EMERGENT LITERACY IN MATHEMATICS (ELM): LEARNING NUMERACY WITH INTERACTIVE TECHNOLOGY IN KENYA GRADE-ONE CLASSES. UNDER REVIEW

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Emergent Literacy in Mathematics (ELM): Learning numeracy with interactive technology in Kenya grade-one classes

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Abstract

While countries in Sub-Saharan Africa have made significant progress towards achieving universal school enrollment, millions of students lack basic numeracy skills. In Kenya where the government mandated one digital device per child in elementary grades, we tested the Emerging Literacy in Mathematics software (ELM) for teaching and learning mathematics. Designed as a pretest-post-test non-equivalent group research, the study of ELM unfolded in 14 grade-one classes from 7 primary public schools. After having learned with ELM for about two terms, the experimental students (N=283) considerably outperformed their peers (N=171) exposed to traditional instruction with the effect sizes of +0.37 on the overall skills measured by the standardized tests of mathematics. The impact of ELM's activities was the greatest on students' ability to take language and concepts of mathematics and apply appropriate operations and computation to solve word problems. On this set of skills, the magnitude of difference between the experimental and control groups was +0.71. This study also revealed shifts in the teachers' perceptions about their practice. The ELM teachers reported having gained more confidence in mathematics and comfort in teaching mathematics with computers.

Keywords to add: interactive mathematic software, primary mathematics instruction, student mathematics achievement, Sub-Saharan Africa, Kenya

1. Introduction

The international community has given considerable attention to improving the quality of primary school education (UNESCO, 2015). Together with literacy, Science, Technology, Engineering and Mathematics (STEM) education has been recognized for the critical role it plays in driving economic growth. In fact, research suggests that mathematics attainment may have a greater impact than reading on an individual's income potential (Crawford & Cribb, 2013; Dickerson et al., 2015). Findings from several African countries indicate that an increase in mathematics test scores of only 0.1 standard deviations produces an increase in income of between 2% and 6.5% (Dickerson et al., 2015, p. 19). However, there is concern that children in developing countries are not learning sufficient mathematics skills. While countries in the Sub-Saharan region of Africa have made significant progress towards achieving universal school enrollment, millions of students lack numeracy skills (WorldBank, 2018). For instance, only one in five third-grade students from this region have second-grade mathematics skills, and less than one third of students can solve a simple two-digit subtraction problem by the end of primary school (Uwezo, 2016). There is a consensus that raising the overall quality of schooling will increase mathematics learning outcomes (Bethall, 2016). At the same time, calls are made for interventions designed to boost the effectiveness of mathematics instruction (e.g., Bold et al., 2017; Fleisch et al., 2016; Metto & Makewa, 2014).

1.1. Effective Mathematics Instruction in Early Elementary School

Research evidence on student mathematics proficiency suggests that, much like in case with literacy, for children to succeed academically, a solid foundation in mathematics needs to be laid early (e.g., Claessens & Engel, 2013). In elementary education, effective mathematics instruction develops students' conceptual understanding of numbers and quantities, connects this understanding to computational methods and strategies, and instills fluency and mastery in their application to solve mathematical problems (e.g., Anthony & Walshaw, 2007; NCTM, 2014, 2009). Computational fluency includes the student's flexibility to choose adequate computational strategies and methods and their capacity to produce accurate answers efficiently. Computational mastery is the student's ability to instantly recall arithmetic procedures and the ability to carry them out automatically. The combination of these particular skills reduces cognitive load and frees up memory resources that can be used to monitor performance and to learn more complex procedures. Gaining mastery and fluency of multiple aspects within the number concept enables the student to proceed from concrete to abstract, reaching the ability to carry out mental computation (e.g., Baroody, 2006). Therefore, building a solid command of whole numbers is both a key outcome of early mathematics instruction and an important prerequisite for learning higher mathematical skills (e.g., NMAP, 2008; Baroody & Purpura, 2017). In this regard, learning mathematics in primary school should be a coherent progression of mastering a critical few topics without revisiting these topics from year to year.

Since children's acquisition of new mathematical ideas depends on their prior knowledge (Anthony & Walshaw, 2007), effective instruction frequently assesses what students understand and are able to do mathematically, and then responds to each individual student's strengths and weaknesses. By adjusting to students' different levels of understanding, differentiated tasks enable students to proceed at their own level of understanding. The recent synthesis of 61 elementary math programs by Pellegrini et al. (2018) revealed that approaches that strongly emphasize personalization of instruction to adequately meet students' learning needs have the strongest impact on students' math achievement. Since no one practice dominates across all settings and learners, a "balanced approach" to teaching mathematics where direct instruction alternates with inquiry instruction can be beneficial (e.g., Gersten et al., 2009; Clements et al., 2017). Such balance allows low-achieving students to learn from explicit and direct instruction (NRC, 2009), while more advanced students enjoy programs offering them opportunities to learn at their own pace (e.g., Fuson et al., 2015). For instance, guided inquiry or guided discovery strategies provide learning scaffolds appropriate to each child's ability and prior experience, while presenting problems in small incremental steps. In addition, the use of cooperative learning strategies and computer technology can reinforce the student-centered aspect of the balanced mathematics instruction (e.g., Li & Ma, 2010).

1.2. Mathematics Instruction in Developing Countries

Much of what is known about effective mathematics instruction has come out of high-income countries that is not always fully applicable to less affluent international contexts. However, Snilsstweit et al.'s (2015) meta-analysis of 238 studies from low-and middle-income countries found that the effect of structured pedagogic interventions was the largest and most consistent across their systematic review (0.14). In their collection of interventions designed to adapt or improve educational content and methods of instruction, only four programs evaluated mathematics-related learning outcomes in elementary schools (Irwing et al.,2008; San Antonio et al., 2011; Piper & Mugenda, 2014; King et al., 2015). Sitabkhan and Platas (2018) completed a narrative review of instructional strategies in early-grade mathematic interventions studied by 24 RCTs and quasi-experiments of math instruction with 11 studies from Sub-Saharan countries. They report the use of manipulatives and developmental progressions as the most prevalent evidence-based practices employed in the interventions. Conversely, the use of strategies targeting higher order skills such as encouraging children to explain and justify their thinking and making explicit connections between formal and informal language were not seen in the reviewed studies. The authors ponder that since the implementation of these strategies requires significant changes in teacher behaviours and attitudes, the studies opted for excluding them from the design of interventions.

The concern about mathematics teacher abilities has been conveyed in the research literature. There is an urgent need to prioritize teachers' capacity for progress in mathematics attainment as expressed in a World Bank commissioned report on mathematics education in Sub-Saharan Africa (Bethall, 2016). Bold et al. (2017) identified important gaps in teacher content knowledge and pedagogical skills. For instance, only 15% can solve a more advanced math word problem, 55% can formulate questions to check understanding; 30% can assess their student's abilities and learning progression whereas 17% are able to apply the full set of general pedagogical skills—structuring, planning, asking questions and giving feedback—in their lessons for the benefit of their students' learning. Teachers' limited proficiency in English may be an additional inhibitor as teachers themselves struggle with subject-specific topics when engaging in formal classroom talk (Kembo-Sure & Ogechi, 2016; McCoy, 2017).

To raise the quality of teaching, the longer-run system-wide actions including improvements to teacher training programs (e.g. Barasa, 2020) could be complemented with short-term solutions. For instance, prescriptive instruction is one such fast-track way to improve low-performing systems where teachers over-rely on basic recall, and rote-learning in their instruction (e.g., De Clercq, 2014; Shalem et al, 2018). Although scripted lessons can guide teachers to correct pacing, sequencing, coverage of the official curriculum and syllabus (e.g., Piper et al., 2016; Fleish et al., 2016), they do not work to improve instruction catering to higher-order learning where teachers struggle the most (e.g., Bold et al., 2017). Questioning the prescriptive approach, Fullan (2016) argues that it is not through imitation but through innovative adaptation that teachers learn about complex solutions that would influence their practice and drive “deep change work”. Computer-assisted teaching and learning has been noted for its potential to bolster students’ access to quality education in low-teacher-capacity settings (Bethall, 2016).

1.3. Computer-assisted Mathematics Instruction in Developing World Contexts

Considerable improvements in connectivity and accessibility of technology account for the increasing enthusiasm that less affluent nations have in using educational ICTs. Moreover, the implementation of computer-based pedagogic initiatives in developing countries, has generated the important body of systematic evidence that indicate positive effects of educational technology on learning. McEwan (2015) in his meta-analysis of primary school interventions, found that computer-assisted instruction was associated with the highest impact on learning outcomes (+0.15). Conn (2017) reports the effect size of +0.43 that computer-assisted learning programs adapted to the student’s learning level may have when compared to traditional instruction. Evans and Popova’s (2016) analysis of six systematic reviews of educational interventions in developing countries, concluded that despite the important variations in the reported findings, the reviews tend to agree that computer-assisted instruction can be highly effective.

Although few individual studies tested the impact of computer-based mathematics interventions in low income countries, their findings suggest positive effects of computer instruction on learning mathematics in primary schools (e.g., Pitchford, 2015), and for students with special needs (Kiboss, 2012). Interactivity (Pitchford et al., 2019) and self-paced learning Banerjee et al., 2007) were the design features with most benefit to students. In view of research sparseness, calls are made for more studies to evaluate the interventions and technologies to improve mathematics instructional practices and learning outcomes (e.g., Bolton, 2019; Bethall, 2016).

The current study targeted teacher implementation of ELM, mathematics interactive software, in grade-one classrooms in Kenya schools. The research that unfolded was influenced by primary school reform including the introduction of a competency-based curriculum with an almost simultaneous roll-out of the TUSOME and PRIEDE national programs. The government also made a massive commitment to the provision of educational technology by implementing the Digital Literacy Programme (DLP, aka Digischool). They successfully deployed technology (tablets, content servers and projectors) in primary classrooms across the nation.

For this context, we developed a multi-component ELM intervention model, brought it into the authentic context of schools, and examined its impact with regard to classroom instruction and student mathematics skills.

Specifically, we examined two sets of questions:

1. Is ELM a usable and effective tool for math instruction in the Kenyan context? How does the software and associated professional development and support impact Kenyan

students with respect to the learning of essential mathematics competencies? Do these effects vary across student characteristics such as gender and baseline achievement?

2. What are the impacts of the software and associated professional development and support on Kenyan teachers' mathematics instructional practices and professional skills? How do teachers adapt and adjust their implementation of the software?

2. Method

2.1. Research Design

This study was designed as a non-equivalent pretest-post-test control group design where teachers and their students were part of either experimental or control conditions. While the ELM intervention unfolded in the experimental classes, the control classes were exposed to their usual method of mathematics instruction. Student and teacher data were collected twice; first in January, at the beginning of school year, before the ELM implementation started in the experimental classes and, then, in late September, at the conclusion of the intervention.

2.2. Study Sample

Seven public schools with comparable socio-economic characteristics from Mombasa area were recruited by the local project coordinator to be part of the project either as experimental or control schools. The total sample of 14 grade-one teachers and their 613 students included nine experimental teachers who used ELM as part of their mathematics instruction with their 358 students and five control teachers and their 255 students who did not use ELM. The number of students in participating classes varied from 28 to 61 students with the average class size of 41 students in experimental and 50 students in control classes. The gender split in both conditions was about equal with ~ 56% of boys and ~44% of girls. Because some students missed either pretest or post-test due to illness or changing school, the data for 454 cases (N_{exp} =283; $N_{control}$=171) were analysed.

Teachers in both conditions (N_{exp}=9; $N_{control}$=5;) were comparable in regard to mathematics training and experience. Besides one control teacher with a high school education, all control and experimental teachers received some certification either from university or teacher training colleges. Only one teacher was able to name a math-related course she took when in university. On average, the teachers taught between three to 34 years with an average of 21 years of experience.

2.3. ELM Program

2.3.1. Emerging Literacy in Mathematics (*ELM*) *Software*

Offered within the Learning Toolkit (LTK+) suite of evidence-based software, ELM is a collection of engaging game-like activities designed to promote the development of young children's foundational skills in mathematics as described by the NCTM (2009) among others (see http://www.concordia.ca/research/learning-performance/tools/learning-toolkit/elm.html)

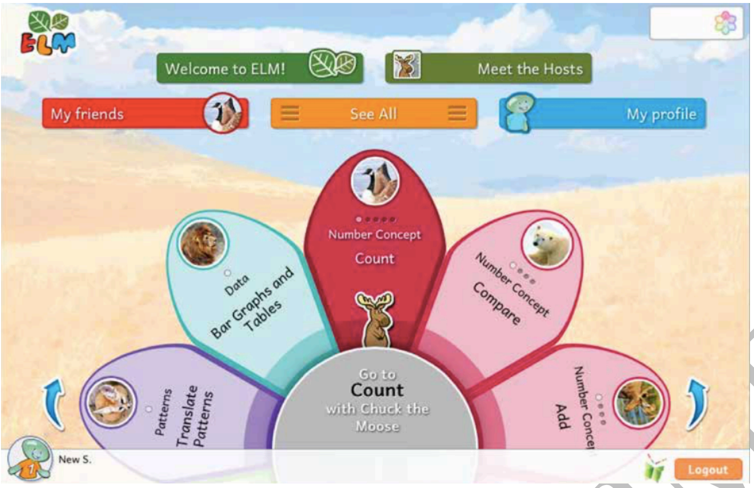


Figure 1. ELM splash page

The software design is based on the current evidence showing promising links between mathematic instruction and computer technologies (e.g., Li & Ma, 2010). Multimedia designed principles (e.g., Mayer, 2008) also informed the design of the software helping reduce cognitive load, engage learners, reduce anxiety, and scaffold the understanding of mathematical concepts. The ELM content is organized into Themes, overarching branches of mathematics, which are further divided into Ideas (mathematical concepts). Figures 1 and 2 illustrate the content structure of ELM.

Figure 2. ELM's Themes and Ideas

In order to build children's understanding of a concept, each Idea then follows a certain number of carefully sequenced activities moving from concrete to more abstract, from images and physical actions to mental images and symbolic representations. For example, initially a student is asked to count by performing the equivalent of touching the image of each object, then by generating a mark corresponding to each object being counted, and finally by counting in their head and reporting that count using number symbols. Each activity is presented as a jigsaw puzzle (Figure 3) having a number of missing puzzle pieces, where each piece represents a set within the activity. The activity is completed once the student gains all the missing puzzle pieces. Through 38 ELM activities, children gain skills and confidence in: Number Concept (Count, Compare, Add, Subtract, Decompose, Place Value); Geometry (Identify shapes); Patterns (Translate patterns); Data (Bar graphs and tables); and Number Line: (Number as displacement).

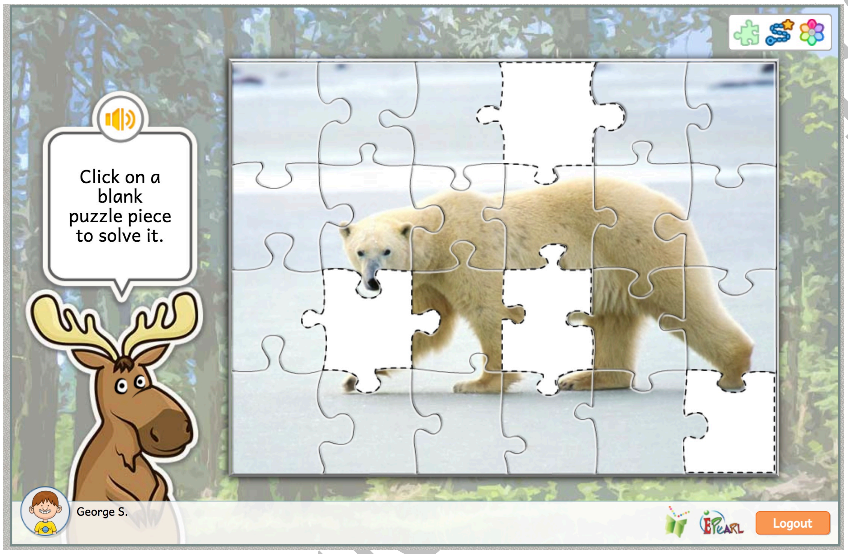
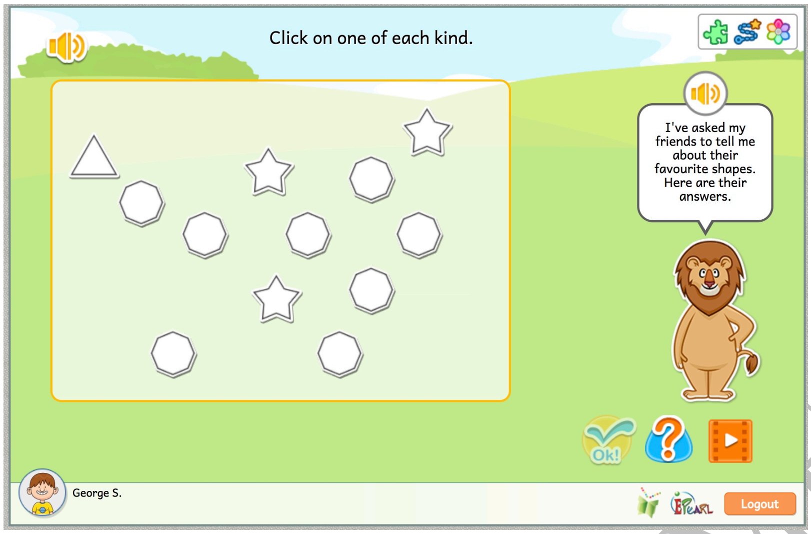

Click on a blank puzzle piece to solve it.

Figure 3. Example of an ELM Puzzle

ELM provides meaningful audio and visual feedback to the students as they complete activities at their own pace, helping to guide them to the correct answer. To encourage student autonomy, ELM offers a system of embedded support. Demos were created for each activity and are presented to correspond with each phase to avoid overwhelming students. All activities have a ‘help’ button to provide built-in just-in-time support (Figure 4). This help generally consists of a brief audio instruction followed by visual cues, and is context-sensitive, dependent on the phase of the activity the student is progressing through.



Click on one of each kind.

I've asked my friends to tell me about their favourite shapes. Here are their answers.

Figure 4. ELM's Help

The teacher interface in the software offers a collection of multimedia resources specifically intended to help teachers use ELM (see https://literacy.concordia.ca/resources/elm/teacher/en/)

These resources include information on each activity within the tool, detailed lesson plans for each activity, with learning objectives, an extension activity and a reflection exercise, video demos, and recommended external resources such as online math games. The ELM report allows teachers to obtain an overview of the progress of their class, as well as the progress of individual students. For example, it provides information about how many puzzle pieces each student has completed, whether the student eventually completed a particular activity, or if the student had trouble at some point in the activity. Further, ELM allows teachers to differentiate instruction. They can create a plan for a single student or groups of students and adjust the number of repetitions required in any given activity, or assign an additional 're-do' for any activity. If a student has been assigned a specific plan, the ELM report reflects the settings of that plan and the students' progress through it.

As part of the design and development cycle, the ELM software passed through initial validation in Canadian grade-one elementary classrooms. Designed as a non-equivalent control group the pilot study with 450 students, the test demonstrated ELM impacts on students' learning outcomes. After having learned with ELM for about one term, the experimental students considerably outperformed their peers exposed to traditional instruction with the effect sizes of +0.22 (Lysenko et al., 2016) on the overall skills respectively measured by the standardized tests of mathematics (CAT-4, 2008). In addition, the effects of ELM were observable on a set of affective outcomes. Students in classes where ELM was part of mathematics instruction reported more enjoyment from learning math and less anxiety and boredom than their peers in the control group.

2.3.2. ELM Intervention

ELM integration in mathematics instruction was in the heart of ELM intervention. The implementation took from 10 to 14 weeks between January and September of 2019 where the tool was expected to be used at least for 60 minutes per week but was often less. The teachers used the school computer lab for the ELM instruction. The devices were desktop computers or government-provided DLP tablets or some combination of both. In the context of big classes, students had to work in pairs or small groups.

To ensure adequate integration of the ELM software into classroom instruction, professional development on ELM was a key component of the intervention. All experimental teachers were trained on the ELM software and its pedagogy at a full day training workshop. Three half-day out-of-school follow-up sessions took place once per term to continue training teachers on how to use ELM for mathematics instruction. In-school support to experimental teachers was provided by an external expert teacher (LTK+ Ambassador) and a school-based LTK+ ambassador (SBA), who was a specially trained school teacher in each experimental school. The SBA facilitated in-school LTK+ planning meetings with her school teachers, helped scheduling access to the computer lab and assisted teachers during the ELM lessons. Since technical issues were frequent, the planning meetings also focussed on using some ELM print-based extension activities. To complement the efforts of SBAs, each LTK+ Ambassador rendered between three to five visits to the assigned classrooms. These visits were held on the days of the in-school LTK+ planning sessions. The topics were of general (LTK+ related) and more targeted (ELM-related), and included establishing the LTK+ school timetable, registering students in the LTK+ database, linking ELM to the curriculum, learning how to differentiate within ELM etc. The Ambassadors also used such visits to observe classes and also assist teachers during the lesson if needed. Both the LTK+ Ambassadors and SBAs benefited from the support system as they met regularly for planning and reflection.

A set of *ELM teaching materials* was offered to teachers. This included an ELM curriculum developed expressly to align the use of the tool with the Kenyan grade-one Mathematics requirements. The ELM supplementary pedagogical materials also included lesson plans, classroom activities, and job aids for teachers. These materials were suggested rather than prescribed and their use was left at the teachers' discretion.

2.4. Instruments

2.4.1. Student Achievement Measures

Students' skills in mathematics were assessed using *Group Mathematics Assessment and Diagnostic Evaluation*, GMADE (Williams, 2004), a standardized achievement measure. GMADE level 1 was chosen to measure the change in the students' mathematic skills. This level covers the age band from 6 to 11 years old by offering items at a wide range of difficulty that allows reliable measurement of low-, average- and high-performing students. Parallel forms (A or B) were used alternatively to collect pre- and post-data. Each form contained eighty multiple choice items pertaining to the content-driven categories such as algebra, comparison, geometry, measurement, money, numeration, quantity, sequence, statistics and time.

The *Concepts and Communication* subtest of GMADE addresses the language, vocabulary and representations of mathematics and contain symbols, words and phrases that fit the content-driven categories (except algebra and statistics). The *Operations and Computation* subtest evaluates the ability to use basic operations of addition and subtraction in both vertical and horizontal forms with a variety of mathematical representations. The *Process and Applications* subtest measures the students' ability to take language and concepts of mathematics and apply the appropriate operation(s) and computation to solve a word problem that fits the content-driven categories (except comparison). The majority are one-step or single-operation problems, whereas one is a multiple-step problem.

2.4.2. Instruction and Teacher Measures

The *Mathematics Teacher pre- and post-surveys* (https://www.concordia.ca/research/learning-performance/knowledge-transfer/instruments.html) were used to collect information from control and experimental teachers. Although obtaining teacher demographic information was the main focus of the pre- survey, it also elicited teacher reports on the content they taught in grade 1, accessibility and use of technology, as well as the comfort and confidence they had in teaching early math and using computers. The post-survey collected teacher self-reports about the instructional methods they relied also including use of ELM.

ELM Trace Data generated by the software provided an estimation of time that a student spent in each ELM activity. The accuracy of these data is dependent upon multiple factors including electricity blackouts, students logging in and out correctly, and students working in pairs or small groups. This statistic was aggregated to reflect time spent on counting, comparing, adding, subtracting, decomposing, place value etc.

Additional information about the ELM implementation was available from the end of term reports from the SBAs and LTK+ Ambassadors. The numeric data collected at this stage of the project were included into the datafiles and used to inform the final analyses.

3. Analyses

All student and teacher data were entered into SPSS 26 for Mac OS X and verified for accuracy. After merging student pre and post-test data, the datafile contained 613 cases. The students who missed either time of testing were excluded from the analyses, the data of 454 students ($N_{experimental} = 283$; $N_{control} = 171$) were analyzed. The data did not deviate from normality; the indices of skewness and kurtosis ranged from -2.5 to 2.8. The composite scores were calculated as a simple sum of the raw scores along the three GMADE sub-scales of Concepts and Communication, Operations and Computation, Processes and Applications, and GMADE Total score. The initial difference between the groups had been detected on the GMADE pretest ($F(1, 453) = 3.85$, $p < .05$), thus the repeated measures analysis of variance (RM MANOVA) was used to analyze the GMADE composite scores. The basic one-way model included testing time (pretest-post-test) as the within-subject variable and treatment (ELM -- no-ELM) as a between subject factor. Supplementary analyses were run to explore if ELM effects a) vary as a factor of student gender and b) are detectable for struggling learners.
At the pretest the complete set of data were collected from 14 teachers. Matching teachers' pre- and post-tests, yielded data for 8 experimental and 2 control teachers. Paired sample t-test

was run to examine the change in experimental teacher self-reports overtime. For both student and teacher data, we report the descriptive statistics by group including mean scores and standard deviations as well as standardized effect sizes (i.e., Cohen's d). Being an index of magnitude of difference between groups, these were calculated as the mean difference between the two groups' pre-post change score divided by the pooled standard deviation.

4. Results

The following section presents the results that we obtained after analyzing the student and teacher data.

4.1. Student results

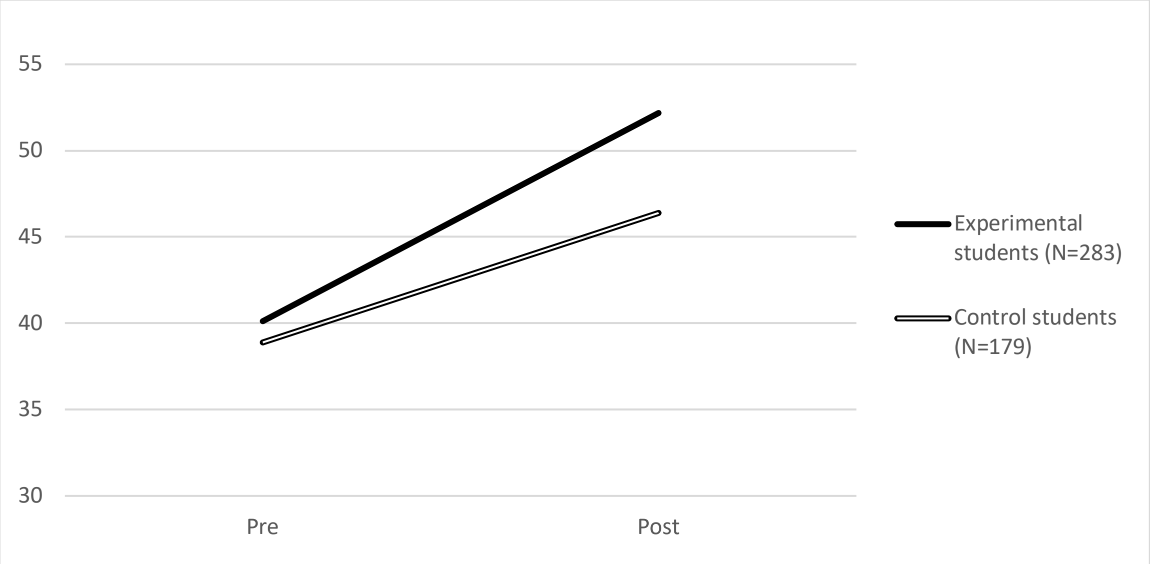
As summarized in Table 1, student achievement data on each of the GMADE subtests suggest that students in both groups improved over time with important benefits to the ELM students. To explore whether the ELM students' mean change in mathematics skills from pre- to post-test on the GMADE differed from those of their peers from control classes, the one-way repeated measures analysis was run with testing time as the within-subject variable, and treatment as a between-subject factor. The RM MANOVA Pillai's trace criterion indicates statistically significant difference between experimental and control students' change scores on a combined set of mathematic measures overtime; Pillai's trace criterion is $F(3, 450) = 14.72$, $p < .000$ with partial eta squared of 0.08 confirming the difference. The univariate tests reveal the significant effects of ELM on the experimental students' mathematic skills measured on the GMADE subtests of Concepts and Communication ($F(1, 452) = 5.95$, $p=0.02$; partial $\eta^2 = 0.01$) and Process and Applications ($F(1, 452) = 42.76$, $p= .000$, partial $\eta^2 = 0.085$) as well as the GMADE Total test ($F(1, 452) = 18.40$, $p=.000$; partial $\eta^2 = 0.038$).

Table 1. *Group means and standard deviations, gains and standardized effect sizes*

	Concepts and Communication (max 28)		Operations and Computation (max 24)		Processes and Application (max 28)		Total Test (max 80)	
	Post	Pre	Post	Pre	Post	Pre	Post	Pre
Experimental group (N=283)	19.90	16.63	16.83	12.92	15.45	10.57	52.18	40.12
	4.02	*3.74*	*5.37*	*5.68*	*3.73*	*4.735*	*10.81*	*11.02*
Change scores	3.27		3.91		4.88		12.06	
Control group (N=179)	18.44	16.22	15.15	11.65	12.8	11.02	46.39	38.89
	5.13	*5.65*	*6.77*	*5.87*	*4.47*	*3.39*	*14.19*	*12.63*
Change scores	2.22		3.50		1.78		7.50	
Effect size (Cohen's d)	*0.23*		*0.07*		*0.77*		*0.37*	
Male experimental students (N=150)	20.05	16.67	16.65	13.43	15.64	10.37	52.34	40.47
	4.09	*3.68*	*5.17*	*5.64*	*3.63*	*4.59*	*10.74*	*10.93*
Change scores	3.38		3.22		5.27		11.87	
	18.01	15.59	13.95	11.21	11.82	10.89	43.78	37.69

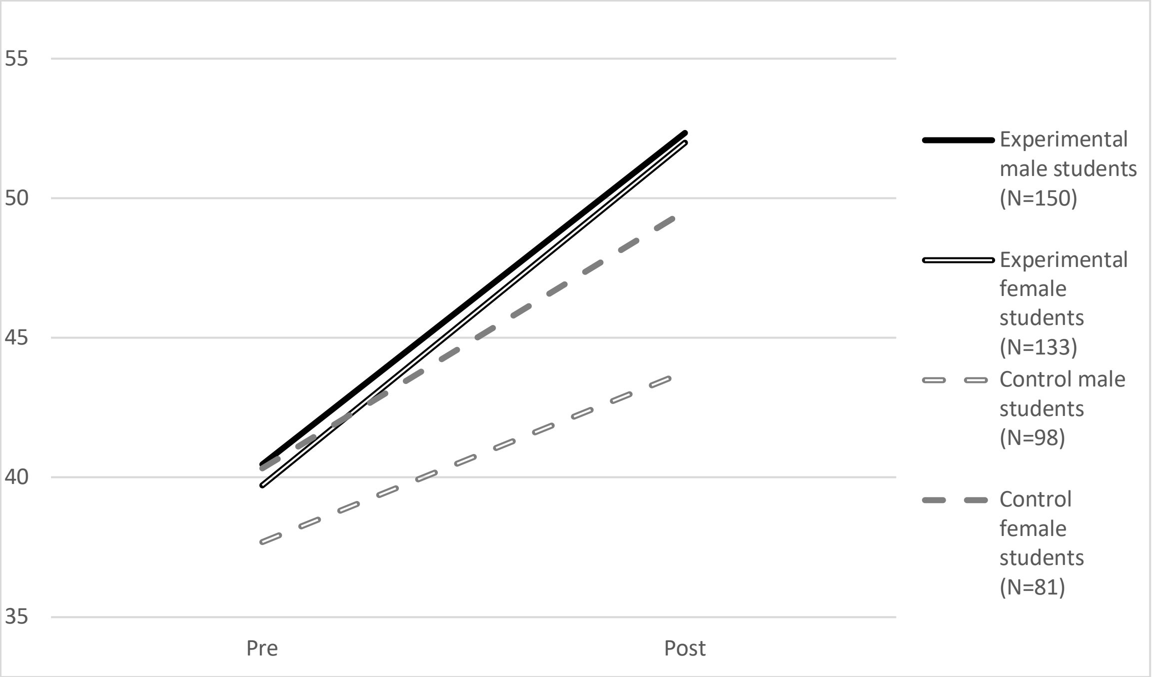
Male control students (N=98)	*5.32*	*5.49*	*6.68*	*5.38*	*4.54*	*3.38*	*14.37*	*12.26*
Change scores	2.42		2.74		.93		6.09	
Effect size (Cohen's d)	*0.21*		*0.08*		*1.08*		*0.47*	
Female experimental students (N=133)	19.74	16.58	17.02	12.35	15.23	10.8	51.99	39.72
	3.94	*3.82*	*5.59*	*5.69*	*3.84*	*4.9*	*10.92*	*11.15*
Change scores	3.16		4.67		4.43		12.27	
Female control students (N=81)	18.96	16.98	16.59	12.19	13.99	11.17	49.54	40.33
	4.87	*5.79*	*6.63*	*6.40*	*4.1*	*3.42*	*13.38*	*12.99*
Change scores	1.98		4.40		2.82		9.21	
Effect size (Cohen's d)	*0.27*		*0.04*		*0.41*		*0.26*	
Experimental low performers (N=97)	18.64	13.69	13.78	7.54	14.55	7.14	46.97	28.37
	3.93	*3.02*	*5.36*	*2.99*	*4.20*	*2.87*	*11.16*	*4.28*
Change scores	4.95		6.24		7.41		18.6	
Control low performers (N=67)	15.57	11.72	10.58	6.48	10.39	8.09	36.54	26.28
	4.92	*3.24*	*5.60*	*2.91*	*3.42*	*2.57*	*11.05*	*4.91*
Change scores	3.85		4.1		2.30		10.26	
Effect size (Cohen's d)	*0.25*		*0.39*		*1.31*		*0.75*	

On the scale of Operations and Computation the groups did not differ significantly (F (1, 452) = .52, p= 0.47, partial η^2 =0.00). Graph 2 illustrates the change of the GMADE total score for the students from both groups. These results are also echoed by the positive standardized effect sizes (Cohen's d) suggesting the most important effects of ELM on the students' ability to solve mathematical problems. On this set of skills, the experimental students outperformed their control peers by .77 standard deviation.



Graph. 2. ELM vs. control students' gains on GMADE Total Score

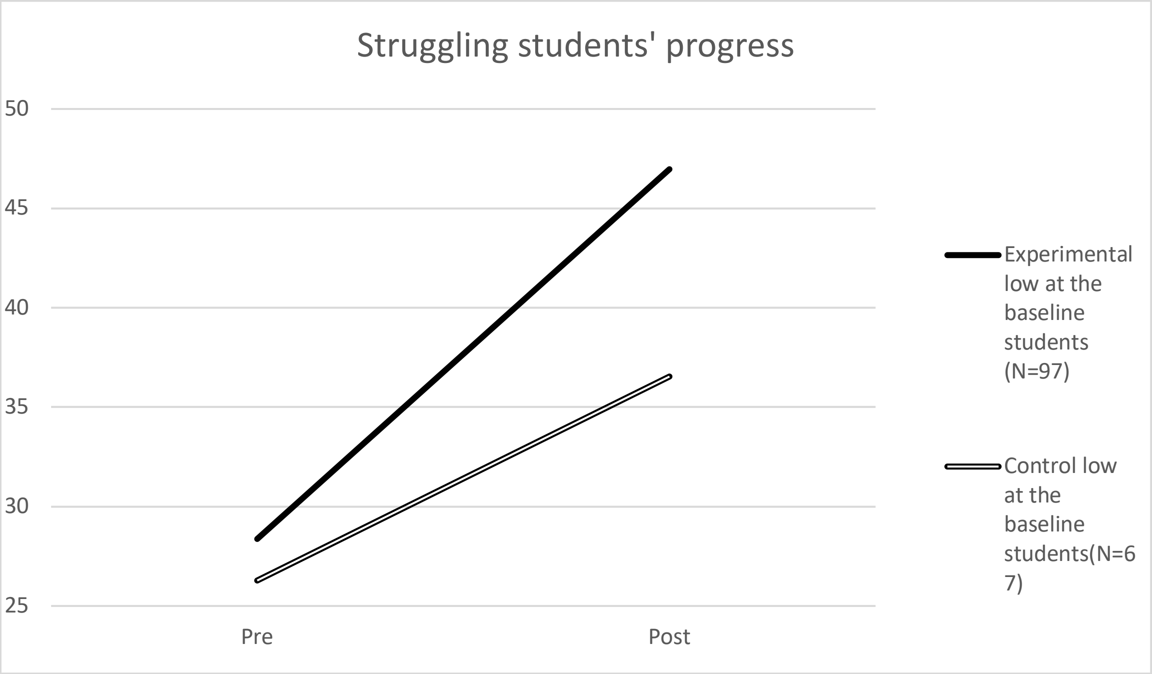
When included to the repeated measures model as another between-subject factor, in addition to the treatment effect, the student gender factored into the difference between experimental and control students' mathematics skills from pre to post-test, F (3, 448) = 3.25, p = .002; partial η^2 =0.02. The univariate results suggest that on each of the four GMADE scales the experimental students of both genders gained more than their control peers with the statistically significant difference on the scale of Process and Applications (F (1, 450) = 8.37, p= .004, partial η^2 =0.02). The variation of gain scores between boys and girls from experimental and control groups on the GMADE total test is reflected in graph 3. The ELM instruction minimized the difference between students of both genders. Not only the control students' gains were significantly smaller than those of the experimental students of both genders, the initial gap between the control male and female students became increasingly larger at the conclusion of the study.



Graph. 3. ELM vs control students gains by gender on GMADE Total Test Score

Finally, we explored if the ELM effects may vary as a function of student pretest mathematic ability differences. We performed a repeated measures analysis to compare pre-post change in GMADE scores of the students of low mathematic ability (scored below 34 points at the pre-test) from experimental (N = 97) and control (N = 67) groups – about 30% of students from both groups. The results reveal statistically significant differences between low performing students from experimental and control groups on the set of mathematic measures – F(3, 160) = 17.34, p = .000, partial η^2=0.25. Univariate tests indicated differences between the groups on all GMADE subtests that were statistically significant for the subtests of Operations and Computation (F(1, 162) = 4.68, p = .03; partial η^2 =0.03), Process and Applications (F(1, 162) = 52.17, p = .000; partial η^2 =0.24) and GMADE Total test (F(1, 162) = 24.61, p = .000; partial η^2

=0.13). Graph 4 illustrates the improvements of low math performing students in the experimental and control groups. As a result of ELM instruction, the low math ability students made an important progress to catch up with an average math student from the experimental group. The overtime improvements of the control students were less important and the gap separating the low-level math ability students from both conditions grew significantly larger at the post-test. It is important to note that it is for the sub-sample of low-achieving math students, that the ELM effects were consistently the largest on all GMADE measures of mathematic skills. It was on the Process and Applications and Total scales that the low-level math skills experimental students outperformed their control peers by 1.31 and 0.75 of standard deviations.



Graph.4. ELM vs control students: low at the baseline on GMADE Total Test Score

In summary, all the analyses yielded consistently positive effects of ELM on the four mathematic outcomes where all grade-one students who learned with ELM for over two terms benefited from the software. The effects were important for the students of both genders and particularly significant for those struggling in mathematics. We observed the largest effects on the student’s ability of solving word problems in algebra, geometry, measurement, money, numeration, quantity, sequence, statistics and time measured on the GMADE Process and Applications subscale.

4.2. Teachers and ELM Instruction

The data from teacher surveys, observations of mathematics classrooms and checklists of ELM activities, although incomplete, allowed us to outline the context in which the ELM and regular grade-one mathematics instruction unfolded.

The summary of *teacher self-reports* is presented below. A combination of computer technology was available for teaching in each participating school. The school computer lab was supplemented with a set of government-provided (DLP) computer tablets. Since a quarter of the experimental teachers reported their classes having no access to technology, scheduling and coordinating access to computer devices was critical at the onset of the study. Around 70% percent of teachers described these devices as reliable. With the average ratio of 2.5 students per computer, about 35% of teachers stated that there were enough of them for the entire class. Availability of electricity was reported as an issue by 17% of experimental teachers. At the pretest teacher self-reports revealed that the experimental teachers felt more comfortable in their abilities to teach with computers (M=3.45; SD=1.44) than their control colleagues (M=2.88; SD=.99). Meanwhile, the control teachers expressed more confidence in teaching early mathematics (M= 3.6; SD=.55) than the experimental teachers (M= 2.8; SD=1.6). In regard to the mathematics content the teachers taught to grade-one students, teachers' responses were split (Table 2). Teachers unanimously reported counting as the concept they taught and decomposing as the concept they did not teach in grade one. The majority of teachers in both conditions reported teaching comparing, subtracting and adding whereas the self-reports of teaching the concepts of place value, geometry and patterns varied.

Table 2. *Teaching grade-one mathematic concepts*

Grade-one math concepts	Experimental teachers(N=9)	Control teachers(N=5)
Counting	100%	100%
Comparing	72.7%	62.5%
Subtracting	72.7%	75%
Adding	72.7%	87.5%
Place value	63.6%	37.5%
Geometry	45.5%	75%
Patterns	45.5%	62.5%
Decomposing	0%	0%

Table 3 summarizes overtime change statistics for the 8 experimental teachers. From pre- to post-test, there were shifts in teaching mathematic concepts. With the exception of counting and decomposing that the respondents either taught or did not teach consistently, teaching all other concepts were reported more frequently. There were noticeable improvements in teachers' perceptions of their own confidence in mathematics as well as comfort in teaching mathematics with computers. For instance, their level grew from “somewhat unconfident” to “confident” in math confidence and from “neutral” to “very comfortable” in ability to use computers for instruction.

Table 3. *Self-reported change from pretest to post-test: means, standard deviations and paired difference statistics for ELM teachers*

	Post-test	Pretest	Paired t-test, significance
Counting	1.00 (.00)	1.00 (.00)	.00
Comparing	.88 (.35)	.75 (.46)	.55
Subtracting	1.00 (.00)	.75 (.46)	1.53
Adding	1.00 (.00)	.75 (.46)	1.53
Place value	1.00 (.00)	.63 (.52)	2.05
Geometry	1.00 (.00)	.63 (.52)	2.05
Patterns	1.00 (.00)	.63 (.52)	2.05
Decomposing	.00 (.00)	.00 (.00)	.00
Confidence in early mathematics	4.38(.74)	2.5 (1.60)	3.07**
Comfort in ability to teach with computers	4.25(.46)	3.25(1.67)	1.60

** p< .00

At the conclusion of the study, experimental teacher reported some details about their experiences of teaching mathematics with ELM. Over the weeks of implementation, teachers became more comfortable in teaching mathematics with ELM (M=3.75; SD=.71). They used the ELM activities to teach a range of mathematical concepts including subtraction (100%) and addition (100%). ELM counting and comparing was used by 62.5% and 50% of teachers respectively whereas 37.5% reported having taught place value, geometry, patterns and number displacement with ELM. ELM bar graphs activities were used by 12.5% of teachers. All eight teachers reported having received in-school support on how to integrate ELM in mathematics instruction and their satisfaction with it (M=4.13; SD=.64).

5. Discussion

This study demonstrates the impact of the ELM computer software on the educational achievement of Kenyan grade-one students. The results complement and extend prior research on ELM (Abrami et al., 2017; Lysenko et al., 2016). Establishing foundational skills in mathematics gives students a headstart on the development of essential numeracy skills useful in STEM subjects in school, after graduation, and later in life. The improved young students' mathematical abilities, as the main outcome include both basic and more complex skills such as understanding mathematic language and solving problems. In addition to putting higher levels of cognitive demands, solving word brings variation to students' practice in basic mathematical operations and prepares students to use mathematical skills in everyday situations outside of the classroom. This improvement in problem solving skills is particularly important in the light of the Kenya results on a mathematic survey conducted by People's Action for Learning (PAL Network, 2020) in 13 low- and middle-income countries. The report suggests that only 29.3% of students in grades 2 and 3 from rural Kenya were able to successfully complete the word problem two-digit subtraction task.

The overall effects of ELM were evident for both genders. In the context of developing countries, the research suggests that significant gender discrepancies in mathematics achievement emerge by the beginning of grade 2 (e.g., Pitchford, 2018). The implementation of ELM instruction in grade 1 not only prevented the initial difference between boys' and girls' mathematic skills from growing, but indeed reduced it to the negligible level. Conversely, the gender discrepancy in the control group became significantly larger. This comes as no surprise since by design, ELM offers mathematic content and activities that equally advantage students of both genders. The training and support materials offered to the teachers suggested ways to enhance gender equality in their instruction.

The gains of low-ability grade-one students who learned with ELM is another critical finding. A key objective of any early intervention is to improve the skills of the students who are in greatest need of instruction. Thus, by diminishing the gap between achieving and struggling students, this result implies that exposing grade-one students to ELM may reverse the "Matthew's effect" (Stanovich, 2009), the phenomenon describing how the gap between high- and low-ability students increases as they progress through the years of schooling. Such important improvement in mathematics ability is promising in the context of evidence suggesting that in developing countries it might be the students with stronger skills who gain more from using technology than their peers with weaker baseline skills (e.g., Kim et al., 2016).

The success of ELM can be explained, in part, by what is known about designing instructional multimedia (Mayer, 2008) and by the research summaries and recommendation of the NCTM (2009, 2014) and others (e.g., Cheung & Slavin, 2013; Hardman, 2019) The application of these principles to the ELM design resulted in a reduction of extraneous elements in the software, by keeping the design simple, supporting working memory with learner-paced segments, and using both verbal and visual modes of representation. Moreover, ELM scaffolds the development of skills and sub-skills identified by the research on emerging mathematical proficiency. Further, the use of interactive multimedia in the tool illustrates key mathematical concepts in an engaging and readily understandable fashion for young learners and because students manipulate the software, it ensures a high degree of learner interactivity, rather than passivity, often associated with teacher-centred frontal instruction. Also, the levelled and progressive difficulty of the ELM tasks insures that students advance through what the research evidence concludes are key mathematical concepts, at a pace appropriate for their prior achievement and understanding. Such features of the ELM software make it an important learning supplement in the context of the national DLP initiative where the curriculum-linked digital content is mainly a static duplication of textbook materials (Gaible et al., 2018).

ELM is not designed to be a substitute for classroom instruction, but instead is meant to support the efforts of classroom teachers when properly integrated into the mathematics curriculum and classroom routines. To this end, the ELM intervention benefited from ongoing professional development as teachers experienced the rewards and challenges of using ELM. The model of in-school continuous professional development is one of the keys to successful implementation, where ELM is an essential part of instruction affecting teacher comfort and student achievement. In short, ELM is not designed as a stand-alone application to replace teachers, but to support them in guiding children to mathematics success through technology integration. It has been widely noted that elementary school teachers often suffer from both a lack of understanding of mathematical concepts and a certain anxiety about teaching mathematics which can be transmitted to students, who may experience their own low mathematical self-concept (e.g., Kaskens et al., 2020). ELM provides the type of scaffolding that teachers need to insure not only that they cover mathematics curriculum but deliver the concepts to students correctly and confidently. Indeed, this intervention involved regular classroom teachers who acted within their regular mathematics classrooms. The ELM teachers had complete autonomy in making decisions about when and how the tool fit the curriculum and syllabus as well as how to integrate ELM into their mathematics instruction.

This study demonstrates that the ELM interactive software impacts positively student learning of key mathematical skills in a developing world context. All students learned whether they were boys or girls, or whether their prior mathematics achievement was low. Classroom integration of ELM, coupled with ongoing professional development and support, suggested important shifts in teaching behavior. Future research of ELM needs to explore the impact of the software on a larger sample of teacher and student participants where data collection is less compromised by attrition. It may also take more government and school administrative effort to improve access to working technology. After all, a longstanding change cannot be maintained through teacher commitment alone; hence, the importance assigned to systematic support including educational policies, school environments, and widespread professional development. At the same time, the instructional design of ELM may need refinement to increase the flexibility with which both teachers and students use the software; for instance, making it easier to navigate activities and addressing difficulty levels. As we work from a research project to wide-scale implementation we hope that this encouraging experimental evidence gets translated to a greater number of schools, teachers, and students. For teachers, this may mean working at both the pre-service and in-service levels and using interactive multimedia to support professional development at a distance that is scalable and cost efficient.

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