Exploring the Effects of Emergent Literacy in Mathematics (ELM) Software on Students’ Achievement, Emotional Engagement, and Social-Emotional Learning Abilities in China

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***Abstract*—This quasi-experimental study investigates the impact of the Emergent Literacy in Mathematics (ELM) software on the mathematical achievement, emotional engagement, and social-emotional learning abilities of second-grade students in China. Participants were divided into two groups: an experimental group and a control group. Over five months, pre-intervention and post-intervention assessments were conducted to evaluate changes in mathematical performance, emotional responses, and social learning skills. Results indicated that there was no significant difference in students’ mathematics achievement (ES = 2.66, $p > 0.05$) through ELM-assisted teaching, while students’ mathematics affects (ES = 2.15, $p < 0.00$) and social emotional learning (ES = 0.88, $p < 0.00$) were significantly improved. Furthermore, an SEM analysis of the relationship between students’ math affects and social-emotional learning has shown that students’ mathematical motivation as well as enjoyment level contribute positively to the enhancement of their social-emotional learning abilities in an ELM-assisted teaching environment. These findings underscore the efficacy of integrating instructional software like ELM in enhancing students’ mathematics cognitive and emotional performances differently, offering valuable insights for educational practices and policy development.**

***Keywords*—Emergent Literacy in Mathematics (ELM), mathematics achievement, mathematics affects, social-emotional learning**

I. Introduction

Mathematics in elementary education is often regarded as the foundation for developing students’ advanced cognitive skills, such as inquiry, problem analysis, problem-solving, critical thinking, and creativity [1]. Yet, many children in developing countries do not acquire adequate mathematical skills or confidence [2]. The results in the 2012 Program for International Student Assessment (PISA) showed that a significant number of students in some East Asian countries and regions were classified as “low achievers”, with Taiwan having the highest percentage at 12.9% [3]. What is particularly concerning is that in the aforementioned areas, even for students who demonstrate relatively high mathematics proficiency, their attitudes toward learning math are predominantly negative [4]. To accurately predict students’ performance in mathematics, it is essential to take a comprehensive approach that considers a range of influencing factors, learning motivation, learning styles, and socio-cultural backgrounds [5]. Thus, addressing the cognitive and affective engagement of students, particularly those who are inclined to face challenges with mathematics, is important [6].

Meanwhile, with the rise of artificial intelligence, the importance of building AI-driven learning platforms to support mathematics education has increased, aiming to reveal the complexity of students’ understanding and personalized learning experiences [5]. Therefore, in recent years, Educators have integrated instructional software in mathematics education to enhance students’ logical thinking, analytic skills, decision-making strategies, critical thinking, and sense of responsibility when facing daily problems [4, 7– 9]. Their research findings suggested that instructional software improves students’ understanding of mathematical concepts by providing personalized learning resources [9] to deepen students’ basic knowledge in geometry, mathematics, and statistics [10]. Additionally, instructional software supports the development of students’ social-emotional skills and improves their interpersonal abilities, especially during social interactions [11]. Thus, the integration of these innovative tools is highly recommended for mathematics teachers to improve students’ learning experience [8], especially to boost students’ thinking by helping them understand topics more deeply and solve problems better [12].

Although the benefits of instructional software in mathematics education are widely recognized, the results have been mixed. Studies indicate that instructional software may not always improve students’ learning outcomes [13]. For instance, research in Malawi has shown inconsistent results in enhancing students’ math performance, despite significant government investment [14]. Similarly, in Peru, while the The One Laptop per Child (OLPC) initiative increased students’ access to computers, it did not lead to improved students’ mathematics skills [15]. Moreover, few previous studies had examined the impact of the instructional software on students’ mathematics attitudes and social-emotional learning ability, which were two critical factors to predict students’ future academic performances [16–19]. These two factors are closely linked to the perception and engage with mathematics, particularly through their self-

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concept and attitude toward the subject. Although the sustainable research has examined the link between mathematical cognitive processes and other systematic factors, such as mathematical emotions in mathematics education [5], Social-Emotional Learning (SEL) has gained significant attention over the past decade. It has been proven to be closely associated with students' physical and mental health, learning ability development, and academic performance [20–22]. However, the relationship between students' social-emotional skills and their cognitive and emotional engagement in mathematics AI-assisted learning environments remains unexplored. Meanwhile, there is a lack of detailed, country-specific data on how to implement these tools in diverse educational settings [10].

These findings highlight the need for further research into how software-assisted teaching tools can enhance both in-class and extracurricular learning experiences. By administering pre- and post-tests over a five-month quasi-experimental study, this research aims to address the research gap through examining the application and effectiveness of ICT in China and evaluating the impact of Emergent Literacy in Mathematics (ELM) software on students' learning outcomes, cognitive abilities, and social-emotional skills. Specifically, the study addressed two main questions:

- Is there a significant difference in mathematics achievement, mathematics-related affect, and social-emotional learning abilities between students exposed to ELM-assisted teaching and those who received traditional textbook instructions only?
- What are the relationships between students' mathematics affects and their social-emotional learning abilities following the use of ELM in mathematics instruction?

II. Literature Review

A. *The Impact of Instructional Software on Mathematics Achievement*

The integration of instructional software in mathematics education has been shown to significantly enhance students' cognitive skills via facilitating deeper understanding and problem-solving abilities [12]. For instance, Pai *et al.* [23] adopted a dialogue-based software to assist Chinese students' mathematics learning. By comparing fifth-grade students' performance in the unit on 'multiplication and division of time expressions' across different teaching modes, the results showed that software-assisted learning not only improved mathematical achievement but also increased students' learning motivation. Moreover, Hwang *et al.* [24] used a math learning software covering all key concepts from the students' current math textbooks. Each concept was presented in three versions: "standard", "detailed", and "advanced", allowing students to choose based on their level. The results indicated that students using the software performed better than those in conventional teaching, and it also reduced students' learning anxiety. In addition, Zaldívar-Colado *et al.* [25] evaluated the use of Sacar10 mathematics by first graders in three schools in Mexico, finding that using it could reduce distractions in first graders and help them deepen their understanding of key concepts. The aforementioned studies underscore the profound cognitive benefits of instructional software, highlighting its potential to transform educational practices by fostering a deeper, more personalized learning experience. Especially, research has shown that the Emergent Literacy in Mathematics (ELM) software has positively impacted first-grade students, helping them grasp essential mathematical concepts and communication (ES = 0.23), mathematical operations and computation (ES = 0.07), and mathematical processes and applications (ES = 0.77) [26]. Additionally, ELM has been particularly beneficial for students who started with lower math skills, as they experienced marked improvements after the intervention [26]. However, most of these studies were concentrated on students' mathematics cognitive improvement, while their emotional engagement impacted by ELM was still unexplored.

B. *The Impact of Software-Assisted Teaching on Emotional Experience*

There has been a growing interest in understanding how instructional software influences students' emotional experiences (e.g., motivation, attention, curiosity, and their capacity to understand and recall information) in learning mathematics [27, 28]. Forsblom *et al.* [19] suggested that emotions like enjoyment, anger, and boredom impact math performance, highlighting that enjoyment leads to better math outcomes, while anger and boredom have the opposite effect. Students' self-concept in mathematics pertains to how students assess their math skills and their learning experience, such as enjoyment and interest in this subject. Students with a positive self-concept and attitude toward mathematics achieve their academic goals faster [18]. Therefore, this concept plays a role in understanding the variations in students' math performance [16, 17].

Pekrun [29] further proposed that students' mathematics emotions can be understood using a framework that categorizes emotions into two main aspects: valence and activation. Valence refers to whether emotions are positive, such as enjoyment, or negative, such as anxiety. Activation refers to whether these emotions are energizing, such as hope, or calming, like hopelessness. Based on this framework, emotions can be further classified into four groups: (1) positive activating such as joy and hope that can increase learning motivation and participation, (2) positive deactivating such as relief, (3) negative activating such as anger and anxiety which can obstruct effective learning and lowers motivation, and (4) negative deactivating such as hopelessness and boredom that decrease both energy and engagement in learning. Building on these insights, multiple studies have explored how to encourage positive activating emotions in math learning [30, 31]. Additionally, digital game-based learning and gamified elements in the instructional software are found to be effective in boosting self-confidence and engagement, which helps to reduce boredom and engage students [32]. This suggests that software's role goes beyond increasing positive attitudes but also alleviating anxiety and stress among students [33]. Further, understanding how specific instructional software impacts students' mathematics emotional engagement practically is also valuable to investigate.

C. *The impact of Software-Assisted Teaching Tools on Social-Emotional Skills*

Social-Emotional Learning (SEL) is a crucial concept impacting students' lives by developing competencies like self-awareness, self-management, and relationship skills [34, 35]. Instructional software plays an important role in developing students' life skills and Social-Emotional Learning (SEL) [27]. Interacting with these tools gives children the opportunity to practice their social skills and build meaningful relationships, which further helps them foster social-emotional development [36]. Many schools have started to incorporate the development of SEL into their curriculum strategies, aiming to not only boost academic performance but also improve class morale [37]. The gamification element in instructional software is found to strengthen students' SEL by encouraging positive emotions and resilience via the trial and error of the fun experiences [27, 38]. For instance, some schools used multimedia programs like KooLKIDS to improve kids' emotional and social skills [39] and social robots to motivate students to interact with people and reduce their anxiety [28, 33]. These positive activated emotions help reduce children's stress, improve overall well-being, and promote better social-emotional learning outcomes [33, 40]. While the potential of instructional software in promoting SEL is promising, research regarding how effective these tools are in developing students' SEL skills is still limited [41]. This study filled the research gap by investigating to the instructional software impacts students' social-emotional skills.

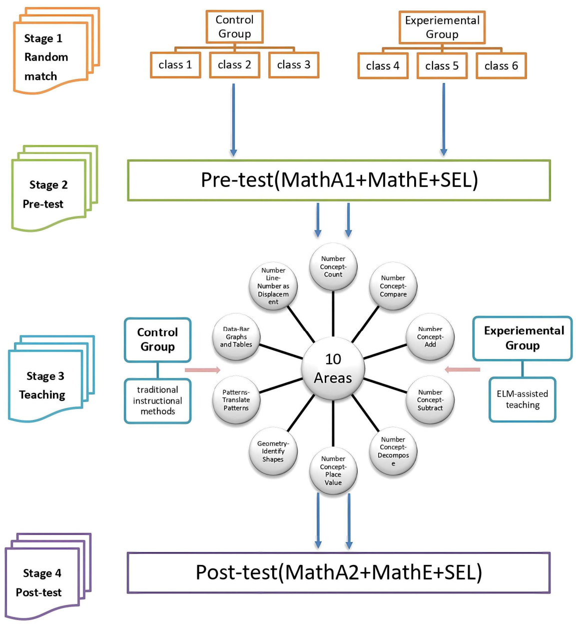
While there is a growing body of evidence [40] supporting the use of Emergent Literacy in Mathematics (ELM) software in mathematics education in developing countries, the question remains unclear whether these positive outcomes are consistent across different cultural contexts in other developing countries such as China. Additionally, research on how ELM can improve students' social-emotional learning and promote other cognitive benefits is also underexplored. By exploring how ELM-assisted teaching affects both students' social-emotional learning and cognitive abilities.

III. Materials and Methods

This study used a quasi-experimental design to examine how the Emergent Literacy in Mathematics (ELM) software affects second-grade students' math achievement, their feelings toward mathematics, and their social-emotional learning abilities. Second graders were chosen as participants because they had moved past the basics covered in first grade and were ready to tackle more advanced concepts and problem-solving tasks. This experimental group was given a computer-assisted instruction with the Emergent Literacy in Mathematics (ELM) as a supplementary teaching tool for a certain number of classes each week, while the control group continued with traditional teaching methods. The research was conducted in a public primary school in a low-income area in southern China, which was equipped with a computer laboratory. The design of the study is represented in Fig. 1.

A. Participants

The participants of this study were 239 second-grade students from a public primary school in Shenzhen, China. There were six classes in grade two, and two teachers with similar teaching experience each taught three classes. By drawing the lot, 124 students from classes 1–3 were selected as experimental groups, and 115 students from classes 4–6 became control groups. The teacher from the experimental group would integrate ELM in class and assign students to complete activities in ELM as an assignment; The teacher from the control group would use the traditional teaching method in class without using other instructional software.



(MathA1= Mathematics Achievement Pre-test, MathE=Mathematics affective learning scales, SEL= Social emotional learning scale, MathA2=Mathematics Achievement Post-test)

Fig. 1. Research procedure.

B. Key Features and Rationale for Using ELM

The Emergent Literacy in Mathematics (ELM) software, which is part of the Learning Toolkit suite, is an innovative AI-based tool designed to make mathematics learning more enjoyable for young students in the early grades. This software transforms traditional math lessons by providing interactive, gamified activities that enable students to explore math concepts in fresh, engaging ways. Powered by instructional software, ELM adapts to each student's learning pace and gives personalized feedback to make learning more engaging. Additionally, ICT-driven features like real-time feedback and adjustable difficulty levels ensure that every student gets a learning experience tailored to their unique needs.

ELM's design is based on recent research linking effective math teaching with computer technology [42] and principles of multimedia learning [43]. These principles help minimize cognitive load, make learning more engaging, and support students as they work through challenging math concepts, which ultimately reduces their anxiety and encourages a more positive attitude toward math. The content in ELM is organized into themed branches of math, which are broken down into specific concepts (see Fig. 2). This structured approach ensures that students cover essential math topics while also benefiting from flexible teaching methods. Additionally, the software includes teaching strategies that are culturally and cognitively responsive, which align with modern educational practices to address the diverse needs of students [10].

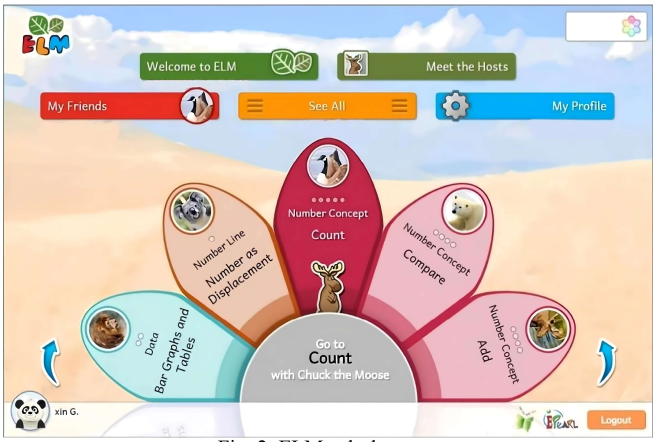


Fig. 2. ELM splash page.

Additionally, ELM also includes a step-by-step challenge system with a built-in point scoring feature (see Fig. 3). In the present study, students work through the first few levels (1–3) in groups, with teachers guiding discussions and helping them reflect on what they've learned. The following levels (4–5) are designed for students to explore independently at home, where they can earn personal points by completing challenges on their own. This phased setup not only reinforces what they learn in class but also encourages self-study and keeps them actively engaged with math. Furthermore, the gamified elements in ELM are also crucial to keep students motivated, with adaptive challenges and personalized learning paths that make the mathematics learning experience both fun and engaging.

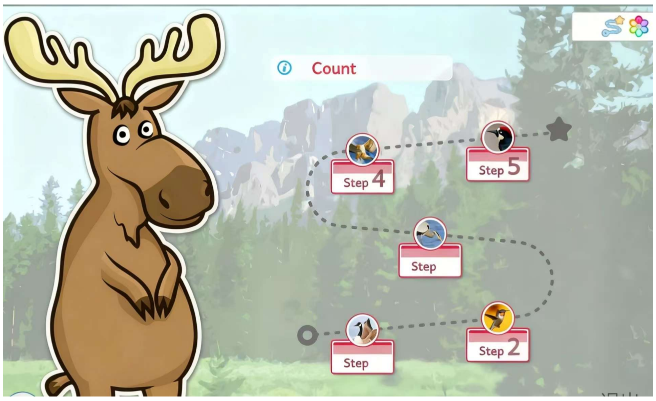


Fig. 3. One of the themes of ELM and its steps.

C. *Instruments*

This study utilized pre- and post-tests administered before and after the intervention to measure students' progress. The instruments focused on three main areas: evaluating students' cognitive achievements in math, their emotional experiences related to math, and their social-emotional skills. Tests including the Mathematics Achievement Test 1 (PMAT1), Mathematics Achievement Emotion Questionnaire (AEQ-M), and Social Emotional Learning (SEL) are among those included in forming the experimental and control groups (see Fig. 1).

1) *Mathematics achievement tests*

A standardized exam developed by the Shenzhen Education Bureau was used to assess students' math performance. This exam aligns with the Chinese middle school math curriculum standards and covers four main areas, including number and algebra, space and geometry, probability and statistics, and problem-solving. The question types include fill-in-the-blank, multiple choice, true/false, calculation, and problem-solving tasks.

2) *Mathematics affective learning scales*

This study explores students' feelings and attitudes toward mathematics by using two Likert scales—the Mathematics Achievement Emotion Questionnaire (AEQ-M) and the Motivation and Intention for Mathematics Scale. Both scales were translated into Chinese. The Mathematics Achievement Emotion Questionnaire (AEQ-M) includes 37 questions [44], while the Mathematics Motivation and Intention Scale (PISA 2012) contains 24 questions. Researchers selected three items from each of these scales to measure four main emotions: enjoyment (e.g., "I like math class"), pride (e.g., "I feel proud when I answer the math teacher's question"), anger (e.g., "I get frustrated with my math homework"), and anxiety (e.g., "I start sweating when I worry I won't finish my math homework"). Additionally, six questions from the Chinese version of the PISA 2012 math test were used to measure students' intrinsic and practical motivation for math (e.g., "Learning math is worthwhile because it will help my career") and their intentions toward math (e.g., "I will learn things in math that will help me get a job"). Furthermore, to make the survey easier for second-grade students to understand, the Mathematics Affective Learning Scales were rated on a 5-point Likert scale, from "strongly agree" to "strongly disagree," with emojis like 😊 for "strongly agree," 😐 for "neutral," and 😡 for "strongly disagree," to represent different levels of agreement. This helped young students engage with the questions in a way they could easily relate to. The students were brought together in a multimedia classroom, where the researcher read each question aloud and guided them as they completed the questionnaire on computers, with their math teacher present for support.

A reliability analysis showed that the reliability coefficients for the AEQ questionnaire in the pre- and post-tests were 0.79 and 0.84, indicating strong consistency. Previous research found that the AEQ-M has solid psychometric properties [45], which this study also supported, Chi-Square (χ^2) = 79.026, degree of freedom (df) = 48, p-value < 0.003, Comparative Fit Index (CFI) = 0.95, Incremental Fit Index (IFI) = 0.96, Root Mean Square Error of Approximation (RMSEA) = 0.04. For the Mathematics Motivation and Intention Scale, the reliability coefficients were 0.67 for the pre-test and 0.73 for the post-test, showing acceptable reliability. The confirmatory factor analysis (CFA) also reflected good fit (χ^2 = 54.244, df = 8, $p < 0.001$, CFI = 0.90, Normed Fit Index (NFI) = 0.90, RMSEA = 0.07).

3) *Social-emotional learning scale*

This study used a 5-point Likert scale to evaluate students' social-emotional learning across four key dimensions, as outlined in the Social Emotional Learning (SEL) user guide: (1) self-management, (2) social awareness, (3) self-efficacy, and (4) growth mindset. Firstly, self-management focuses on how well students control their emotions, thoughts, and behaviors in various situations (e.g., I often pay attention and ignore distractions during the past 30 days). Secondly, social awareness evaluates how much students consider others' perspectives and empathize with them (e.g., I often listen to other people's point of view carefully during the past 30 days).

Thirdly, self-efficacy measures how confident students are in achieving successful academic outcomes (e.g., I'm sure I can complete all the work that is assigned in my class during the past 30 days). Lastly, the growth mindset examines students' perception of their potential in areas related to their academic performance (e.g., I believe my level of intelligence is great). Reliability analysis indicated that the reliability coefficient was 0.79 for the pre-test and 0.84 for the post-test. Additionally, the CFA result also has good properties (χ^2 = 90.096, df = 48, $p < 0.001$, CFI = 0.93, NFI = 0.92, RMSEA = 0.04).

D. Intervention

1) Research procedure

The experiment was conducted with the hope of ensuring that no significant difference exists between all participants. Classes, regardless of experiment or control, were selected randomly according to different teachers. As shown in Fig. 3, the experimental group, consisting of students from Classes 4, 5, and 6, used an ICT tool called Emergent Literacy in Mathematics (ELM) during their math classes and for their daily homework. On the other hand, the control group, which consisted of students from Classes 1, 2, and 3, learnt using traditional teaching methods (such as asking questions and solving problems) and completed ordinary homework that did not incorporate any ICT tools. Additionally, two math teachers with less than 10 years of teaching experience were trained for approximately 10 hours to be part of the experiment. One teacher worked with the control group and did not use the ELM software, while the other teacher used the ELM software to complement the traditional teaching methods in the experimental group.

In experimental class, each instructional session adheres to a standardized duration of 40 minutes, the same as traditional classroom teaching. During the introduction phase, the teacher presents the pre-configured ELM software to students. Guided by the software's algorithmic prompts, the teacher selects game-based assessment items that are intricately aligned with the core content of the current lesson. In the subsequent knowledge acquisition stage, the teacher adopted school textbooks as the primary instructional resource. During the consolidation and enhancement phase, the teacher encourages students to engage in independent practice by utilizing the test questions available on the ELM software. This self-directed learning activity allows students to apply the newly acquired knowledge in a practical context, thereby reinforcing their understanding and retention.

2) Lesson plan sample of the experimental classes

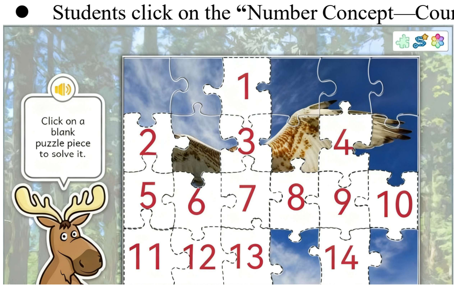
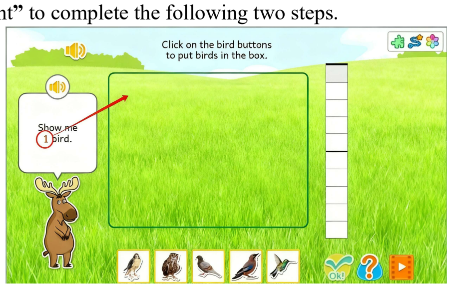
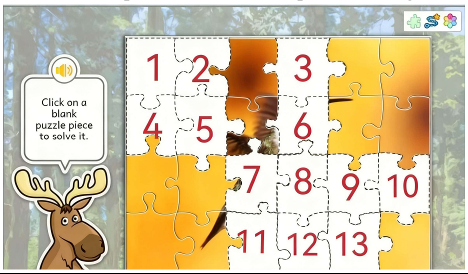
This lesson plan (Table 1) is derived from one of the experimental class sessions utilizing the ELM software in the instructional process. The lesson topic is "Who Scored Higher?—Addition and Subtraction Operations". The allocation of class time, specific pedagogical activities, and the integration of the ELM throughout the teaching sequence are meticulously outlined in this lesson plan. In this particular case of instructional design, students primarily employ the ELM software for problem-solving and knowledge consolidation. The sequential arrangement of ELM software enables students to apply the newly acquired knowledge and enhance their understanding and retention of addition and subtraction operations.

Table 1. Who scored higher?—Addition and subtraction operations: Class schedule and activities (ELM-assisted)

<table>
<tr><th>Time Allocation (Total 40 min)</th><th>Teaching link</th><th>Teaching and learning activities</th></tr>
<tr><td>0–5 min</td><td>1. Warm up + Problem Introduction</td><td>● Teachers guide students to warm up by using ELM software.
● Students were divided into teams and sent representatives on stage to challenge the other team members and start the game.
● Competitors click on the "Number Concept-Count" to complete the first two steps.
➢ For example, "Count the birds by clicking them one by one."


● Teacher concludes:
After going through the game, do you still want to become more powerful? Let's go on and learn more about addition and subtraction</td></tr>
<tr><td>5–10 min</td><td>2. Link textbook knowledge</td><td>With the help of students' learning enthusiasm through ELM teaching software, teacher appropriately adjusts the Chinese curriculum content: Beijing Normal University Mathematics Textbook (Semester 1, Grade 2).
● Courseware:
Textbook 2-page situation diagram and score statistics table.


● Teacher question:
This is Naughty and Smile's score table, carefully observe the table what information you get?</td></tr>
</table>

		➢ Preset 1: Naughty gets 24 points the first time, 30 points for the second time. The third time gets 41 points ➢ Preset 2: Naughty gets 24 points the first time, Smile gets 23 points, Naughty gets a higher score than Smile the first time
10–35 min	3. Real-World Problems Solving + Students' Activities	● **Question: Who's the winner?** These two good friends are quarreling over whether to win or lose the game. Who do you think is right? Why？ Students discuss, try to calculate and report. ● **Activity 1: Group discussion** Students discuss and speak independently. ● **Activity 2: Courseware presentation** Textbook page 2 dialogue situation diagram $\begin{cases}\text{Naughty: } 24 + 30 + 41 = 95 \\ \text{Smile: } 23 + 44 + 29 = 96\end{cases}$ ➢ **Naughty** Step 1: 20 + 30 + 40 = 90, 4 + 1 = 5, 90 + 5 = 95 Step 2: $\begin{array}{r}24\\+30\\\hline 54\end{array}$, $\begin{array}{r}54\\+41\\\hline 95\end{array}$ Step 3: $\begin{array}{r}24\\30\\+40\\\hline 95\end{array}$ ● **Teacher:** Students use different methods to calculate Naughty's marks. Can you use these methods to calculate Smile's marks? ➢ **Smile:** Step 1: 20 + 40 + 20 = 80, 3 + 4 + 9 = 16, 80 + 16 = 96 Step 2: $\begin{array}{r}23\\+44\\\hline 67\end{array}$, $\begin{array}{r}67\\+29\\\hline 96\end{array}$ Step 3: $\begin{array}{r}23\\44\\+29\\\hline 96\end{array}$ ● Students try to calculate, teachers tour the classroom through using ELM software, and instruct individual struggling students.
	4. Independent Inquiry	● The teacher give more opportunities to students do exercises through ELM. ● Students click on the "Number Concept—Count" to complete the following two steps.   ● The teacher summarizes the students' answers and assigns homework.
35–40 min	5. Summary and Enhancement	● The teacher summarized the knowledge points of this lesson. ● The teacher assigned homework: 1. Math textbook P3 "Practice" 2. The fifth step of "Number concept—Counting" in ELM. 

E. Analysis and Power Estimates

An Analysis of Covariance (ANCOVA) was carried out on each outcome measure separately. To adjust for any initial difference between the treatment and control groups and to increase statistical power, composite pretest scores were used as covariates in the model. The unit of analysis was at the student level. Outcomes were characterized in terms of effect sizes, which are the difference between ELM and control means divided by their pooled standard deviation. With an expected total number of 239 students in the study, the statistical model would provide adequate statistical power to detect an effect size of +0.25 at the student level using Analysis of Covariance (ANCOVA). Using an average estimate of $r^2 = 0.50$ and $d = 0.25$, the estimated power for the anticipated sample size of over 250 students would be over 0.80 [46].

IV. Results

A. Influences on Math Achievement Outcomes, Math Affects and Social Emotional Learning by Using ELM-Assisted Teaching

Table 2 shows the results of the experimental effects, including mathematics achievement, mathematics effects, and social-emotional learning. There was no significant difference between the control and experimental classes in pre-test, including mathematics achievement (Effect Size = −0.21, *p*-value > 0.05), mathematics affects (*ES* = −0.08, *p* > 0.05) and social emotional learning (*ES* = −0.31, *p* > 0.05). For the post-test, although there was no significant differences in mathematics achievement (*ES* = 2.66, *p* > 0.05) between the experimental and control group, the former's mathematics affects (*ES* = 2.15, *p* < 0.00) and social emotional learning (*ES* = 0.88, *p* < 0.00) were significantly improved, compared to the control group in the post-test.

Table 2. Comparisons of students' mathematics achievement, effects, and social-emotional learning by using ELM-assisted teaching

Social Emotional Learning		Condition	N	Mean	SD	Adj.Mean	*p*-value	ES
Pre-test	Mathematics Achievement	ELM	115	77.72	20.46	/	0.93	−0.21
		Control	124	77.92	18.06	/		
	Mathematics Affects	ELM	115	1.78	0.70	/	0.35	−0.08
		Control	124	1.86	0.63	/		
	Social Emotional Learning	ELM	115	2.04	0.61	/	0.66	−0.31
		Control	124	2.07	0.54	/		
Post-test	Mathematics Achievement	ELM	115	81.21	19.62	81.28	0.057	2.66
		Control	124	78.69	16.60	78.62		
	Mathematics Affects	ELM	115	4.42	0.56	4.41	<0.001	2.15*
		Control	124	2.25	0.92	2.26		
	Social Emotional Learning	ELM	115	4.42	0.56	4.36	<0.001	0.88*
		Control	124	3.47	0.53	3.48		

Note: * *p* < 0.05, ES: Effect Size, Adj.Mean: Adjust Mean.

B. *Influence of Factors of Social-Emotional Learning by Using ELM-Assisted Teaching*

An in-depth analysis of social-emotional learning dimensions is shown in Table 3. The table shows the results of the experimental effects, including self-management, social conception, self-efficacy and growth mindset. There was no significant difference between the control and experimental classes in pre-test, including self-management (*ES* = −0.01, *p* > 0.05), social conception (*ES* = −0.18, *p* > 0.05), self-efficacy (*ES* = −0.30, *p* > 0.05) and growth mindset (*ES* = −0.13, *p* > 0.05). For the post-test, except for the Social Conception sub-dimension (*ES* = 0.23, *p* > 0.05), there were significant interactions for the other sub-dimensions of social emotional learning between different groups on the post-tests. These results indicated that while the ELM-assistant software did not enhance students' social conception, it did improve their competencies in self-management, self-efficacy, and growth mindset. In addition, in the remaining three sub-dimensions, ES for self-efficacy (*ES* = 2.37, *p* < 0.00) was significantly higher than self-management (*ES* = 0.56, *p* < 0.00) and growth mindset (*ES* = 0.65, *p* < 0.00).

Table 3. Results of the post-test on social emotional learning

Social Emotional Learning		Condition	N	Mean	SD	Adj.Mean	*p*-value	ES
Pre-test	Self-Management	ELM	115	1.67	0.06	/	0.91	−0.01
		Control	124	1.68	0.06	/		
	Social Conception	ELM	115	2.77	1.42	/	0.31	−0.18
		Control	124	2.95	1.31	/		
	Self-Efficacy	ELM	115	2.50	1.45	/	0.11	−0.30
		Control	124	2.80	1.43	/		
	Growth Mindset	ELM	115	3.06	0.55	/	0.07	−0.13
		Control	124	3.19	0.55	/		
Post-test	Self-Management	ELM	115	4.45	0.70	4.44	<0.001	0.56*
		Control	124	4.01	0.86	4.00		
	Social Conception	ELM	115	3.34	1.41	3.34	0.59	0.23
		Control	124	3.15	1.24	3.11		
	Self-Efficacy	ELM	115	4.45	0.79	4.44	<0.001	2.37*
		Control	124	2.07	0.92	2.07		
	Growth Mindset	ELM	115	4.39	0.61	4.37	<0.001	0.65*
		Control	124	3.87	0.97	3.88		

Note: * *p* < 0.05, ES: Effect Size, Adj.Mean: Adjust Mean.

C. *SEM Analysis*

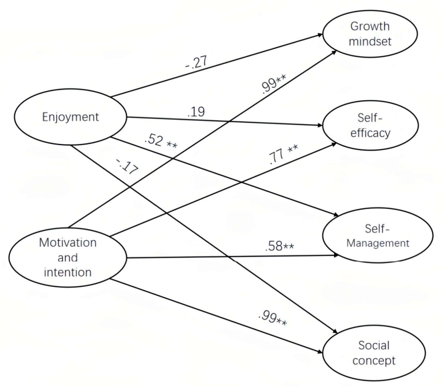


Fig. 4. The SEM analysis results.

The SEM model (see Fig. 4) was constructed and tested to explore the relationship between students' different factors of mathematics affects and social emotional learning through using ELM-assisted teaching. The model reached an acceptable model fit: χ^2 = 1458.83, df = 153, *p* < 0.01, RMSEA = 0.05; CFI = 0.97; Tucker-Lewis Index (TLI) = 0.97). The results indicated that students' mathematical motivation and intention were significantly positively associated with all factors of social emotional learning, including growth mindset (β = 0.99, *p* < 0.01), self-efficacy (β = 0.77, *p* < 0.01), self-management (β = 0.58, *p* < 0.01) and social concept (β = 0.99, *p* < 0.01). While students' positive achievement emotion (i.e., enjoyment) was only significantly positively associated with their self-management (β = 0.52, *p* < 0.01).

V. Discussion

A. ELM-Assisted Teaching Enhances Students' Mathematical Affect Rather Than Cognitive Performance

Results of this study have shown that ELM experimental group students demonstrated higher mathematics affects ($ES = 2.15$, $p < 0.00$) and social emotional learning ($ES = 0.88$, $p < 0.00$), compared to the students who learn without using instructional software, which is consisted to the previous research, indicated that using instructional software can boost students' positive emotions and enhance their learning experiences [23, 24].

On one hand, ELM experimental students showed a greater effect of math ($ES = 2.15$, $p < 0.00$). Previous research has suggested that when students experience higher enjoyment through the instructional software, they are more inclined to use the tool to solve difficult ideas, which improves their motivation in their learning [47]. In this study, students' higher level of engagement may be due to ELM's engaging gamified features, such as bright visuals, diverse animated characters, and challenges, which maintain students' interest and help them build their confidence as they progress from easier to more complex tasks. On the other hand, the use of ELM significantly enhances students' social emotional learning of dimensions as self-management ($ES = 2.37$, $p < 0.00$), self-efficacy ($ES = 0.56$, $p < 0.00$), and growth mindset (a belief that students fare better if they believe that their intellectual abilities can be developed ($ES = 0.65$, $p < 0.00$), but shows no significant difference in their social conception. This aligns with findings from a recent experiment by Wang and Zheng [32], demonstrating that students in the software-assisted group exhibited significantly higher learning motivation. In this present study, while the teacher guided students through the software in class before and after lessons, students were encouraged to take ownership of their learning as self-directed learners when using ELM, managing their own pace and tasks. This autonomy further contributed to the development of their self-management abilities and growth mindset.

While the research finding suggests that ELM does not significantly impact students' academic achievement, this might be because the tasks designed for second graders are quite simple, so they do not significantly challenge the students or show big differences in how well they perform. Meanwhile, this result echoes the results of the previous studies [48] on the one hand, in which using instructional software may not always lead to improved academic performance. On the other hand, we found that mathematics teaching in most classrooms in China still follows the traditional direct teaching model, which leads to time-consuming and laborious learning burdens, causing students to lack sufficient enthusiasm and motivation to delve into mathematics [49]. Software-assisted teaching tools, to some extent, alleviate the monotony of pure lecturing and can promote improvements in academic performance. However, Chinese students have long been facing immense academic pressure, which is an inevitable reality [49].

B. The Development of Mathematical Motivation and Intention Can Promote Students' Social-Emotional Learning

The SEM suggested that students' intrinsic and practical mathematical motivation and intention developed through ELM contribute positively to the enhancement of students' social-emotional learning abilities, which was consistently confirmed across all dimensions of social-emotional learning. Social-emotional learning is a process in which individuals integrate their thoughts, emotions, and behaviors [50]. In this study, students' mathematics learning motivation and intention were regarded as the combined effect of achievement needs, perceived probability of success, the motivational value of task completion, and the motivational value of avoiding failure in the learning context [51], which was related to students' social-emotional learning abilities and their academic performance with instructional software [52, 53]. Previous research has indicated that students' learning motivation would be positively related to SEL, including its subdimensions as growth mindset, self-efficacy, self-management, and social concept [54]. In the process of mathematics learning with ELM software, students' learning motivation drives them to actively adopt various problem-solving strategies for self-regulating and thus improve their growth mindset within SEL abilities [55]. Moreover, students' strong motivation not only improves their cognitive and behavioural levels but also with social skills [56]. Those students with strong intrinsic motivations and intention through instructional software tend to consider more deliberately what might influence their math performance, to gain better self-management skills in learning. Furthermore, instructional software can also catalyse solidarity and cooperation in students' math learning [53]. The acquisition of SEL skills is inherently tied to an e-learning environment, through which a secure sense was provided to students [57]. ELM in this study incorporates a collaborative group project, wherein students collectively address a defined math problem. Teachers assign students with high levels of intrinsic motivation as group leaders, leveraging their enthusiasm to inspire and guide the entire group. Chinese students generally face significant pressure in learning mathematics, which is partly due to the tension between adhering to Confucian philosophy that emphasizes harmony within the group and responding to the Asian educational advocates' emphasis on social competition [56]. To some extent, software-assisted teaching tools alleviated this conflict, achieving simultaneous progress for both the group and individuals. Thus, students in this study not only acquire social concepts through the learning content but also via participatory activities such as group inquiry and collaboration, to improve their SEL abilities.

C. The Enjoyment of Learning Math through ELM Promotes Self-Management Abilities

The SEM also indicated that students' enjoyment level significantly influenced their self-management, despite that their enjoyment does not significantly enhance other domains of social-emotional learning, regarding social concept, self-efficacy, or growth mindset. Yet, one's positive emotions are crucial for various learning-related cognitive processes, such as information processing, communication, negotiation, decision-making, categorization tasks, and creative problem-solving [58]. These processes are components of self-management. The experience of using ELM is important, as when students explore the instructional software on their own, the sense of control experienced can generate positive emotions, and sustained positive emotions further enhance students' ability to regulate and manage their learning. Schweder [59] also pointed out that when students can learn according to their own pace, they would plan how to achieve their learning goals and decide study plans based on their existing skills and knowledge. Also, when teachers integrate instructional software in class, it fosters positive emotions and attitudes towards mathematics, motivating students to actively engage in learning [10]. As a result, students are more likely to focus on mathematics learning and are eager to invest more time and effort, thereby strengthening their self-management skills.

VI. Conclusion and Implications

Past studies have shown that different instructional software can open up new possibilities for enhancing math teaching and learning. This study builds on that by examining how ELM software affects students' performance and their emotional experiences in mathematics class. Although the result shows that cognitive improvements were limited, students did show significant improvements in areas related to emotions, motivation, and social-emotional learning skills in math.

Integrated experiential learning and gamification, ELM enabled students of different ages to collaborate and complete tasks. This combination of teaching methods enabled students to develop social-emotional skills, including expressing their feelings and resolving conflicts while completing the tasks, which could improve their understanding and enjoyment of mathematics. To better support cognitive development, ELM should also include specific teaching strategies such as scaffolding and clear, direct instruction tailored to the needs of each student. AI tools that offer personalized tasks can be particularly effective in meeting these individual needs. Furthermore, the notable improvements in students' emotions and motivation highlight the need to increase opportunities for collaborative learning. Therefore, while ELM shows potential for boosting student motivation and emotional engagement, it may benefit from being combined with group activities to promote peer interactions and foster social-emotional development, especially when developing Social-Emotional Learning (SEL) is a primary goal.

Currently, research on the connection between cognitive and emotional outcomes in developing countries remains limited. Findings from this study indicate that ICT tools like Emergent Literacy in Mathematics (ELM) can be extremely beneficial to support learning, particularly for students who struggle with lower confidence, weaker math self-concepts, limited self-management skills, or a tendency to procrastinate. These tools are most effective when they are closely aligned with the curriculum and offer engaging, interactive learning experiences. As for younger students, increasing the use of game-based learning through ICT could not only boost their motivation but also support the development of their social-emotional skills.

However, this study has some limitations. First, younger students in classrooms with limited teacher support might find it hard to stay focused and could get distracted by the entertaining aspects of the instructional software. Even the most advanced AI tools are not able to replace human reasoning when it comes to fostering critical mathematical thinking and creative problem-solving skills in math. Additionally, since this study was a short-term intervention with second graders, the findings might not apply broadly. The positive changes seen in students' emotional and social learning skills could be temporary, and the long-term effects of ELM are still underexplored. Thirdly, the quality of the mathematical cognitive measurement used in this study requires careful evaluation, and the lack of challenging cognitive tests may lead to potential mismatches between the design and testing objectives of the ELM software. Future research should examine whether these benefits persist over time and in different educational settings. Moreover, it would be useful for future research to see how well ELM software works with students of different ages, genders, and personality types. It would also be valuable to consider cultural and educational differences, especially in developing countries, to better understand how adaptable and scalable AI-assisted tools like ELM can be.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Wei Lin, Xin Guo, and Sihan Wang conducted the research; Xintong Lai analyzed the data; Wei Lin and Xintong Lai wrote the paper; all authors had approved the final version.

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