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Using Interactive Software to Teach Foundational Mathematical Skills

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Abstract

The pilot research presented here explores the classroom use of Emerging Literacy in Mathematics (ELM) software, a research-based bilingual interactive multimedia instructional tool, and its potential to develop emerging numeracy skills. At the time of the study, a central theme of early mathematics curricula, *Number Concept,* was fully developed. It was broken down into five mathematical concepts including counting, comparing, adding, subtracting and decomposing. Each of these was further subdivided yielding 22 online activities, each building in a level of complexity and abstraction. In total, 234 grade one students from 12 classes participated in the two-group post-test study that lasted about seven weeks and for which students in the experimental group used ELM for about 30 minutes weekly. The results for the final sample of 186 students showed that ELM students scored higher on the standardized math test (Canadian Achievement Test, 2008) and reported less boredom and lower anxiety as measured on the Academic Emotions Questionnaire than their peers in the control group. This short duration pilot study of one ELM theme holds great promise for ELM's continued development.

Keywords: Interactive online software, early elementary, mathematics instruction, numeracy skills, number concept, dispositions towards mathematics, two-group post-test design

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Introduction

A growing body of research evidence shows that numeracy skills on par with literacy skills are important predictors of subsequent academic achievement and school success, because such skills provide the foundation for more advanced and complex skills (e.g., Claessens & Engel, 2013; Duncan et al., 2007). Furthermore, early development of mathematical skills leads to a higher likelihood of entering math-intensive fields of tertiary study and math-based careers (Orpwood, Schmidt, & Jun, 2012). Although international comparisons such as TIMSS (Martin, Mullis & Stanco, 2012) and PISA (Organization for Economic Cooperation and Development [OECD], 2014) have shown certain improvements of students' mathematic achievement, these results yet imply that after years of schooling a large number of children fail to demonstrate understanding of basic concepts and fail to apply this knowledge in straightforward situations. Even in the countries whose outcomes in mathematics compare favorably, a large proportion of the population function at a low numeracy proficiency (e.g., Statistics Canada, 2005; 2011) that can be traced back to not acquiring appropriate prior knowledge in elementary school (NMAP, 2008).

At the same time, numeracy research accumulated in the past decades has pointed to what effective teaching of mathematics entails. Primarily, such instruction builds a solid understanding of numbers and quantities, and connects this understanding to a range of computational methods and strategies (e.g., Anthony & Walshaw, 2007). It also develops procedural and conceptual fluency and mastery in selecting and using these strategies in practice (NCTM, 2014). Further, it reduces anxiety, an important barrier to learning mathematics (Ma, 1999). The research also indicates that wise uses of learning technology applications designed to provide additional instruction at students' assessed levels of need can strengthen mathematic instruction (e.g. Cheung & Slavin, 2013). Mayer (2008) devised a set of evidence-based principles of multimedia instruction design. The application of these principles to learning software design allows for reducing extraneous elements in the software, keeping the design simple, and supporting working memory with learner-paced segments and using of both verbal and visual modes of representation.

Given this evidence of the importance of numeracy and the promise that learning technology holds to mathematic instruction in early elementary classes, this paper reports on a pilot study that examines the following research question: Does using ELM software package in grade 1 mathematics classrooms enhance student numeracy skills and improve attitude towards learning mathematics?

Literature Review

In this section we provide an overview on what the literature tells us about effective early grade mathematics curricula, beneficial instructional practices and the use of technology in the teaching of early grade mathematics.

Effective Early Grade Mathematics Curriculum

Key advocacy groups for mathematics education, such as the National Council of Teachers of Mathematics (NCTM) and the National Mathematics Advisory Panel (NMAP), issued their position statements on the importance of developing early numeracy skills. For instance, building a solid command of whole numbers is an important prerequisite for learning higher mathematics (Fennell et al., 2007; Geary et al., 2007; NCTM, 2000; NMAP, 2008). Whole number competencies in K–2 grades include basic number properties such as count and position on a number line; change in count and position; cardinality; four arithmetic operations; composition of numbers; estimation; mathematical equality and the relationship between arithmetic operations and counting.

The literature emphasizes the importance of elementary students having conceptual understanding of numbers and quantities, and connecting this understanding to computational methods and strategies (e.g., Anthony & Walshaw, 2007). Achieving fluency and mastery in using these methods and strategies is the key expectation of an effective mathematics curriculum and instruction (NCTM, 2014). Computationally fluent students are flexible in the strategies and methods they choose; they understand and explain these strategies and produce accurate answers efficiently. Computational mastery manifests in students' ability to instantly recall arithmetic procedures and the ability to carry them out automatically. These particular abilities decrease cognitive load and free 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 allows the student to proceed from concrete to abstract, reaching the ability to carry out mental computation (e.g., Baroody's (2006) phases of progress to computational mastery and fluency).

Student motivation towards mathematics is yet another important factor contributing to a student mathematics proficiency and achievement. In particular, mathematics anxiety has been a prominent concern as it leads to avoidance of the subject and inability to achieve in it (Ma, 1999). According to Ashcraft and Kirk (2001), anxiety also adds an additional burden to working memory that reduces the availability of the cognitive resources needed to complete certain types of mathematical tasks.

Instructional Practices

Research evidence points to instructional practices that drive student motivation and improve proficiency in mathematics. These range from broad curricular approaches to specific instructional techniques. Specifically, based on the comparison of international curricula, the National Mathematics Advisory Panel proposed that a curriculum that is focused and has a coherent progression on mastering critical topics is essential for students to learn mathematics. In their 2008 report, the Panel recommends that K–2 curricula should focus on a few topics but reach complete mastery closure on each of them without revisiting these topics from year to year.

Many instructional techniques have been found to enhance student performance in mathematics (e.g., Baker, Gersten, & Scanlon, 2002; Gersten et al., 2008; Gersten et al., 2009). For instance, effective mathematic instruction is tuned to students' prior knowledge of mathematical concepts. According to Anthony and Walshaw (2007), children's acquisition of new mathematical ideas depends on them having the prerequisite knowledge that varies as a factor of children growing up in a variety of environments. Hence, to be effective, instruction has to frequently assess what students understand and are able to do mathematically, and then respond to each individual student's strengths and weaknesses. To respond to students' different levels of understanding, differentiated tasks enable students to proceed at their expert level.

Since no one practice dominates across all settings and learners, Gersten and his team (2008) recommend a "balanced approach" to teaching mathematics where direct instruction is balanced with inquiry instruction. Such balance allows students with low achievement or learning disabilities to benefit from explicit and direct instruction in mathematics, while gifted students enjoy programs providing them with opportunities to learn at their own pace. Guided inquiry or guided discovery may be an example of a balanced approach as it provides scaffolds for learners appropriate to each child's ability and prior experience whereas problems are presented in small incremental steps. A balanced approach also includes student-centred elements (working in groups, in pairs, etc.), the use of computer-assisted instruction, and teacher-centred elements (sequencing of tasks and direct instruction when needed) (Gersten et al., 2008; Sweller, 2008).

Technology and Teaching Mathematics

With an increased presence of computer technologies (CT) in classrooms, the use of CT has become a distinct subject of study in systematic research (for example, Li & Ma, 2010; Slavin & Lake, 2008; Cheung & Slavin, 2013). Although evidence for the effectiveness of computer-assisted instruction is mixed, one consistent finding has emerged: effects of CT on students' math achievement, while modest, are higher at the elementary level and for those students with special needs and those at risk of failure (Li & Ma, 2010; Slavin & Lake, 2008). Offering drill and practice, computer-assisted instruction showed positive impact on computation (Slavin & Lake, 2008) and helped young children with counting, sorting and fluency in addition (Clements, 2002), as well as understanding abstract mathematical concepts (Li & Ma, 2010). When combined with a constructivist approach (e.g., guided inquiry, discovery learning), computer-assisted instruction had even better results than if combined with a traditional teaching approach (Li & Ma, 2010). The capacity of software to provide frequent feedback (short, explicit error messages) also improved students' achievement (Li & Ma, 2010). Students performed best when technology use was blended with regular classroom instruction or was part of a more comprehensive program (Cheung & Slavin, 2013). Game contexts, if incorporated in mathematics software, provide motivation to learn for children accustomed to being entertained by television and online, mobile or computer games (Vogel et al., 2006).

Furthermore, it is important to note that computer technology may reduce the challenges that teachers face when they try to implement complex strategies in their classrooms. Designing instruction that involves the application of multiple strategies is difficult for many reasons, including the time and energy it takes teachers to prepare adequate instructional materials, as well as the training required for teachers to become fluent in the strategies and their systematic and appropriate integration into teaching the domain knowledge (Boekaerts & Corno, 2005). For instance, Baroody, Eiland, Purpura, & Reid (2013) emphasize that a well-designed computer program is able to offer the scaffolding for guided discovery learning that most teachers cannot provide. Specifically, it can underscore connections that may not be known, explained clearly, or emphasized by most teachers (e.g., number-after relations and adding 1).

ELM Design and Development

Based on the current evidence showing promising links between mathematic instruction and computer technologies, an interactive online bilingual (French, English) tool, Emerging Literacy in Mathematics (ELM), was developed. The design of the tool was also rooted in empirically grounded multimedia learning principles (Mayer, Heiser, & Lonn, 2001; Mayer, 2008) to reduce cognitive load, engage learners, reduce anxiety, and scaffold understanding of mathematical concepts. Research evidence on effective mathematic instruction also guided the development of ELM.

ELM encourages the development of early numeracy skills by offering a hierarchical approach towards supporting students in their learning of foundational numeracy concepts. At the time of this study, a central theme of early mathematics curricula, Number Concept, was fully developed in ELM. This theme was broken down into five ideas (or mathematical concepts) including counting, comparing, adding, subtracting and decomposing. Each of these ideas was further subdivided into a number of activities, yielding a total of 22 online activities, each building in level of complexity and abstraction. Thus, the theme introduces a mathematical concept through a sequence of activities that moves the student from concrete images and physical actions to mental images and abstract symbolic representations.

This design also allows teachers to observe how each student is performing on an activity, and determine whether the student understands or is performing tasks in a rote manner. Each concept is broken down into a multi-step sequence to allow for differentiation based on each learner's current knowledge as well as his or her ability. 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. Following such a sequence provides each student with support; in particular, a fall-back resource if at any stage they become unsure of how to perform a task.

For each activity, students are presented with a jigsaw puzzle having a number of missing puzzle pieces, where each piece represents a set, or repetition, of the activity. The activity is completed once the student gains all the missing puzzle pieces. In order to make some activities more manageable for students, the activities were broken into multiple phases. Only when students provide a correct answer for the first part of an activity are they allowed to move on to the second part of the same set. Completing all the phases earns the student the corresponding puzzle piece.

To encourage student autonomy, ELM offers a system of embedded support. A demo was created for each activity. Each demo video shows students the steps involved in completing the activity. Because receiving information for the whole activity all at once might overwhelm students, demos are presented to correspond with each phase. All activities have a 'help' button to provide built-in just-in-time support. 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.

Context sensitive error feedback was built into each of the activities. If a student makes an error, the tool provides an audio cue to draw students' attention, which is followed by visual feedback to help students see where they made an error. A soft-lock feature has also been incorporated into the tool to send a student experiencing repeated difficulties in a particular skill a notice that the teacher should be called for help. An unobtrusive icon appears on the student's screen prompting a student to ask the teacher for help and visually alerting a circulating teacher that this particular student is experiencing difficulty and needs assistance. In addition, the teacher is notified by an electronic report as to which students triggered such a soft-lock and during which activity a student is experiencing difficulty.

To develop mathematical skills within a "global" framework, and to expose students to basic geographic regions, each theme is assigned to a particular continent. In turn, each idea within a theme is associated with a particular animal category and each activity within an idea has a particular animal assigned to it. This animal is an "animal friend" and the picture of that animal friend is used for the jigsaw puzzles that students are asked to complete. Once a student completes an activity, the animal friend in the picture is added to the student's collection of animal friend pictures providing a fun and engaging environment for grade 1 students.

A Teacher Module allows teachers to explore the various ELM activities. Further, the Teacher Management feature offers opportunities for teachers to provide instructional differentiation and also allows the teacher to review their students' progress in ELM. Teachers 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 'redo' for any activity. The 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, if the student had trouble at some point in the activity and whether the student is currently soft-locked. If a student has been assigned a specific plan, the report reflects the settings of that plan. A collection of multimedia resources specifically intended to help teachers in their use of ELM is also part of the teacher module. 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.

In order to help parents support their children in the home environment as they develop numeracy skills, a Parent Module has also been developed. Its content provides parents with an overview of numeracy and why it is important, an explanation of ELM and how the software helps to develop numeracy skills, and advice on how to support their children's budding numeracy skills outside of school. The overall objectives of each theme are described, as well as detailed descriptions of the activities their children are engaging in. The module also provides additional links to other early numeracy resources.

Objectives of the Study

This pilot study was performed to begin the evaluation stage of the design and development of the ELM software and to explore whether using ELM in classroom instruction provided to grade 1 students would yield higher mathematics achievement and more positive dispositions towards mathematics compared to students in control classes in the same schools.

Method

Study Design

Twelve teachers and their students from five schools from English and French school boards in an Eastern province of Canada participated in this study designed as a small-scale quasi-experimental two-group post-test study. The six control classrooms were selected from the same schools to match as closely as possible the six experimental classrooms. All teachers followed the provincial curriculum requirements for the development of mathematics and were at liberty to decide on the method of classroom instruction as well as the instructional tools and techniques they would use. The six experimental teachers taught with the aid of ELM, while their control counterparts relied on their usual teaching approach. Student data were collected after ELM had been implemented in the experimental classes for about seven weeks. In order to learn about the use of the software by teachers and students, mathematics instruction was observed in each of the experimental and control class twice. In addition, the trace data generated automatically by the ELM software were used. Informed consent was obtained from teachers and students' parents following Canada's Tri-Council Policy on the ethical treatment of research participants.

Study Sample

Of the 234 grade one students who participated in the field test, 120 came from six control classes who did not use ELM whereas 114 students were from six experimental classes where ELM was used. An initial reduction in sample size occurred after parents of 27 students did not give us their permission to use their children's data. Further, 9 grade-two students from one split class in the control condition were excluded, leaving the data collected from grade one students only. Also 12 students did not complete the test for mathematics achievement and 20 students did not complete the test for attitudes towards mathematics. Consequently the final size of the sample was 186 students (N_{exp} = 99, N_c = 87) for the achievement test and 178 students (N_{exp} = 95, N_c = 83) for the attitudinal measure.

Intervention

During the study, the six experimental teachers received two one-day bilingual ELM training workshops. The purpose of these workshops was twofold: to help teachers build capacity in using ELM for mathematics instruction as well as to offer a space for discussion and sharing. The research team also provided bilingual teaching materials including lesson plans for each of the activities within ELM. The decision of whether or not to use these materials was left to the teachers' discretion. Technologies used for mathematics teaching varied among the experimental classrooms. Some arranged for access to a stationary computer lab to be used on a weekly basis, while others brought a mobile lab into their classroom. If available, teachers also used interactive electronic boards to demo the ELM activities or to complete the activities as an entire class. To maximize access to the technology, laptops were loaned to the experimental classrooms in order to have a ratio of at least one laptop per six students. Oftentimes teachers chose to add to the existing classroom centers by arranging the laptops as an "ELM center". Rotation between stations enabled students to use ELM individually.

Instrumentation

Students' skills in mathematics were assessed using a customized version of the 4th edition of the *Canadian Achievement Test*, CAT-4, Mathematics subscale (2010), a standardized achievement measure developed in the Canadian context. Seventeen multiple choice items from CAT-4 levels 10 and 11 were selected in the compilation based on their relevance to the concepts and operations addressed by ELM such as counting, adding, subtracting, and pattern recognition.

An abridged version of the *Academic Emotions Questionnaire* – Elementary School, AEQ, (Lichtenfeld, Pekrun, Stupnisky, Reiss, & Murayama, 2012) consisting of 20 items was used to measure students' emotions about mathematics. These tapped into one of three emotional states commonly experienced in the school context: mathematics enjoyment, anxiety, and boredom. Students were expected to rate each read-aloud statement using a five-point Likert-type picture scale.

In order to fit the context of the French and French immersion classrooms, a professional translator translated both instruments into French.

A *Mathematics Instruction Observation* form (Lysenko, Rosenfield, Dedic, & Searle, 2014) was used to collect and report observations in each of the 12 classrooms. The form focused on the following aspects: classroom physical context, classroom management, effects of technology, structure of mathematics instructional activities, students' motivation, engagement and enthusiasm, and ELM implementation. Besides the above, the form also offered a scale of overall quality of teaching and student engagement. The observation schedule included two visits to each classroom: the first wave was completed in the beginning of the implementation and the second one after sustained use of ELM. Control and experimental classes from the same school were observed on the same day in sequence by a trained observer with mathematics teaching experience.

The ELM software also generated statistics concerning the time that students spent logged-in in ELM and allowed for estimating the amount of student exposure to ELM. These data were retrieved monthly.

Analyses

All student data were entered into SPSS 21 for Mac OS X and verified for accuracy. Students for whom the test data were missing were excluded from analyses. Standard screening procedures suggested data normality. Independent two-sample t-tests were performed on the post-test scores as dependent variables to examine the difference between the ELM and control scores on the standardized mathematics scale and academic emotions questionnaire. Observation data were examined via SPSS descriptive analysis. In addition, standardized effect size coefficients (Cohen's d) were calculated to identify the magnitude of difference between the experimental and control groups on mathematics achievement test scores.

Results

The following section presents the results that were obtained after analyzing the student and classroom data. The CAT-4 and AEQ results make up the core of this section whereas the description of the ELM instruction allows for situating these results within the instructional context.

Achievement Data

Composite scores were calculated by averaging the sum of the CAT-4 items pertaining to the same mathematics concept/operation. As a result, the following six composite scores were formed: count and compare; count and subtract; add; subtract; pattern; and count. Since one item required a combined operation of adding and subtraction, the add and subtract score was also analysed. An independent sample t-test was run to test for the difference between experimental and control groups.

The scores presented in Table 1 indicate that students in the ELM classes consistently tend to outperform their peers in the control group on all mathematics concepts and operations measured by the customized version of the standardized test. However, the difference between the groups was statistically significant (2-tailed) only for the complex task of combining addition and subtraction skills ($t\ (184) = 5.24$, $p < 0.000$). On this task ELM students' average score ($M=0.64$, $SD=0.48$) is significantly higher than that of an average grade 1 Canadian student tested in spring ($M=0.45$, $SD=0.50$) (http://www.canadiantestcentre.com/pdfs/CAT4TechnicalManual.pdf). The magnitude of difference between these groups also favors students in the ELM group but varies from large (add and subtract) to small (e.g. pattern recognition, count and subtract) to minimal (e.g. add).

Table 1. Descriptive statistics (means and standard deviations), t-test values (significance levels) and effect sizes with CAT-4 scores for ELM and control

	ELM group (N=99) Mean score (SD)	Control group (N=87) Mean score (SD)	t-test (p values)	ES
Add	0.73 (0.31)	0.71 (0.33)	0.46 (0.65)	0.06
Subtract	0.56 (0.42)	0.53 (0.42)	0.52 (0.61)	0.07
Count & compare	0.93 (0.17)	0.92 (0.15)	0.43 (0.67)	0.06
Count & subtract	0.68 (0.25)	0.64 (0.27)	0.96 (0.34)	0.15
Add & subtract	0.64 (0.48)	0.28 (0.45)	5.27 (0.00)	0.77
Pattern	0.65 (0.30)	0.59 (0.29)	1.41 (0.16)	0.20
Count	0.75 (0.44)	0.72 (0.45)	0.36 (0.72)	0.07
TOTAL	12.83 (3.71)	12.02 (3.53)	1.52 (0.13)	0.22

Mathematics Emotions

To analyze the difference between the experimental and control students on their dispositions toward mathematics, three composite scores of enjoyment, anxiety and boredom captured on the abridged AEQ Mathematics scale were formed and analysed (Pekrun et al., 2011).

As Table 2 shows, students in ELM classes tended to report less boredom and anxiety than their control peers. However, we found no statistical significance between the experimental and control students' self-reports. The reported effect sizes are consistent with the t-values showing that the existing differences between the groups on the three constructs are small in size.

Table 2. Descriptive statistics (means and standard deviations), t-test values (significance levels) and effect sizes with AEQ scores for ELM and control groups

	ELM group (N=95) Mean score (SD)	Control group (N=83) Mean score (SD)	t-test (p values)	ES
Enjoyment	3.73 (1.27)	3.79 (1.13)	-0.31 (0.76)	-0.05
Boredom	2.30 (1.32)	2.46 (1.27)	-0.86 (0.39)	-0.12
Anxiety	2.04 (1.16)	2.12 (1.09)	-0.45 (0.66)	-0.07

Mathematics Instruction

In total, 24 observations were taken in six experimental and six control classes where each class was observed twice over the two months when ELM was used in math instruction. On average in both groups the quality of teaching and student engagement ratings measured on a five-point scale were around 4 (M_{exp}= 4.08; M_c=4.04). In both groups, most students were attending to the given task. There was minimal or no off task behaviour. The teacher was able to guide students through activities effectively.

Observation reports show that in their instruction the control teachers relied on technology in some form; almost all used interactive whiteboards and some educational mathematics software (for instance, Fish Game, www.toytheatre.com/fishing.php). Table 3 presents the mean scores based on the ratings of a few quantitative questions pertaining to mathematics instruction provided in the observation reports of the experimental and control classes. The ratings given to ELM teachers' pedagogical actions tended to be higher than those given to control teachers on all items except reinforcing mathematics concepts and skills and encouraging student dialogue and discussion.

Table 3. Ratings of mathematics instruction (mean and SD scores) by ELM and control teachers

Teacher self-reported behaviour	Control teachers (N=6) Mean score (SD)	ELM teachers (N=5*) Mean score (SD)
Teacher used mathematical language when giving instruction	3.92 (1.51)	4.00(1.33)
Teacher provided clear directions	3.75(1.42)	4.50(1.27)
Teacher circulated and provided feedback	4.25(1.14)	4.50(1.27)
Teacher reinforced math concepts and skills	4.25(0.97)	4.00(1.49)
Teacher allowed the students who mastered the basics taking more challenging tasks	2.08(1.56)	3.20(1.81)
Teacher took initiative to check on student understanding during instructional time	4.08(1.51)	4.40(1.26)
Teacher took initiative to check on progress during work time	4.08(1.56)	4.40(1.26)
Teacher encouraged student dialogue and discussion during activities	3.25(1.29)	3.15(1.53)
Total scale	31.92(6.95)	32.15(6.67)

* *Scores for a teacher-student removed*

Observation and trace data reports highlighted the following features of ELM instruction. Students were exposed to ELM either in their regular classrooms where available computers (including the lent laptops) were organized in ELM centers around which students rotated, or in the school computer labs. The monthly trace data reports showed that on average an ELM student interacted directly with the tool from 21 to 32 minutes per week. Observation reports in their turn suggested that the optimal focused time a student spent on ELM software runs from 20-30 minutes per lesson. Students are most successful when, before use of ELM, the teacher explains and demonstrates an ELM activity and also models how to use the ELM help. In addition, ELM instruction seems to be more effective in a computer lab. On the one hand, there is an optimal computer-student ratio (one to one). On the other hand, teachers manage homogeneous all-class tasks more effectively, whereas managing students working in different centres within a classroom appears to be more challenging and requires additional skills from the teachers. One of the observers wrote: “Teachers attempting to establish part of the class on computers and part with another activity very often had difficulty providing sufficient support simultaneously to both groups.”

It is important to note that observation reports indicate that teachers were split in their preference for providing “flexible” or “controlled” instruction, resulting in the fact that some teachers allowed their students to progress with the activities at whatever rate the students preferred, whereas other teachers had their students only perform the activities they had chosen. This did not seem to have any effect on students’ engagement or their ability to navigate the activities, though it may imply that some students would repeat earlier activities instead of moving on to the more difficult ones.

Observation reports indicate that student responses to ELM were very positive. The majority of students indicated that they found the activities enjoyable and either easy or just challenging enough. Any issues that arose were around technical difficulties with the beta version, and as expected, when students were able to help each other, those having trouble with the instructions were able to succeed.

Discussion

This pilot study sought to explore whether integrating the ELM software into grade 1 classroom instruction would yield higher achievement scores and better dispositions towards mathematics when compared with students in control classes.

It is important to note that the two-group post-test only research design used in this study imposes limitations on the interpretation of the results. Although experimental and control teachers and their classrooms were pre-selected to be similar, it was not possible to control for lack of initial equivalence among students in the two groups. Small sample size and relatively high variance in scores have also affected the statistical power of the analyses rending it inadequate to detect statistically significant results.

However, despite these limitations, a few important, encouraging results may be gleaned from this study. The outcomes of this short-duration field study suggest that in the hands of teachers, this initial version of ELM shows potential for increasing young students’ understanding of mathematics, particularly of more complex situations, while decreasing their mathematics anxiety and boredom.

In particular, the item in the mathematics test where the ELM students significantly outperformed the control students was the single most difficult question among the seventeen questions asked. In this question the students were presented with a picture of a cube with two numerals on it that required manipulation in order to answer the question. First, students had to translate this story in words that the teacher had read aloud, they had to add the two numerals in the picture (no objects in the picture to enable them to simply count), then they had to either subtract or count down to obtain the correct answer. Further, on this same question the ELM students also outperformed the average Canadian grade-one student, where the ELM students were tested in the middle of the first term of grade one, after a seven-week long intervention, and the Canadian norm set at the end of a full year of grade one mathematics instruction. We believe that this particular result is perhaps indicative of the emphasis in ELM on scaffolding learning so that students are led to successfully solve successively more complex problems. We also suspect that the lack of differences between the control and ELM students on the remaining questions may lie in the fact that the other questions may be answered either by simply counting or by carrying out a formal algorithm without even understanding that algorithm.

Positive results were noticeable in ELM classes after only about seven weeks of implementation (30 minutes of weekly exposure per student). Yet, this duration is far from optimal. According to research on technology interventions, the length of student exposure to the programme is a critical element in its success. Specifically, to ensure that any impact of an instructional programme is reliably measurable, Cheung and Slavin (2013) recommend that an implementation must be at least twelve weeks. Our own research (Meyer, Abrami, Wade, & Scherzer, 2011) on the use of educational technology with young students suggests that an average student direct interaction with the tool should approach 60 minutes per week. Comprehensive integration of ELM into mathematics classrooms is another important aspect if we are to reinforce the fidelity of the implementation. This implies going beyond engaging students in ELM sequences and repetitions, but systematically using the recommended ELM pedagogical approach, including pedagogical materials such as ELM extension activities, suggestions for how to engage students in classroom discussion that will consolidate the learning that took place during software usage, and explanations of conceptual difficulties that students are likely to encounter.

The authenticity of ELM implementation in this pilot study merits special discussion. Traditionally, before education technology enters the real world of classroom instruction, trials of efficacy are performed in controlled settings by researchers themselves or by specially trained professionals. Based on research evidence in the areas of early mathematic instruction and instructional design, ELM is being developed as a free tool available online to allow maximal accessibility to teachers interested and willing to try it in their classroom instruction. Hence, from the beginning, it was important to test it in real-world conditions. Thus, this intervention involved regular classroom teachers, acting within their regular mathematics classrooms. The researchers' involvement was sporadic (they intervened solely on a "when needed" basis) and they never taught the students. The ELM teachers had complete autonomy in making decisions about when and how the tool fit the curriculum and syllabus, how to integrate it into their mathematics instruction, as well as how much freedom to allow their students concerning ELM activities, including the selection and sequencing of those activities. Researchers were involved in the initial training and the provision of ongoing support to participating teachers, and in supplying didactic materials to them.

Although the study showed that the intervention could successfully be driven and directed largely by the teachers themselves, it also revealed the necessity to further develop the teachers' capacity to be in control of the affordances that ELM offers for mathematic instruction and, consequently, to adequately use the ELM features. For instance, to help the teacher address the specific needs of each student, ELM generates an overview of each individual student's progress through ELM. It also allows the teacher to create an individualized plan for each student (or group of students) controlling the assignment of activities and the number of repetitions in each activity. Training with ELM should equip teachers with basic techniques so that they can better address the classroom environment, such as the management of classroom centres, rotation of students, organization of group work, as well as managing ELM homework that would include the meaningful engagement of parents when supporting their children's homework activities using ELM. To enhance the effectiveness of ELM training, there is a need to provide details concerning the fit between the normative requirements (e.g., the NCTM (2006) standards, or locally in Quebec (Ministère de l'Éducation du Loisir et du Sport du Québec [MELS], 2009) and ELM.

Conclusions

The outcomes of this short-duration pilot test suggest that in the hands of teachers ELM, an evidence-based tool, may increase student math abilities and reduce math anxiety and boredom. Although achievement and attitude scores obtained in the pilot favored ELM students, indeed we were able to detect only one statistically significant difference between them and their control counterparts on the single most complex mathematic task tested. This result may in part be due to multiple limitations this pilot study suffers, such as a shorter than recommended intervention duration, limited numbers of students, lack of pre-testing, and only a single item that examined student ability to solve complex tasks.

Further Work

Therefore this small-scale study opens the door to a larger and longer field experiment, whose rigorous design with pre-test data collection will allow for more conclusive findings and generalizable results. Next steps will also focus on the support that teachers need to comprehensively and successfully integrate the program (a more complete version) into their classroom practices. This is a work in progress.

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