for two days to use the IM in teaching and learning. This was decided like that because the experimentation should be conducted during school activities. Therefore, teachers were free for training at weekends. In addition, the training should be directly followed by the teaching to avoid teachers' failure to recall the mechanism of teaching using IM. During that training period, teachers were trained in basic computer skills associated with manipulating the IM, developing a lesson plan integrating IM content and instruction, and conducting micro-teaching sessions as trials before the actual teaching with IM. However, teachers found this period insufficient to master the use of IM during teaching. They explained it as follows: "*the two days we were trained were not enough. It should have been increased to allow us to get more* *familiar with the IM by navigating through other units/ contents*" *(Teacher 1)*. This influenced their mastery of the teaching methodology using IM, and some learners manifested less engagement in learning, especially in lower primary. According to one teacher, "*learners are assisting or watching what has been developed before without their involvement, which leads them to learn passively without their engagement. There was no participa- tion in the workings; they simply clicked and saw the answer without engaging in the process of discovering it (Teacher 4)*. "*Many learners were not following (lower level) because these small children need the teacher's constant attention; they always need the teacher to be nearer to be engaged in class activities. IM is suitable for upper primary; there is no problem but not for small children*" *(Teacher 6).*

From some teachers' points of view, using IM in lower primary may lead to learners' failure to develop writing skills, while this is among the general objectives of lower primary. One of them said that " … *their writing abilities did not improve; there was a tendency to leave behind learners writing abilities because they don't write while learning with IM. The side of skills development in mathematics seems to be left behind; their fingers (dexterity) were not trained to write while they were in lower primary. You know that even teaching how to write a letter takes time and requires different steps" (Teacher 4).*

However, other teachers (like teacher 5 below) manifested opposite views about the training period and evidenced their understanding of the methodological consideration while using IM. "*The software explains very clearly, where it comes from, and the teacher also starts with developing the lesson traditionally and shows the learners where things are coming from and how to work on it for the learner to fix them. But if the teacher uses the software only without mixing it with the traditional teaching way, learners may take it as a game then fail to develop the understanding, to take risks in their learning, to think, reason, etc*." *(Teacher 5).*

Teaching various contents

Another challenge raised by teachers is the content developed in IM, which did not cover all lower and upper primary topics to allow teachers to experience IM-supported teaching in various con- tents. For example, in upper primary, the IM content developed so far was only about integers in primary-4 and primary-5. Their perceptions were formulated as follows: "*the first challenge that I noticed was to teach only one chapter with IM. I was wondering how the teaching of other chapters using IM would look like*" *(Teacher 1)*. For another teacher, "*the software has many gaps, and there are many missing features. For example, the software does not allow learners to rework a failed exercise because it directly brings a new one to replace a failed one. It should also include word problems and show how to work on them" (Teacher 4).*

Besides, some topics used terminologies that were found to be different from the ones under use, whereby in the teaching of comparison in primary 2, the traditional textbooks use comparison terms like "greater … than and less than" (Teacher 2) while the software used "bigger … .than and less … than" (Teacher 2). Teachers perceived this as confusing learners and wished for harmoniza- tion of the content stipulated by the curriculum and the IM content. They also found it better if the IM-supported teaching was conducted while all learners had their computers. One teacher said: "I taught in two classes; in one class, every child had his computer (P4), and in another whereby I was the only one having a computer. So when all learners have computers (without sharing), learning becomes very easy" (Teacher 1).

The present study findings mentioned the insufficiency of computers as one of the chal- lenges faced by the teacher when using IM software. Our findings are in line with Rajan and Manyala (2021)'s findings who reported challenges linked to ICT integration in teaching and learning, such as the lack of internet and electricity in remote areas, the high cost of ICT equipment and students' and teachers' insufficient (or lack of)skills to use ICT tools. Within this context, Naidoo (2020) suggested that teachers and students should be provided with sufficient resources that are easy to use and cost-effective. In addition, there is a need to improve the way IM is constructed since teachers reported that IM software contains errors in terminologies used in IM content which are different from the ones normally used. Furthermore, there is a need to build IM on a wide range of content since teachers reported that IM software content was developed on a few mathematics contents, which restricted the teaching to some mathematics content. Thus, the provided challenges about how they teach mathematics through the use of IM are expected to change the pedagogy in use and take adequate educational policies to improve the teaching and learning of basic mathematics (Zakaria, & Daud, 2013).

Conclusion

The recent educational aspirations to integrate ICT in teaching and learning activities stressed the importance of teachers' awareness of the potential of ICT to promote quality education and their experience and perception of using ICT in their daily activities. The present study aimed to explore primary teachers' lived experiences and how they perceived using Interactive Mathematics (IM) software in mathematics classroom activities. The result of this study revealed that teachers perceived difficulties in teaching mathematics tradition- ally using chalk and talk, which likely led to learners' low understanding of mathematics concepts. However, the use of IM in teaching and learning appeared to be beneficial to quality teaching and learning in terms of increasing learners' understanding and interest to learn as well as easing teachers' load and lesson planning. Some shortcomings were realized because the IM software was newly used in a classroom situation. These included short training periods for teachers and IM content limitations. This did not likely allow teachers to extensively explore IM's potential to support quality teaching and learning. Therefore, the study formulated some recommendations for improving the IM software and its effective use in teaching and learning.

Recommendations and suggestions

From the findings, all teachers appreciated the potential of IM to promote quality education. Therefore, Rwanda Basic Education Board should integrate IM software into the curriculum as an instructional tool to teach primary mathematics and extend the software to other subjects. This implies equipping all schools with ICT facilities and training teachers with basic ICT skills, especially those from remote areas who are far behind in general awareness and use of computers and ICT tools. As it was realized that the software was not completely developed for all contents embodied in the curriculum of mathematics, REB should speed up the complete development of IM, incorporating missing contents and correct terminologies used in IM in the light of those recommended by the CBC. For example, from teachers' perception, the teaching of comparison should use "greater than" but not "bigger than" as it is in the IM software. Therefore, an extensive diagnosis followed by adjustments of IMcontent errors of terminologies and others not mentioned in the interview should be initiated and conducted by REB in collaboration with SAKURASHA. Co. Ltd. to develop the final product of IM to be used by Rwandan schools. In addition, from teachers' perceptions and the researchers' understanding, the IM development team should involve mathematics teachers to provide the guidelines so that those preparing a certain program can prepare the way it will be delivered using this technology.

Acknowledgements

We would like to express our appreciation to Japan International Cooperation Agency (JICA) through the Sakura-Sha Project, to teachers and schools that partici-pated in this study.

Funding

The University of Rwanda- SIDA Programme and the African Centre of Excellence in Innovative Teaching and Learning Mathematics and Sciences (ACEITLMS) hosted at the Univerity of Rwanda-College of Education funded this research.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Additional information

Additional information is available for this paper

Citation information

Cite this article as: Perceptions of using interactive mathematics software among Rwandan primary school teachers, Innocente Uwineza, Alphonse Uworwabayeho, & Kenya Yokohama, *Cogent Education* (2023), 10: 2170113.

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Chapter V. Discussion and recommendations

5.1. Introduction

This study's findings that addressed the three research questions were presented as published articles under chapters 2, 3, and 4. The present chapter starts by presenting the overall findings as per the study's theoretical underpinnings and the related literature explored. Next, based on these findings, the study concludes by providing a summary of findings, limitations, and contributions. It also examines the significance of investigating teachers' perceptions alongside learning outcomes within the IM environment. The chapter concludes with recommendations for practical applications in the field and suggestions for future research topics.

5.2. Discussions

5.2.1. Effects of IM-supported teaching on learning outcomes in primary school mathematics

This study aimed at analyzing the learning outcomes of IM-supported teaching in primary schools in Rwanda and how teachers perceived IM-supported teaching. Analysis of performance in terms of learners' performance and conceptual understanding development was observed at the research groups' level (control and experimental); school status level (public and private); and at primary educational levels (lower and upper primary). Moreover, experimental groups' teachers expressed their perceptions regardless of their school status or educational level, although some of their contributions may indirectly inform the level at which they teach.

Based on learning gains and effect size, the study showed that IM-supported classes performed better than ordinary classes overall. Descriptively, P5 control and experimental group learners' knowledge was equivalent before experimentation ($p > .05$, $f = -19$). However, a significant difference between control and experimental group learners' performance was realized after intervention ($p < .01$, $f = -.38$) in favor of the experimental group (paper #1). Moreover, as explained in paper #2, IM descriptively improved P3 learners' performance based on highly significant differences realized, effect size, and learning gains ($p < .001$, $f = 1.07$, $g = 1.57$), although learners' knowledge was found to be equivalent prior to experimentation ($p > .05$, $df = 136$, mean pre-test [only] = 38.558, mean pre-test [both] = 31.354). The distribution of post-test scores revealed that IM helped students close performance gaps, with the exception of primary

#2, where a higher standard deviation (mean = 50.46; STD = 26.067) accompanied the improvement in post-test mean score (paper #3). Additionally, IM's beneficial effects on performance were demonstrated by statistically significant changes ($p <.05$) between pre- and post-tests for all classes combined, favoring the experimental group. As demonstrated by Table #2 of Appendix #1, the control groups' means were 28.02% and 43.22%, respectively, in the pre-test and post-test, while the experimental group means were 24.53% and 47.89%. It therefore appears that the experimental groups' post-test performance was better than the control group's based on pre-test mean differences (3.495, standard error difference = 1.724) and post-test mean differences (-4.664, standard error difference = 2.259) (Appendix #1, Table #3).

These findings support Uwurukundo et al.'s (2022) study, which discovered that students who used GeoGebra in their learning manifested greater success than students who did not use GeoGebra. Accordingly, students who learn by observation and manipulation might comprehend concepts that they previously thought were abstract when blackboards and chalk were the only teaching tools accessible. Thus, based on the CTML, IM software allowed learners to learn by observing semi-concrete mathematics objects that were attractively presented in various forms and colors with different movements accompanied by sounds. This allowed learners to be motivated to learn and to easily grasp different basic mechanisms associated with new concepts before engaging in an abstract level of quick exercises and evaluation.

The teachers' technology-supported teaching competencies to effectively teach using IM were also explored in support of the TPACK framework. Although some control group teachers manifested a high level of PCK in teaching mathematics, IM-supported teaching demonstrated the role of TPACK in fostering students' activity, engagement, and understanding in technology-enhanced teaching (Lange et al., 2012; Keller et al., 2017). Nonetheless, IM operationalization complexity disturbed learners' attention and understanding to some extents, underscoring the necessity of extensive teacher training and assistance in developing technology-supported teaching competencies (Schubatzky et al., 2023).

Based on data analyzed at the school type level and at the class level, private schools' learners' performance was better than public schools' (paper #1). These results align with Khun-Inkeere's (2016) study, which found that public schools are generally outperformed by private schools because of their differences in student-teacher ratio, class population, and availability of resources. Nonetheless, IM manifested the potential to close pedagogical gaps between public and private schools by mitigating public schools' overpopulated classrooms and resource scarcity (Ministry of Education, 2018a; Nizeyimana et al., 2021).

On the analysis of conceptual understanding at the school status level, the results indicated that private school students demonstrated the highest conceptual understanding in both tests, although public schools showed better understanding on certain items both before and after the intervention (refer to paper #3). These results converge with previous studies findings that pointed out that private schools' students achieve better than public schools' ones (Nwafor, 2013; Shabbir et al., 2014; Wolf, 2014). Considering that some public schools' students' conceptual understanding development was better than private school ones on some items, the role of teachers' PCK, regardless of school status, is of paramount importance in fostering quality learning outcomes (Lange et al., 2012). These findings align with Cobbold's (2015) argument stipulating that factors differentiating the two types of schools should be taken into consideration while comparing the quality of education in public and private schools. Therefore, factors including the number of students per classroom and per teacher, student socioeconomic background, school management practices, and resource availabilities should be considered while comparing learning outcomes in the two types of schools.

In conclusion, the findings pinpoint IM potential to raise the standards of mathematics learning outcomes and enhance the conceptual understanding of primary school learners in public and private schools in Rwanda. Thus, further studies should tackle IM implementation issues and expand on other educational contexts in primary schools in Rwanda.

5.2.2. Differences in IM-supported teaching effects on learning outcomes between lower and upper primary levels

The analysis of learning outcomes at lower and upper primary school cycles, all classes combined revealed that IM-supported teaching improved outcomes for both lower and upper primary schools similarly (Appendix #3, Table#6 and Table #7). The mean pre-test scores for students attending public and private schools were 42.50% and 44.58%, respectively, at the school level. In the analysis of IM-supported learning outcomes at lower and upper primary levels, based on P2 and P4 data and cumulated data at cycle level, it was found that IM improved lower and upper primary levels' learning outcomes similarly. Their corresponding post-test mean scores rose to 49.00% for public schools and 54.58% for private schools in P2 after the intervention. In P4, the pre-test mean scores also increased, for the experimental group from 14.08% to 60.00% and for the control group from 19.31% to 57.94% (paper #3, tables #2 and #5). When all classes are taken into account, the descriptive results show a significant improvement in the post-test performance of upper primary students, with mean scores rising from 35.84% in the pre-test to 43.85% in the post-test and from 8.01% in the pre-test to 18.94% in the post-test for lower primary students (Appendix #3). Moreover, p-values less than 0.05 were found in favor of upper primary pupils in both the pre- and post-test findings of the repeated measures ANOVA evaluating the influence of the intervention, with a strong effect size of $\eta^2 = 0.269$ in the post-test. The fact that upper primary students achieved better than lower primary students confirms the findings suggesting that students' educational levels adapt to particular educational technologies (Jalinus, & Alim, 2019). Moreover, the findings align with arguments stipulating that contemporary multimedia approaches to learning suit various levels of education and with varying degrees of involvement (Milovanovic et al., 2016). Therefore, considering these findings, the development of educational technologies for teaching at the primary school level should draw from learners' needs to acquire the desired quality.

5.2.3. Teachers' perceptions of IM use in mathematics-related instructional activities

From qualitative data analysis, it was found that all teachers (100%) perceived issues in teaching mathematics using chalk and talk. The challenges mentioned consisted of teacher heavy load (coded 5 times and mentioned by 42.8%), students' poor understanding (coded 16 times and mentioned by 72% of respondents), and reduced motivation (coded 9 times and mentioned by 100% of respondent teachers) (refer to paper #4). This underscores that chalk-and-talk teaching is perpetuating a pedagogy that leads to poor learning (Sharndama, 2013). However, teachers expressed their gratitude with IM-supported instructions, underscoring, among others, its role in promoting students' interest in learning (coded 23 times), students' engagement (coded 9 times), conceptual understanding development (coded 38 times), and lessening the teaching of big classes (coded 14 times). Moreover, teachers expressed their concern with IM use in teaching. Accordingly, IM content limits the teaching of various contents (coded 9 times). They found that the IM training period was too short to master it (coded nine times). In addition, one teacher discovered that IM content presents errors in terminologies (coded 1 time). These findings align with arguments stipulating that technology-enhanced environments promote student engagement and understanding (Chipangura & Aldridge, 2017). Therefore, students' regular exposure to multimedia learning environments may improve their participation and mathematical conceptual understanding development.

Teachers highlighted IM's ability to reduce their workload, simplify lesson planning, and manage large classes, echoing findings from Sharndama (2013) regarding the facilitative role of ICT tools, such as multimedia devices and internet technologies, in supporting effective teaching in large classrooms. The findings align with arguments stating that technology-supported teaching can improve classroom management even in difficult teaching conditions by promoting students' self-regulation and meeting the task completion deadline (Yamada et al., 2016).

Teachers' responses align with the ICT educational benefits advanced by Ndihokubwayo and Habiyaremye (2018), Das (2019), and Radovi et al. (2020), as IM-supported teaching was perceived as a tool promoting quality classroom practices in primary schools in Rwanda. The Technology Acceptance Model (TAM) framework supported our findings, illustrating how teachers' perceptions of IM influence their usage patterns during instructional periods. This aligns with Momani's (2020) assertion that user satisfaction with technology impacts its perceived quality and effectiveness in achieving educational goals. Thus, it underscores the role of teachers' views of IM usability and IM potentials to boost quality learning achievement.

5.2.4. Importance of teachers' perception about IM-supported teaching on learning outcomes

At the heart of the current education sector strategic plan in Rwanda, enhancing the quality of learning outcomes is a key priority in achieving quality education through the implementation of the CBC (Ministry of Education, 2018a). Thus, it is crucial to comprehend the connections between the roles of the teachers, the students, and technology (like IM) as the instructional tools in effective implementation of the CBC and question why it has been necessary to consider all of them in this study. These interactions were explored throughout this study's research processes and expressed by teachers during interviews. Furthermore, their attitudes towards IM were observed from their communication (verbal and non-verbal) with the researcher, together with their flexibility in using IM in their teaching practices. From the researcher's observations, teachers' attitudes toward IM influenced their free consent to adhere to the control or experimental group and to teach using IM.

Throughout the experimental phase, teachers' varying levels of IM proficiency directly impacted student engagement and motivation, thereby influencing learning outcomes. Therefore, the differential effects of IM-enhanced teaching on learning outcomes observed within individual classrooms (see papers #1, #2, and #3) and between experimental and control groups (refer to Tables #2 and Appendix #1) likely stem from teachers' interpretations of technology-enhanced teaching and their grasp of IM, developed during training and applied throughout the teaching period.

The improvement of IM-supported teaching and learning outcomes aligns with educators' perceptions of IM's ability to increase the quality of mathematics instruction, as indicated by the 38 times that educators stated this opinion. In addition, 42.8% of teachers indicated how much they liked how IM increased student involvement, and 85.7% of teachers mentioned how much it increased learners' interests. As to the statement made by Teacher #1 in a public school, "IM content, colorful presentations, and interactive demonstrations facilitate learners' easy understanding of the concept of distance between integers and allow learners to engage with active participation and receive direct feedback." Another teacher expressed her perceptions in the following terms: "teaching with IM promotes time management, allows a learner to engage with various exercises, and offers learners' self-evaluation opportunities thanks to IM quick feedback options" (Teacher #2, private school). IM positive effects on student performance resonate with studies that found a correlation between access to technology and the promotion of learner-centered pedagogies (De Witte & Rogge, 2014).

In addition, teachers' interview feedback indicates their opinions about IM's suitability for different primary school cycles. However, lower primary school teachers (P2 and P3) were skeptics about IM relevancy and manifested a preference for concrete manipulation over IM at the lower primary level. One teacher explained, "IM may be more suitable for upper primary than lower primary because younger children need hands-on learning with concrete materials, which IM does not provide. Upper primary students have already mastered basic skills from earlier grades" (Teacher #6, public school). Another teacher, expressing satisfaction with traditional methods for younger children, commented, "Young children find mathematics enjoyable and easy. But as they advance to higher grades, mathematics becomes more challenging, and their performance declines, which can affect their attitude towards the subject"

(Teacher #4, private school). Teachers' opinions about IM-supported teaching, stipulating that this software is better suited for upper primary teaching levels, resonate with quantitatively cumulated data results. The analysis of post-test results for all class levels considered indicates that IM manifested a substantial impact on upper primary level learning outcomes compared to lower primary (<0xC8> = 0.269).

The achievement of targeted, quality mathematics education faces issues related to the abstract nature of mathematics. This study's findings illustrate that IM integration in primary school mathematics teaching facilitated the very first introduction of challenging topics like integers to students by easing the demonstration visualization of abstract concepts, which is otherwise difficult to achieve with traditional teaching methods. One of them explained that "in traditional teaching, we are challenged to make different drawings to visualize because it is time-consuming to clean and draw many number lines and it makes it difficult to manage the blackboard, but the software can show various drawings like number lines with different data in an effective way and in a short time" (P4 teacher, private school).

From qualitative data analysis, it was mentioned that IM benefited the teaching activities by allowing teachers easy load (7 times from 57.1% of teachers), easy lesson planning (9 times from 71.4% of teachers), and easy teaching of big classes (14 times from 100% of teachers). In teachers' terms, it was mentioned that "in the traditional way of teaching integers, learners struggle to draw a number line to find out the distance between two integers. It causes many difficulties in understanding the distance between two integers for learners while using a drawn number line. However, the IM software teaches that lesson using different colors, arrows, and other types of demonstrations (dragging for changing the positions or the numbers involving corresponding distances), which facilitates the easy understanding of the distance between integers. Learners developed an understanding of that concept and managed to easily find the distance between two integers, which is not easy to achieve in traditional teaching methods" (Teacher #5, public school).

Furthermore, IM use likely changed learners' understanding of the nature of mathematics. According to teachers, "while teaching using chalk, we also draw number lines and different graphs to visualize numbers and facilitate concretization, but when the learner observes it on the computer, they get very interested and excited that mathematics also exists in computers (i.e., ICT allows learners to know that mathematics makes sense). They understand that they can learn mathematics not only from the teacher but also from the computer. Then they understand that mathematics exists in everyday life. They develop another understanding of mathematics" (P4 teacher, public school). This was evidenced by learning outcomes at the class level, whereby results from descriptive and inferential statistics in testing revealed that IM significantly improved learners' performance based on significance of difference, effect size, and learning gains (mean = 39.56, STD = 19.77 for the pre-test, mean = 64.83, STD = 18.46 for the post-test, with g =.41, p =.001, and f = 1.32 in P5). Moreover, the descriptive and inferential statistics in teaching intervention revealed an important distinction between the traditional and experimental learning outcomes (p.01, f =.38) in favor of the IM class (mean = 56.71, STD = 23.31 for the control class and mean = 64.83, STD = 18.46 for the IM class) (see paper #1).

Additionally, teachers expressed some IM-related shortcomings realized during experimentation. These challenges include the limitations of IM-developed content to teach various contents. It is also worth noting that teachers realized the mismatch between IM content terminologies and the CBC syllabus of primary mathematics. They claim that in the mathematics syllabus, teachers' guides, and students' books, the study of comparison uses the terminologies of greater than and less than. However, they realized that IM terminologies of comparison are bigger than and less than. Thus, IM content mismatches with the CBC may be a source of confusion in teaching and learning.

Briefly, test results and interview findings agree with research that supports the idea that one method of creating the conditions required for successful learning is through technological innovation (Delen & Bulut, 2011). The present findings demonstrate that IM-supported teaching is a suitable method to transform the classroom educational process as per the ESSP 2028-2024 priority target (Ministry of Education, 2018a). In accordance with Heng and Said's (2020) study, the findings confirm that technology-enhanced teaching, based on Mayer's CTML, positively impacts learners' learning and performance.

5.3. Conclusions

5.3.1. An overview of the results

The present study explores the outcomes of IM-supported teaching in primary schools in Rwanda. Guided by three research objectives, the study starts by analyzing the effects of IM-supported teaching on learning outcomes, with a focus on learners’ performance and conceptual understanding, considering all selected classes. From the results, the experimental class descriptively outperformed the control class across all classes combined, as indicated by significant differences, effect sizes, learning gains, and improved outcomes between the control and experimental groups. IM also manifested a weaker effect on improving performance in private schools than in public schools across all classes. Further, IM improved learners’ conceptual understanding, which was observable through learners’ performance and work at the class level.

For the second objective, comparing the influence of IM-supported teaching on learning outcomes between lower and upper primary, IM significantly improved both lower and upper primary learners’ post-test scores. However, more improvement in upper primary than lower primary, all classes combined, was realized with a strong effect. Therefore, this study revealed those IM-assisted learning likely improved learners’ conceptual understanding and performance. The fact that IM-supported teaching influenced students better at the upper primary level than at lower primary levels, with a strong effect, indicates that this software is likely effective in supporting quality learning outcomes at the upper primary school level.

On the third objective, which examined teachers' opinions of utilizing IM in instructional activities, the findings pointed out that teachers thought it proved challenging to teach mathematics using chalk-and-talk, which probably contributed to students' poor comprehension of mathematical ideas. However, it seemed that using IM in instruction enhanced learners’ engagement, understanding, and interest in learning, allowing teachers to easily manage learners’ distractions as well as easing teachers’ load and lesson planning. Additionally, teachers predicted that, upon formal recommendation to use IM as an instructional tool in all primary schools in Rwanda, that software will be a suitable pedagogical tool in the future that will effectively support the teaching of big classes prevalent in public schools in Rwanda.

The present investigation serves as a reference to assess and evaluate the academic merits of IM for CBC effective implementation across primary schools in Rwanda. It set out to examine the difference between public and private primary schools as well as between lower and upper primary educational levels. Drawing on findings, this study advocates that IM software has the potential to improve learners' outcomes for public and private schools' lower and upper primary cycles, with important effects at the public and upper primary levels. This observation was emphasized by teachers' testimonies about the IM gain in improving attention and comprehension, especially in crowded classes. Therefore, more IM-focused studies that can draw from the present study and incorporate other pedagogical dimensions are needed.

5.3.2. Limitation of the study

Various limitations in technical, research, and analysis aspects were encountered during the research processes. First, teachers' and learners' basic computer skills were poor or even nonexistent to fluently teach and learn in an IM-enhanced environment. According to Mugiraneza (2021), the majority of teachers in Rwanda lack adequate competence in using ICT technologies, which may have an impact on the standard of instruction. In addition, it was noted that there is a discrepancy between classroom practices and policies that support ICT use in education (Ministry of Education, 2018a). This was more experienced during the training and experimentation periods, when some teachers were assisted in performing some basic ICT skills. In addition to that, public school classes were overpopulated by learners compared to private school classes. Therefore, teachers who were themselves struggling to use IM in teaching faced difficulties assisting learners in using it, especially in public school classes. In addition to that, IM was newly introduced in classroom situations. Thus, teachers and learners experienced IM software for the first time. Therefore, the experimentation period was the same to learn IM features and their manipulation. It was then not easy for teachers and learners to use it fluently and smoothly. In addition, the IM content developed at the upper primary level was limited to the content of integers. Besides, some mathematics content about measurements and geometry was not reflected in IM for lower primary. Besides, teachers faced difficulties with the terminology mismatch between the content in the syllabus and the IM content. Although teachers were trained before the experimentation period, the training period was not enough to become accustomed to implementing technology-supported teaching methods by using IM fluently and using ICT as an instructional tool for the first time.

Secondly, the IM piloting project was limited to Kigali City due to different factors, including the availability of ICT infrastructures and their functionality. It would have been better if rural area schools participated in the pilot project. This should have brought additional information as these two environments present differences in learning philosophy and others, including computer literacy for teachers and learners. Although IM was developed to be used on learners' XO laptops, the type of experimentation considered was limited to the use of teachers' laptops and the projector. However, XO laptops were only distributed in public schools but not in private schools, and few of them were in good enough condition to allow IM use.

Thirdly, examining all aspects of educational procedures and identifying the function of IM in student participation in mathematics learning were beyond the scope of this study. Moreover, learning outcomes result from many factors or may be analyzed using other variables that could not all be controlled during this study. Besides, the quantitative side of this study is supposed to conduct statistical analysis and compare two tests between the experimental and control groups. However, 2019 project activities consisted of a pre-test for both groups and an experimental group post-test only. Therefore, the use of the one-group pre-test-post-test method and design for the 2019 data limited the comparison of both test results for the two research groups, which should have been different if the after-intervention test was given to the non-experimental group too.

5.3.3. Contributions

This study aimed to empirically analyze the learning outcomes of IM-supported teaching and explore teachers' perspectives on using IM in teaching. Based on the findings, it was observed that IM software could effectively serve as an instructional tool for mathematics in upper primary before its introduction to lower primary. This recommendation stems from the observation that upper primary teachers, who tend to be younger and more familiar with ICT skills, are more likely to adapt to 21st-century teaching standards compared to their lower primary counterparts, who are often older and less comfortable with ICT. This study's overall objective was to scientifically investigate the IM-supported teaching effect on primary school mathematics learning outcomes. The findings revealed IM potential to effectively support mathematics teaching in upper primary first and in lower primary later. This recommendation resonates with the researcher's observation indicating that upper primary teachers are mostly younger, vibrant, and more technologically literate than lower primary teachers, who are mostly older and educated some decades ago, when educational ICT knowledge was yet to be known. Furthermore, it contributed to finding IM content mismatches with mathematics syllabuses at the primary school level. It therefore formulated recommendations for IM content improvements.

Despite the limitations encountered, this study is among the few interventionist studies conducted in mathematics education in elementary schools in Rwanda. Consequently, it is an effort to tackle the issue of high-quality education from its very foundation. Furthermore, it contributed to enriching the literature about technology use in mathematics education, especially at the primary school level, while many studies in that domain are mostly found at the high school and higher education levels. The study resulted in four articles published in the International Journal of Educational Research, benefiting from constructive feedback from multiple reviewers. Furthermore, the dissemination of findings through these publications has raised awareness of IM software within the research community. Thus, drawing on this uncovering, further studies are encouraged to deepen knowledge about IM aspects of boosting quality mathematics teaching and learning.

Furthermore, teachers became aware of how computers and ICT in general can assist classroom activities instead of being used for administrative activities only. They practiced ICT-supported teaching, while learners also became aware of learning in a multimedia environment. As observed, some teachers and nearly all learners experienced, for the first time, the use of a computer and a projector in teaching. It also contributed to implementing the CBC with the support of ICT, as recommended by the ICT policy in the Rwandan education system. The study also emphasizes how challenging it is for public schools to deliver higher-quality instruction because of the high student-teacher ratio and lack of instructional resources. Private schools differ in formative assessment, teacher-student contact, and individualization since their students are more mobile and find it easier to sit and write.

5.3.4. Implications for teachers' CBC conceptualization

Drawing on my observation from the seminar when teachers were trained about IM through IM-supported teaching and interview periods, teachers are challenged by the conceptualization of CBC instruction, learner-centered methods, and ICT-supported teaching. Accordingly, many primary school teachers think that CBC does not have any business with the knowledge-based curriculum (KBC) that was under use before 2015. Apparently, they think that the CBC teaching principles consist of engaging learners in group activities with less focus on individual learners's learning. Besides, they think that competence-based effective instruction is that which engages learners in knowledge discoveries by themselves without the teacher's help. Thus, IM-supported teaching was highly influenced by teachers' poor concept of the CBC and resultant instruction. However, the KBC had been reviewed and improved into a CBC with strong emphasis on young people's acquisition of competence and vocational skills necessary for the sustainable development of the nation and for meeting international educational competition standards (Ministry of Education, 2015). Therefore, teachers should be made aware of the values of the KBC and how they should be catered for in the CBC implementation. Thus, re-thinking teacher training about the concept of CBC, learner-centered, and ICT-supported pedagogies and instruction should be emphasized in the education system of Rwanda if quality education achievement at an exceptional level is the ultimate national and regional goal (Ministry of Education, 2018a).

5.3.5. Implications for TPACK framed studies

Technology-infused curriculum and instruction must be designed, implemented, and evaluated using the TPACK framework (Abubakir & Alshaboul, 2023). The use of IM to support primary school mathematics teachers implies experimental group teachers' TPACK level. Thus, teacher training about IM before experimentation was about improving teachers' TPACK with respect to IM software. Besides, the IM-supported teaching was another chance for educators to enhance their context-based TPACK. However, during the training period, it was observed that teachers' effects towards ICT use in education started to manifest and affected their adhesion to experimental groups. In addition, their expressions during the interview revealed their differences in position towards IM software use, whereby some were excited while others' attitudes appeared to discourage IM use (like in lower primary), apparently because they felt confident to teach in the traditional method or due to their resistance to change. A number of studies highlighted the importance of participants' opinions in the success of the TPACK framework in educational research. For instance, a study discovered a weakly favorable association between the participants' opinions regarding computer-assisted instruction and their TPACK competencies (Baturay et al. 2017). It was also found that attitude and TPACK are crucial predictors of effective technology integration (Raygan & Moradkhani, 2022). Moreover, it was discovered that pre-service science teachers' technological proficiency is connected to their attitudes toward incorporating simulations into the classroom together with their perceptions on the value of simulations (Lehtinen et al., 2016). Thus, from this study, it appeared that the technology acceptance model (TAM), a theory explaining the importance of technology users' behavior vis-à-vis the educational technology under consideration (Lee et al., 2003; Momani, 2020), should support studies grounded in the TPACK framework for curriculum implementation. Accordingly, ICT users' impressions about its ease or complexity of use and about its perceived quality and effectiveness to produce desired learning outcomes influence their acceptance and motivation to use it. By considering TAM theory with the TPACK framework, teachers' technological pedagogical content knowledge would be improved, as would their technological pedagogical content and technology acceptance knowledge (TPACTAK). Indeed, the context should always define the type of content knowledge and associated pedagogy that need to be developed. In this study, mathematics was considered the context that implied specific pedagogy.

5.3.6. Recommendations

Drawing on the above findings, several recommendations have been developed. Firstly, curriculum developers should reconsider the planning of ICT subject teaching at the primary school level by increasing teaching periods from one to two per week. This adjustment would allow a larger number of learners to access computers and develop basic computer skills while providing ICT teachers with adequate time to assist individual learners in basic computer operations. In addition, teachers' perception of educational technologies to teach a particular subject would be enhanced by this increased focus, thereby improving their teaching preparation and delivery.

Considering teachers' perception of IM's potential to enhance educational quality, the Rwanda Basic Education Board should officially allow the use of IM to support the implementation of mathematics CBC at the primary school level. IM integration should, however, be done at the mathematics understanding level for the development of conceptual understanding and learners' motivation. This should be effective in supporting the accustomed chalk-and-talk teaching method. In fact, the traditional teaching method can still be beneficial to students' development of dexterity skills in mathematics education. The formal inclusion of IM in the CBC should, however, start at the upper primary level, as suggested by the study results. Then, following the potential success of IM-supported teaching at the upper primary level, IM use as an instructional tool should extend to the lower primary level. In addition, all primary schools in Rwanda should be equipped with ICT infrastructures, and primary school teachers, particularly those in remote areas who may lag behind in computer literacy and the use of educational technologies, should be trained in basic ICT. Moreover, REB should speed up IM's complete development to include missing components since the software does not yet fully cover all mathematics curriculum content. Furthermore, IM content should be improved by correcting terminologies in light of the primary school mathematics syllabus under use.

Educational research domain offers a variety of approaches, methods, and research techniques. Thus, this standard suggests future studies that could benefit from exploring alternative methodologies successfully employed in other research areas, despite encountering hindrances. In that way, future research could consider participants' ICT skills, learning abilities, and teaching professions. While test scores were used to analyze learners' conceptual understanding and performance, alternative empirically validated methods such as assessing learners' abilities to comprehend mathematical relationships (Salim Nahdi & Gilar Jatisunda, 2020).

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Appendices

Appendix 1. Effects of IM-supported teaching on learning outcomes between control and experimental groups

Table 2: Descriptive statistics of control and experimental groups' performance

Source	Group	N	Mean	Std. Deviation	Std. Error Mean
Pre-test	Control group	332	28.02	23.177	1.272
	Experimental group	310	24.53	20.279	1.152
Post-test	Control group	332	43.22	28.514	1.565
	Experimental group	310	47.89	28.691	1.630

Source: primary data, 2020

Table 3: Inferential statistics t-test of control and experimental groups' performance

Source	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Pre-test	2.028	640	.043	3.495	1.724	.110	6.880
Post-test	-2.065	640	.039	-4.664	2.259	-9.100	-.229

Source: primary data, 2020

Appendix 2: Effects of IM-supported teaching (intervention) on learning outcomes between public and private schools pre and post-tests to see the difference in effect of intervention by school status.

Table 4: Descriptive statistics of private and public schools' performance

Source	Type	Mean	Std. Deviation	N
Pre-test	Public	18.76	17.237	196
	Private	34.44	21.328	114
	Total	24.53	20.279	310
Post-test	Public	39.57	26.921	196
	Private	62.19	25.956	114
	Total	47.89	28.691	310

Source: primary data, 2020

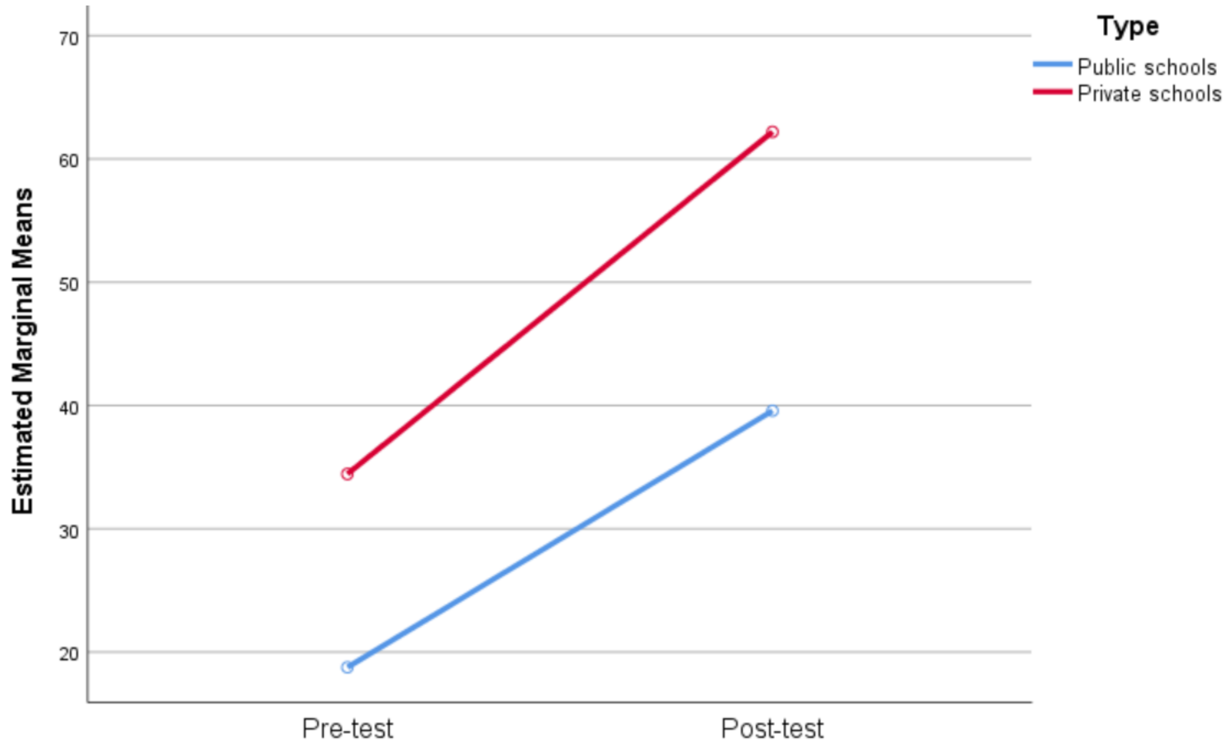


Figure 5: Students' performance by school type before and after intervention

Table 5: Inferential statistics tests of private and public schools' performance

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Pre-and post-test	84968.468	1	84968.468	240.603	.000	.439
Pre-and post-test * Type of school	1735.923	1	1735.923	4.916	.027	.016
Error	108769.544	308	353.148			

Appendix 3: Effects of IM-supported teaching (intervention) on learning outcomes between lower and upper primary levels.

Table 6: Descriptive statistics of students' performance in lower and upper primary

Source	Primary level	Mean	Std. Deviation	N
Pre-test	Lower primary	22.93	20.884	139
	Upper primary	25.83	19.740	171
	Total	24.53	20.279	310
Post-test	Lower primary	30.94	25.506	139
	Upper primary	61.67	23.284	171
	Total	47.89	28.691	310

Source: primary data, 2020

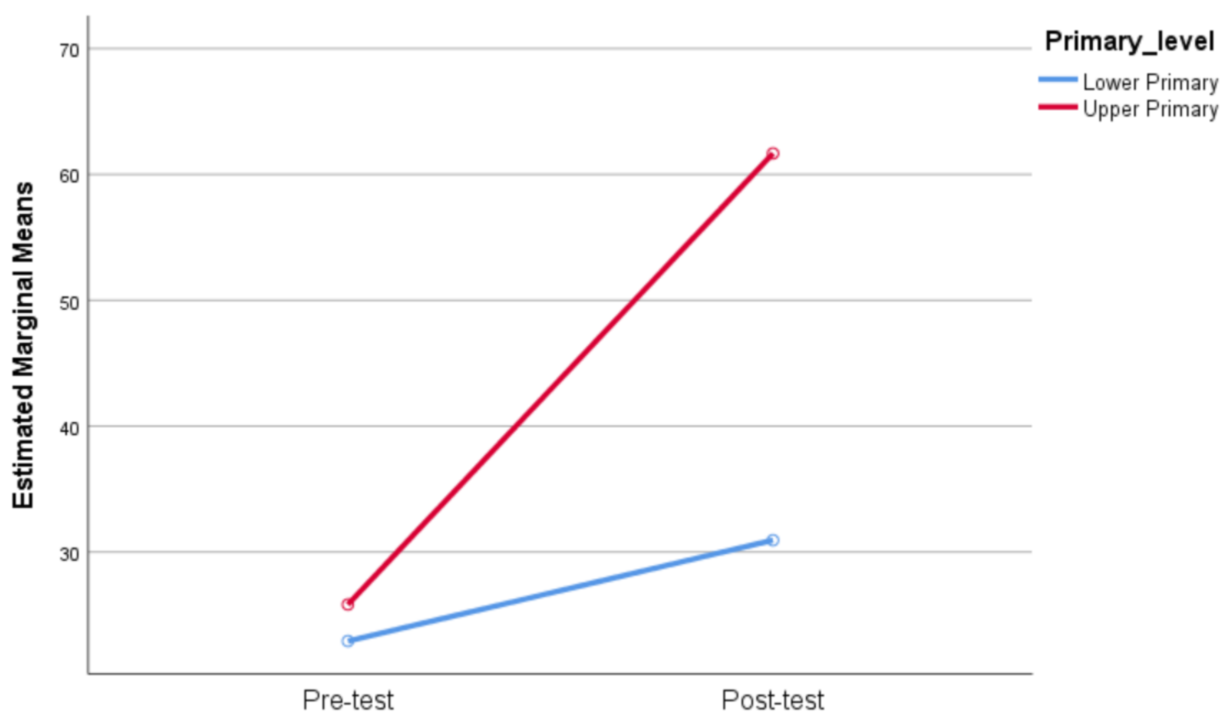


Figure 6: students' performance per primary levels in both pre-test and post-test

Table 7: Inferential statistical tests of students' performance in lower and upper primary

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Pre- and post-test	73707.554	1	73707.554	280.911	.000	.477
Pre- and post-test * Primary level	29690.186	1	29690.186	113.154	.000	.269
Error	80815.282	308	262.387			

Source: primary data, 2020

Appendix 4: Interview guide for teachers

Study Title: Teaching mathematics supported by the Interactive Mathematics Software for primary schools in Rwanda: Analysis of teachers' perceptions and learning outcomes

Teacher Semi-Structured Interview

The interview will be arranged at a time to suit the teacher and last between 30 minutes and an hour. The bullet points below serve as a guide for the areas to be covered in the interview. The teacher will be reminded that they do not have to answer any questions they are uncomfortable with. The interview will be audio recorded, I will make notes. I will conduct the interview using either English or Kinyarwanda, following the stated preference of the teacher. A summary of the notes will be read back to the teacher and verified or changed based on their comments.

Guiding questions:

1. What experience do you have in teaching mathematics? *(ni ubuhe burambe ufite mu kwigisha imibare?)*
2. What challenges do you face in normal way of teaching mathematics using chalk and black board? (probe: methodology, classroom management, teaching aids,…) (*ni izihe nzitizi uhura nazo igihe wigisha imibare ukoresheje uburyo busanzwe bw'ingwa n'ikibaho?)*

3. Did you ever teach mathematics using ICT? *(Waba warigeze wigisha imibare ukoresheje ICT?)*

4. Did you know interactive mathematics software before? How did you know it for the first time? Have you ever taught mathematics using interactive mathematics software? *(waba wari usanzwe uzi ICT tool yitwa interactive mathematics software mbere? waba warigishije imibare ukoresheje interactive mathematics software?)*

5. How did you appreciate teaching using IM? *(waba warishimiye kwigisha ukoresheje IM?)* Did you experience some benefit of teaching supported by IM? *(Waba warabonye ibyiza cyangwa inyungu yo kwigisha ukoresheje IM?)* Did you experience challenges of teaching with IM? *(waba warahuye n'ingorane zo kwigishaga ukoresheje IM?)*

6. How did you appreciate IM mathematics content presentation? *(waba waranyuzwe cyangwa utaranyuzwe n'uburyo imibare iteguye muri IM software?)*

7. What can you say about the importance of IM in addressing the teaching aids issues? (*ni iki wavuga ku bijyanye n'akamaro ka IM mu gukemura ikibazo cy'imfashanyigisho mu mibare?)* What can you say about the importance of IM in addressing the teaching in crowded classrooms? (*ni iki wavuga ku bijyanye n'akamaro ka IM mu gukemura ikibazo cyo kwigisha mu ishuri ririmo abanyeshuri benshi?)*

8. How can you evaluate the role of IM on learners' post-test performance? *(Wasobanura ute akamaro ka IM mu mitsindire abanyeshuri bagaragaje nyuma yo kwiga hakoreshejwe IM?)* Do you think that IM influenced learners' performance or not? *(Urakeka ko gutsinda kwabo byaturutse kuri IM?)*

9. Do you find IM software with respect to maths effective teaching and learning?

10. Which recommendation about ICT-supported teaching and IM in particular can you formulate? *(ni iki wifuza cyangwa wasabi kijyanye no kwigisha hakoreshejwe ICT ndetse na IM by'umwihariko?)*

End of study interview teacher

Appendix 5: Learners' tests

Isuzuma ryo mu wa 2 (Test for P2)

Amazina y'umunyeshuri:……………………… …………………………

Numero y'umunyeshuri:………Igitsina: G☐ Ga☐

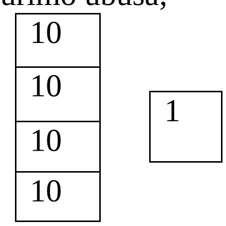
Ikigo:……………………… Ishuri:……………………………………

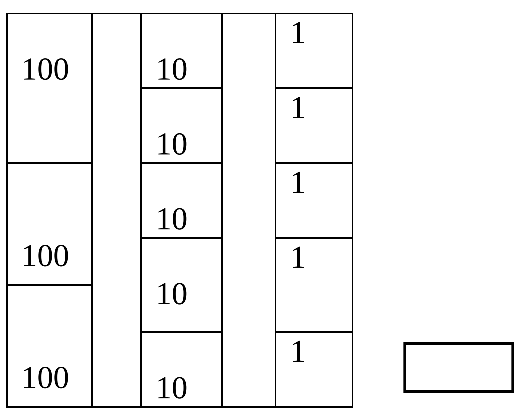
1. Uzuzuza mu mwanya urimo ubusa:

435, 436, ☐

240, 250, ☐

2. Bara kandi wandike umubare mu mwanya urimo ubusa;





3. Uzuza mu mwanya ukurikira ukoresheje ikimenyetso gikwiye:

271 ☐ 259

4. Tondeka imibare uhereye ku muto ujya ku munini:
371, 348, 427

5. Tondeka imibare uhereye ku munini ujya ku muto:

398, 447, 412

6. Kora imibare ikurikira:

164 +232 ____	318 +165 ____
297 -154 ____	351 -291 ____

Test for P3

Pupil's name (Izina ry'umunyeshuri)……………………………………………………………………………………

Pupil's number: (numero y'umunyeshuri)……Gender: Female (Gore) ☐ Male (Gabo) ☐

1. Workout the following (Kora imibare ikurikira)

```
  258        29
 +634       -24
 ----       ---
```

2. Fill in the box (Uzuza mu kazu)

7+7+7 → 7x ☐

9+9+9+9+9+9+9+9 → 9 x ☐

3. Work out the following (kora imibare ikurikira)

7x3= 7x8= 8x4=

8x6= 9x2= 9x7=

4. Fill in the box (Uzuza mu kazu) ☐
   [Multiplication] (Ikuba)

↓	0	1	2		4	5	6	7
X 8				24				☐

Division (igabanya)

↓	7	14	21	28	35	42	49
: 7				24			☐

5. Workout the following (Kora imibare ikurikira)

```
 197
 X 7
 ---
```

```
 146
X 13
```

Test for P4

Pupils' name:……………………………………………………………………

Pupil's number:…………..… Gender: Female: Male

1. Fill in the box below with number:

-10 -5 0 +5 +10

The inverse of +8 is

The inverse of -4 is

(+3)+(-3)=

(-7)+ =0

+(+6)=0

2. What is the distance between the following integers?

-7 and +2
-9 and -4

3. Fill in the box with the word of 'less' or 'greater'

-3 is than +5

+4 is than -8

-5 is than -3

4. Write the number from smaller to greater in ascending order.

-2, +5, -6, +9, -8

5. Write the number from greater to smaller in descending order.

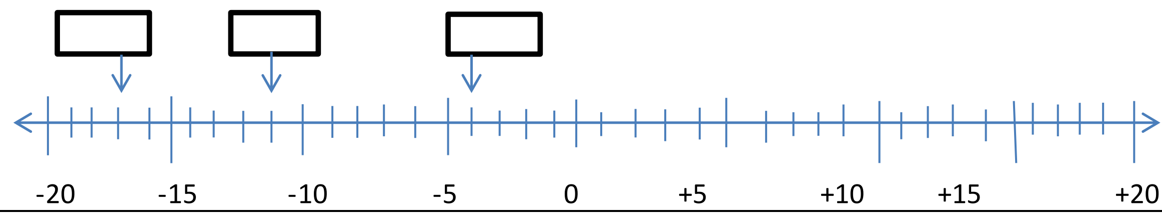
+5 -5, 0, -7, +6

Test for P5

Pupils' name:………………………………………………………………

Pupil's number:…………..… Gender: Female: Male

2. Fill in the box below with number.



2. Match the right and the left by drawing the line

Negative numbers . .+20, +11,+8, +15

Zero . .+17, -9, +25, -31

Positive numbers . .-8, -17, -25, -14

Integers. .0

3. Fill in the box with "less" or "greater".

+14 is than -18

-15 is than -5

4. Fill in the box with the sign (< or >)

-11 +9

-12 -23

5. Write the numbers from smaller to greater in ascending order.

-12, +15, -6, +9, -18

6. Write the numbers from greater to smaller in descending order.

-12, +15, -16, 0, +9

7. Calculate the following:

(-6) + (+3) = (+5) – (-5) =

(-2) – (-6) = (-3) + (-7) = 8.Fill in the box below with number

(-13) + = 0

+ (+18) = 0

8. Fill in the box below with number

The inverse of +5 is

The inverse of -8 is

Appendix 6: UR-CE Ethical clearance

UNIVERSITY OF RWANDA

COLLEGE OF EDUCATION

RESEARCH AND INNOVATION UNIT

Rukara, 15th January 2019

Mrs Innocente Uwineza
PhD Student
School of Education
UR-CE

Dear Sir,

RE: RESEARCH ETHICAL CLEARANCE FOR YOUR STUDY

Following your application for research clearance for your study entitled: "**The role of Interactive Mathematics (IM) content software on students' numeracy performance and attitudes.**"

Having reviewed your application and being satisfied by your protocol (your research topic, interview schedule, and informed consent), your study is ethically acceptable. This ethical clearance shall last for three years (36 months) and is renewable upon request and presentation of the progress report to the UR-CE Research Screening and Ethics Clearance Committee (RSEC-C) through the Research and Innovation Unit. Please note that you will have to apply for ethical clearance before making changes in the protocol during the implementation phase. At the end of your study, the Research and Innovation Unit shall receive a final copy of your study report.

We wish you success in your study.

COLLEGE OF EDUCATION – UNIVERSITY OF RWANDA – RESEARCH AND INNOVATION UNIT

Assoc. Prof. Eugene Ndabaga
Chairperson, UR-CE RSEC-C
Director of Research and Innovation Unit
Tel.: 250788308862
Email: ndabagav@yahoo.ie
UR-College of Education

Cc:

- The Principal, CE
- Postgraduate Coordinator, School of Education, CE

Appendix 7: Plagiarism check

I, Innocente Uwineza, PhD student by research program in Mathematics education (registration number: 216366305), in the year 2023. I do hereby declare the following:

- The work has been passed through the Turnitin Software and found to comply with ranges of Turnitin report.
- I am aware that plagiarism of others' work is academically unpleasant and not accepted.
- I certify that the work submitted for evaluation has properly and academically acknowledged the contributions of other writers.
- I have referenced other people's ideas and opinions in accordance with the rules.
- I am aware that the University of Rwanda has the right to discipline me if someone believes that any of my writing is not original to me or if I have not given credit to the authors of the ideas that I have used in it.

Thesis Plagiarism checking

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