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

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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.*

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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.

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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.

Models of Conceptual Understanding Development

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 et al. (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:

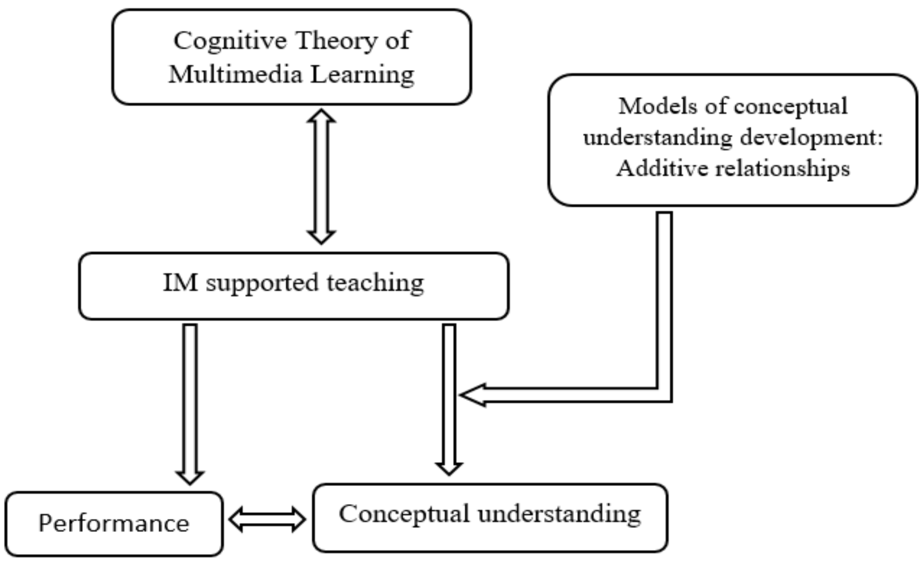

Figure 1. Conceptual Understanding Development Model by IM Multimedia Learning (Source: authors' drawing)

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 instructions 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 development.

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.

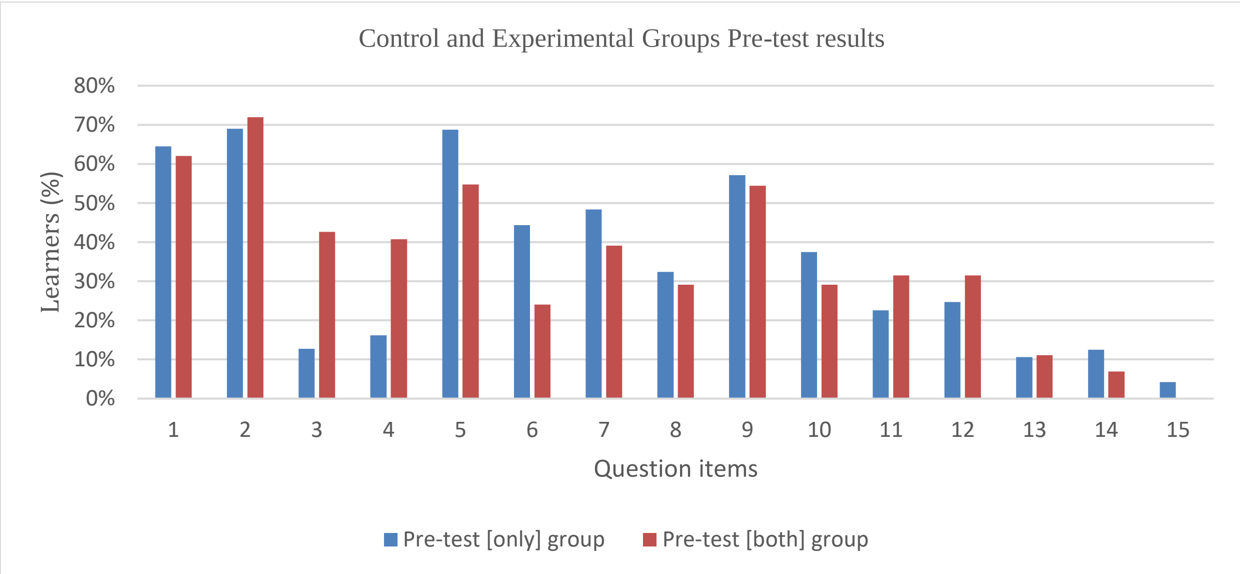

Figure 2. Conceptual Understanding of Control and Experimental Group Before Intervention

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.

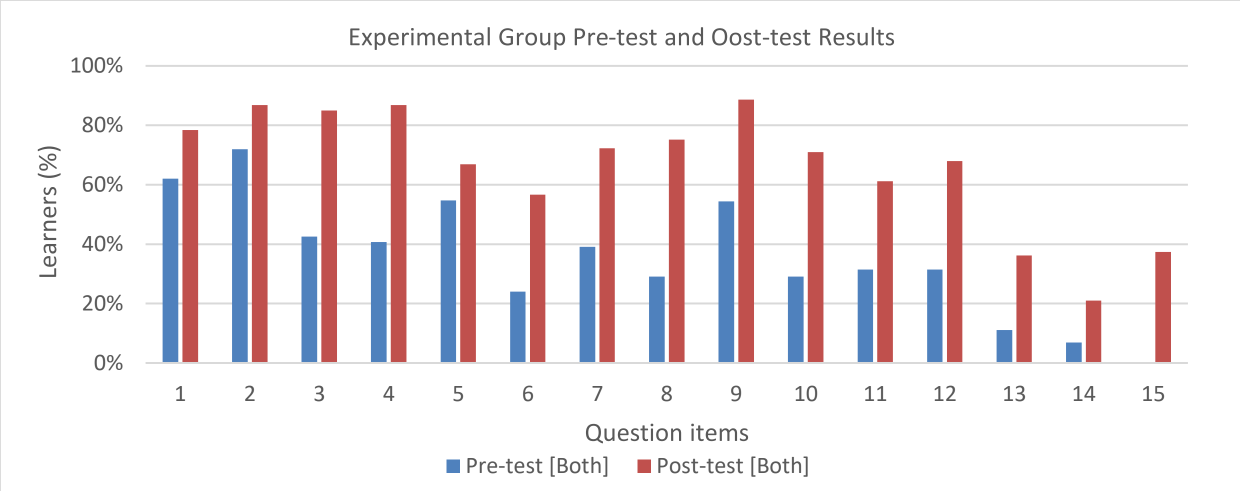

Figure 3. Conceptual Understanding of Experimental Group Before and After Intervention

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.

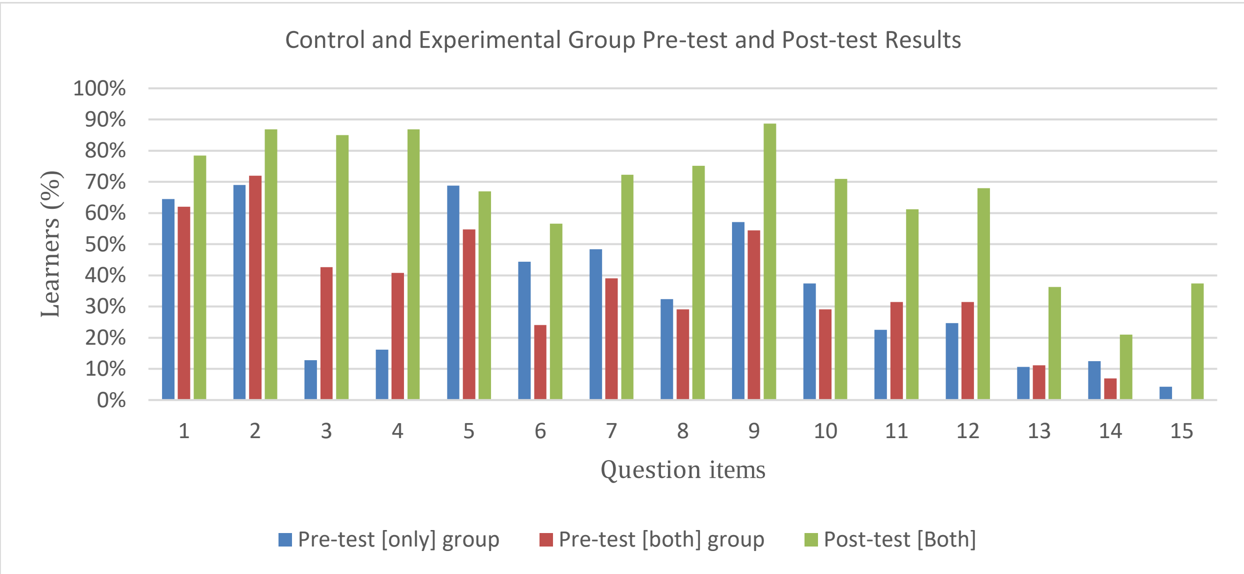

Figure 4. Conceptual Understanding of Control and Experimental Group Before and After Intervention

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 multidigit 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 as a result 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 main 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.

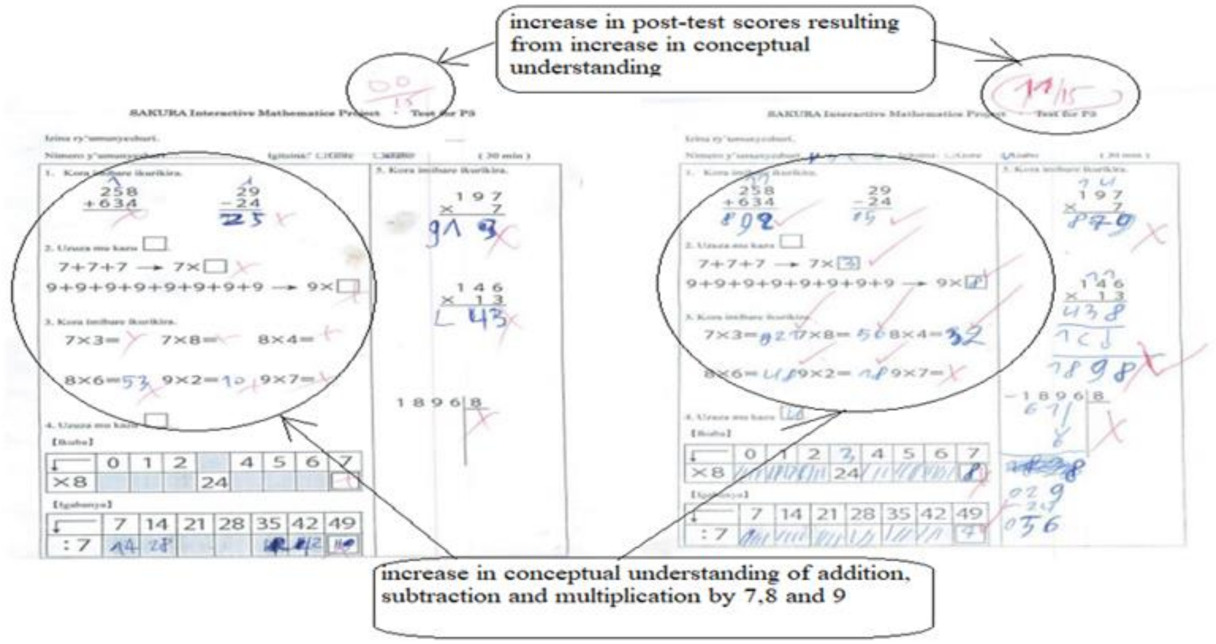

Figure 5. Learner 1's Scriptural Work of Pre-test and Post-test, Field Study, 2019

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.

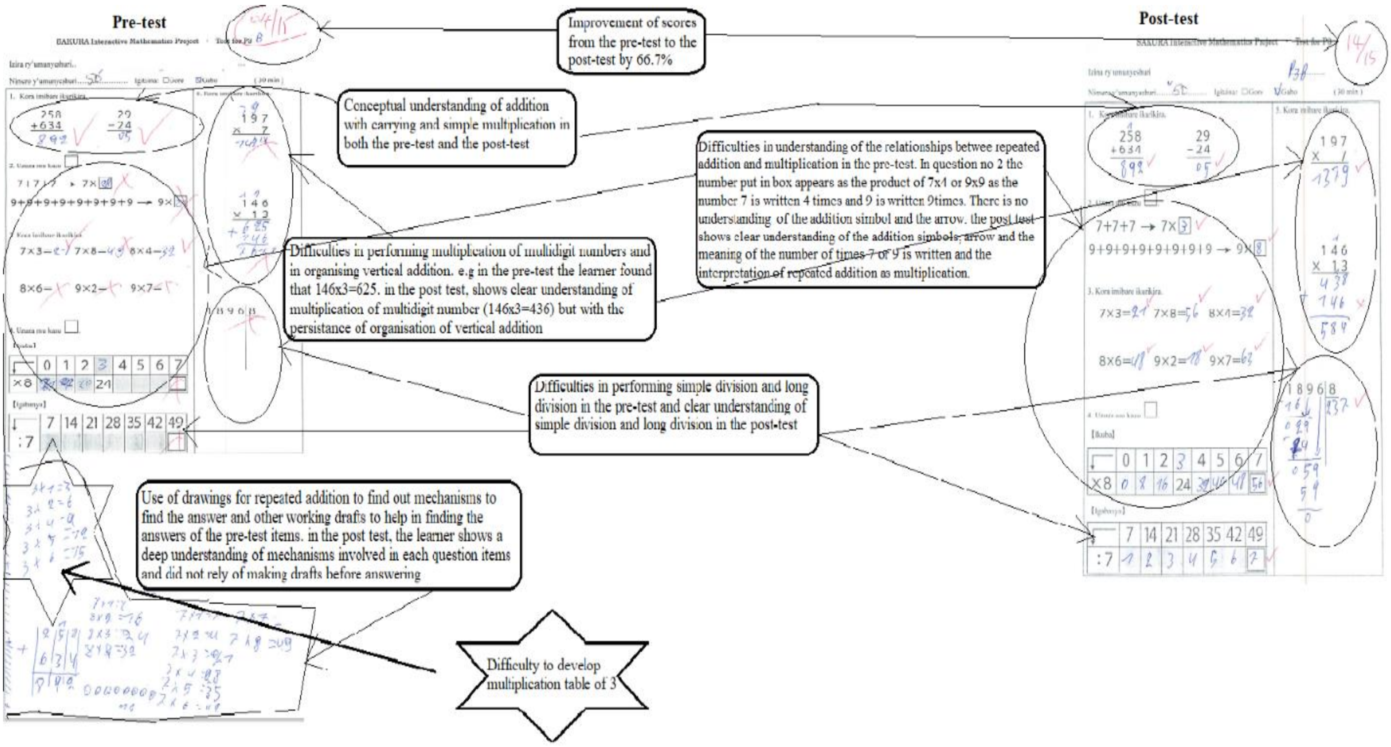

Figure 6. Learner 2's Scriptural Work of Pre-test and Post-test, Field Study, 2019.

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:

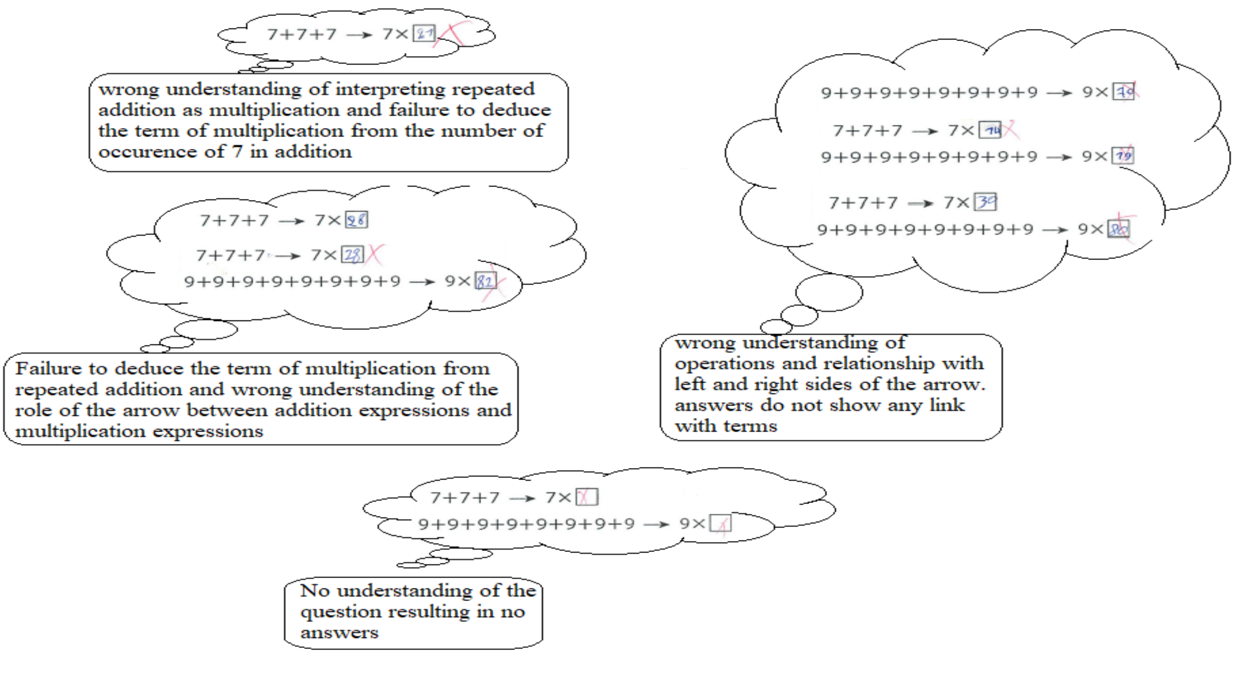

Figure 7. Types of Errors of Multiplication Committed in the Pre-test, 2019

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 $p<.05$ $(p=3.05E\text{-}18, p<.001)$. 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:

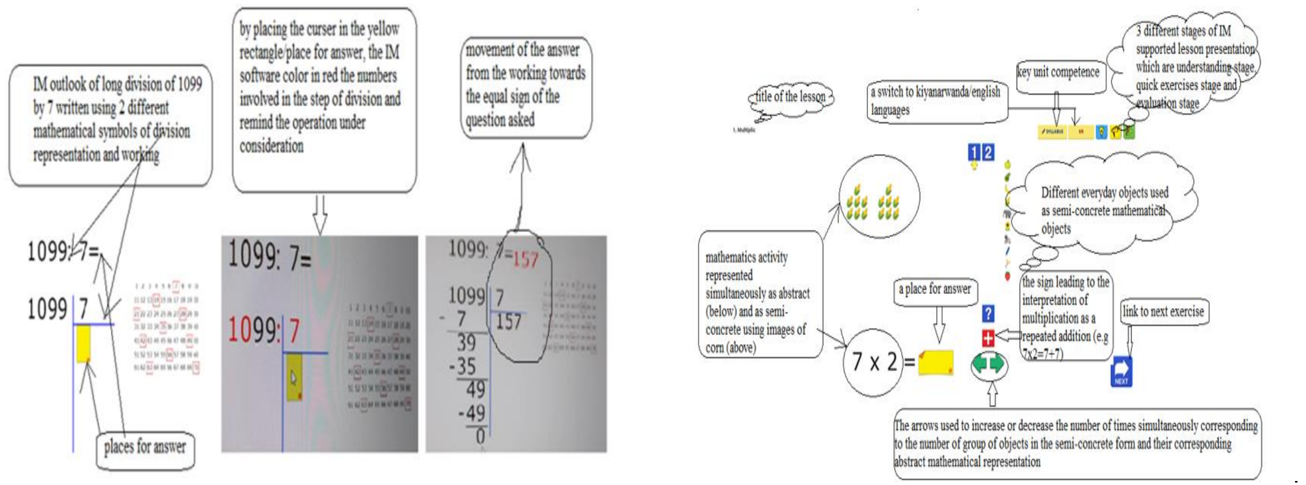

Figure 8. Annotated IM Outlook of the Long Division of a Multi-digit Number by one digit Number (Left) and Multiplication by 7 (Right)

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, and conceptual 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.

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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

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 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

1896 | 6