Maintaining Student Engagement in Extensive Practice by Implanting Gaming Factors

Oskar Y.M. Ku[a], Jesse C.Y. Wu[b], Blake C.J. Yang[b], Chi-Jen Lin[c], Tak-Wai Chan[b]
[a]*Department of Computer Science and Information Engineering, National Central University, Taiwan*
[b]*Graduate Institute of Network Learning Technology, National Central University, Taiwan*
[c]*Department of Learning and Digital Technology, Fo Guang University, Taiwan*
ymku@cl.ncu.edu.tw

Abstract: In this study, we report a work of using one-to-one technologies to motivate a class of elementary students in extensive practice of mental calculation. Specifically, each student in the classroom uses a notebook computer to practice mental calculation. The goal of extensive practice is to increase procedural fluency in mental calculation. Generally, except for a small portion of highly motivated students, the rest of students easily get bored in extensive practice and soon become reluctant to practice more. To motivate the students to practice mental calculation more, some gaming elements were implanted to promote student engagement in extensive practice. As a result, all the students practiced a lot and encouraging improvements of student learning achievement were reported by the classroom teacher. Among others, their achievement scores of a subsequent summative evaluation were dramatically improved in comparison with other classes in the same school.

Keywords: student engagement, extensive practice, game-based learning, mental calculation

1. Introduction

One-to-one technologies, which means technologies that are commonly possessed by each individual, have a profound impact on education. Centuries ago, educational practices significantly changed when it became affordable for each student to possess his/her own books and pencils, the contemporary one-to-one technologies. With the recent booming market of low-price computers, such as Eee PCs and the likes, another evolution of educational practices is being stirred up by these increasingly prevalent one-to-one technologies [2] [16]. In this period of time, it is essential to explore practical and effective educational practices that adopt these new one-to-one technologies.

Besides learning efficiency and learning effectiveness, another use of one-to-one technologies in educational practices is to enhance student engagement, which is generally considered as a good predicator of student learning [1]. In this study, our primary investigation goal is to explore the use of one-to-one technologies to maintain student engagement in extensive practice of mental calculation.

1.1 Why mental calculation

Like a pendulum, mental calculation was emphasized in some decades, and ignored in some decades in past century due to different reasons for several times [14]. Recently, mental calculation gains attraction again and appears in mathematics curriculum standards of many countries or regions, like Singapore, Hong Kong, Taiwan, the Netherlands, and so on.

Mental calculation is sometimes misunderstood as mechanical drill and practice. People may regard mental calculation as skills of memorizing pithy formula for coping with specific patterns of arithmetical calculation. In fact, mental calculation does not emphasize memorization of pithy formula. Instead, good mental calculators find out fast calculation rules by observing numbers [5]. They also choose the most appropriate calculation method from their minds to solve problems. There are four reasons to teach mental calculation: (1) many calculation tasks are performed mentally in daily life; (2) mental work develops insight into number sense; (3) mental work helps develop problem solving skills; (4) mental works promotes success in written calculations [17].

1.2 Effectiveness of extensive practice

Mathematical proficiency is essential for the success of mathematical learning. Five strands constitute mathematical proficiency: (1) conceptual understanding; (2) procedural fluency; (3) strategic competence; (4) adaptive reasoning; (5) productive disposition [6]. Procedural fluency is the skill to carry out procedure in flexible, accurate, efficient, and appropriate manner. Fluent calculation plays an important role in developing mathematical knowledge; students cannot deepen their understanding of mathematical ideas without sufficient procedural fluency [6].

In those five strands of mathematical proficiency, procedural fluency can be obtained through extensive practice, which also brings in student improvements in accuracy and response time. Newell and Rosenbloom [10] discovered a relationship between student error rate and practice amount. The relationship is governed by a power law, which can be formulated as $Y = aX^b$, where [Y, X, a, and b] represent [error rate, practice amount, error rate on the first trial, and the learning rate], respectively [3]. Pauli et al. [11] also obtained similar results in trainings their participants on single-digit multiplication problems [11]; the results are illustrated in Figure 1. According to Figure 1, accuracy is significantly improved after an initial amount of student time on practice and then approaches an asymptote; response time still improves after accuracy approaching the asymptote, but the improvement rate becomes insignificant. Therefore, extensive practice helps students obtain high accuracy and low response time in the performance of learning tasks.

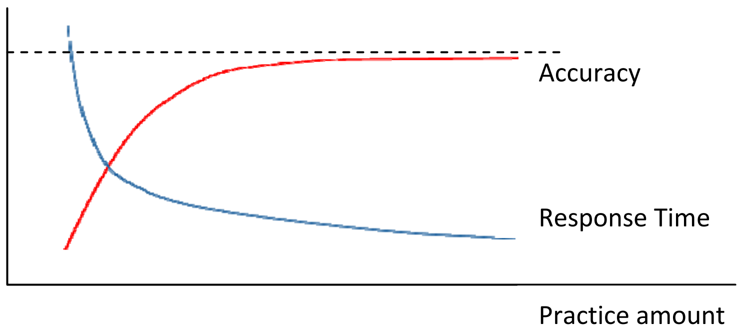

Figure 1. Effectiveness of extensive practice on accuracy and response time

1.3 The need of student engagement in extensive practice

Mental calculation, one of mathematical skills, is considered that the performance of which can get great improvement after extensive practice. It's a common phenomenon in Asian countries that parents often purchase additional workbooks, which have large numbers of questions for students to practice calculation skill (either mentally or not mentally), but students don't like that. This kind of drill and practice often cause student bored.

In general, students don't like extensive practices, especially paper-based drill and practice ones. Most students are impatient to do this kind of work and are easily to get distracted. On the other hand, students are easily engaged in computer games for a long period of time. It is reported that educational games are potentially strong motivators and can be used to reinforce skills and concepts embedded in the games [8]. Minsky also said "Enjoyment, which has been banished to the realm of the entertainment science, may be the most powerful influence of all on how each person learns."[9] Therefore, turning extensive practice into games is potentially a good way to maintain student engagement in extensive practice of mental calculation.

2. Learning activity design

In order to maintain student engagement in extensive practice, several learning activities were designed. The design of these learning activities is composed of three parts: content, games, and system architecture. Each of the topics is described in details below.

2.1 Learning content

In this study, some number patterns in mental calculation problems were imposed for teaching fast alternative calculation methods. For example, to calculate 384×5, the students were taught to divide 384 by 2 first, which produced 192, and then added a zero to the tail of the division result to obtain the final result, which was 1920. The students were also taught the reason why this calculation method produced correct answers, which was because 5 equals to 10 divided by 2. The numbers used in this study were all in similar special patterns. The goal is not to produce super human calculators, but to help students in gaining more "number sense", so that students, in addition to extensive practice, may learn to analyze number patterns, generate ideas on simplifying problems, and then solve them.

We surveyed many popular mental math books, and then we developed a mental calculation curriculum in accordance with elementary mathematics curriculum. This curriculum is composed of 4 basic operation parts (＋, －, ×, and ÷), each part contains several calculation skills, each skill forms a unit. Questions are categorized to different difficulty levels according to number complexities.

2.2 Implanting gaming factors

From an educational perspective, games mean motivation, which is believed to be an indispensable element of successful learning [12]. And well-designed computer games are helpful in enhancing students' motivation and learning [7][13][15].

The goal to implant gaming factors into extensive practice is to motivate students to engage in the learning activity that students previously perceived it as boring. In this study, several strategies are used to maintain student engagement in extensive practice and to propel students to achieve high accuracy and low response time on mental calculation tasks: (1) fantastic multimedia scenes; (2) curiosity in popular cartoon characters; (3) desire to obtain high scores; and (4) time constraint on providing answers to given problems. The results are a series of “mini games”, which require students to practice a lot of mental calculation. Figure 2 illustrates the screen dumps of the games.

Game A Game B Game C Game D

Figure 2. Mini games

These four games are arranged in an order of decreased scaffolding. Problems given in game A and B are equivalent to multiple choice questions, while problems given in game C and D are equivalent to fill-in questions.

- Game A is a shooting game. Problems are given on the top; potential answers are attached to meteoric stones, which move toward the spacecraft of the student from the top; the student has to choose the correct answer from potential answers in order to shoot meteoric stones before they hit the spacecraft.
- Game B is also a shooting game; the student also needs to choose the correct answer from four potential answers that move horizontally.
- In game C, a cart loaded with a bomb appears from the left and moves forward to the right; the student has to answer the question displayed at the bottom before the cart disappears.
- Game D is a vertical style game. An enemy on the top throws a question toward the user’s avatar (at the bottom); the student must provide an answer before the question hit the avatar.

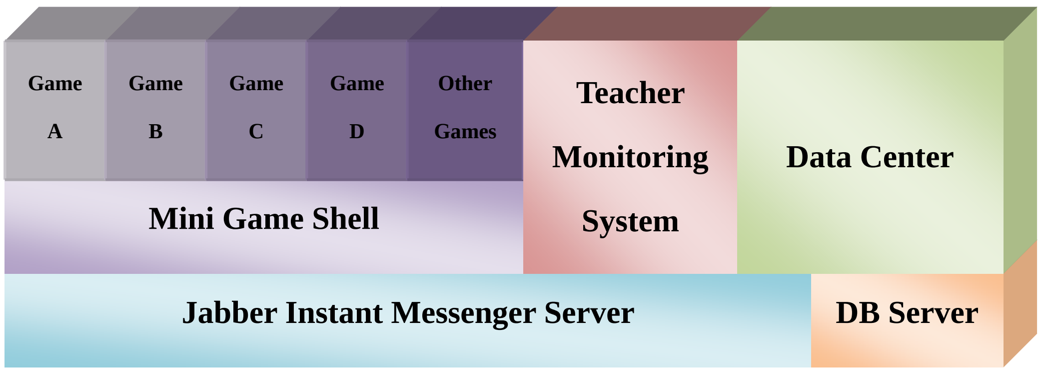

Figure 3. System architecture

2.3 System architecture

The system architecture is shown in Fig. 3; it includes an instant messenger server, a database server, data processing center, student’s client (mini games built on a game shell) and teacher monitoring system.

Due to massive data transfer during game playing, we adopted Jabber instant messenger server (IM server), which is an open-sourced and full functioned messenger server, as our solution to relay data among server and clients. The data center handles database access, when receiving a message with a store tag coming from IM server, it writes the data into database; when receiving a message with a retrieve tag, it reads the corresponding data and sends the data to destination via IM server.

Student's client is mini games built on a mini game shell; it receives commands sent from teacher's monitoring system, controls games execution, and sends students' data log to data center.

Teacher monitoring system displays all students' status such as online or offline, students' progress and so on. The teacher also controls the whole practice process through the monitoring system. All data are communicated via IM server. When a student logins the system, student's client sends a message to the IM server, then the message was relayed to the teacher monitoring system. After all students are ready, the teacher constructs a practice session on her/his computer, then the teacher monitoring system sends command sequences to ask the data center to deliver questions to student client via IM server. Meanwhile, some commands were also relayed to students' clients.

Although all data were transferred via IM server, the teacher client can also access database directly to review students' learning profiles when activities is not running.

3. Experiment

In order to study student engagement in extensive practice with the above design, instruction was delivered to a class of fourth grade elementary students twice a week and continued for 9 weeks. There were 17 instruction sessions totally because the last week has only one instruction session. Each instruction session endured forty minutes, from 8:00 to 8:40 am, which was pre-class time and was free for teacher use.

The 17 instruction sessions is structured as the following units: (1) introduction to mental calculation, one session, paper-based practice; (2) introduction to computer use, two sessions; (3) multiplication of numbers with tailing zeroes, two sessions, using game A for practice; (4) three digit numbers divided by two, four sessions, using game B for practice; (5) three digit even numbers multiply by five, four sessions, using game C for practice; (6) three digit odd numbers multiply by five, four sessions, using game D for practice.

Starting from the third instruction unit, the instruction format is generally consisted of five stages, as illustrated in Fig. 4, but sometimes adjustment is required. Whenever a new unit started, students would receive a worksheet with two illustration examples and fourteen practice problems on it to be used in the "worksheet practice" stage. The teacher first explained the mental calculation skill shown on the worksheet by lecturing (first stage), and then asked students to complete the practice problems on their worksheets. For the later sessions of a unit, the teacher only reviewed the mental calculation skills by lecturing without asking students to practice worksheet problems. Therefore, the "worksheet practice" stage was skipped and the students had additional 5 minutes to practice in games in later sessions of a unit.

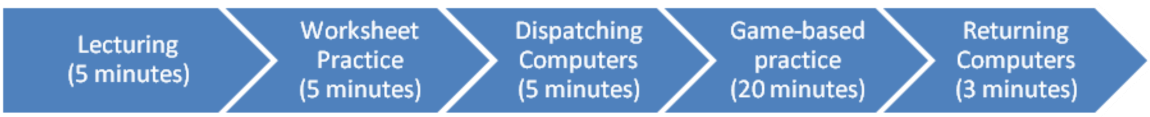

Figure 4. Sample instruction format of the experiment

4. Experimental results

Students were highly motivated by games. Each time they turn on the computer and login to the system, they expressed their impatience to wait even they had known there are a lot of mental calculation questions waiting for them. After game started, they were concentrated on playing the game. In our previous observation in paper-based practice, students were easily distracted by external events such as sound and people walked by, students also tended to disturb their neighbors when they don't want to continue the exercise. However, those behaviors did not appear in our game-based practice environment. Students were engaged in their task, and try to get more scores. When time was up, we announced we were going to terminate the game, most students ask us don't stop it. In each game practice session, we set up a goal score for students, and we found that students cared about the goal very much. A concrete goal is an important element of a game. In a twenty minutes game-based practice, students can solve 100 problems on average, without any complaint. This is very different from traditional paper-based practice.

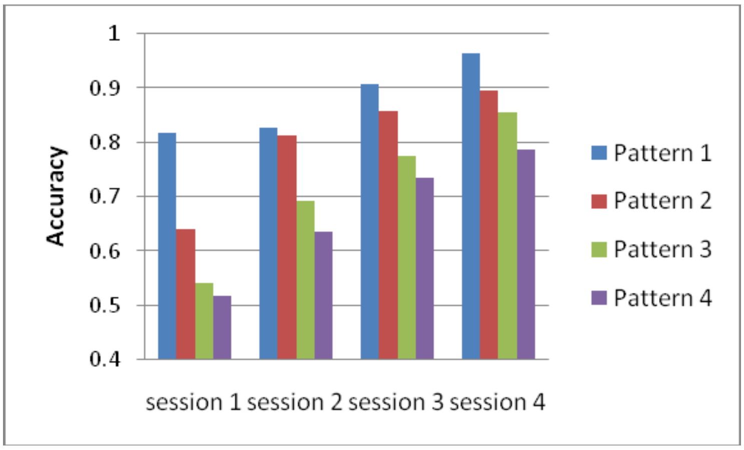

Figure 5. Average accuracy of unit "3 digit numbers divided by 2"

Figure 5 shows the average accuracy of the class when practicing on the unit "3 digit numbers divided by 2." The three digits in pattern 1, 2, 3, 4 are even-even-even, even-odd-even, odd-even-even, odd-odd-even 3 digit numbers respectively. Students' accuracy in every pattern is getting better and better from session 1 to session 4.

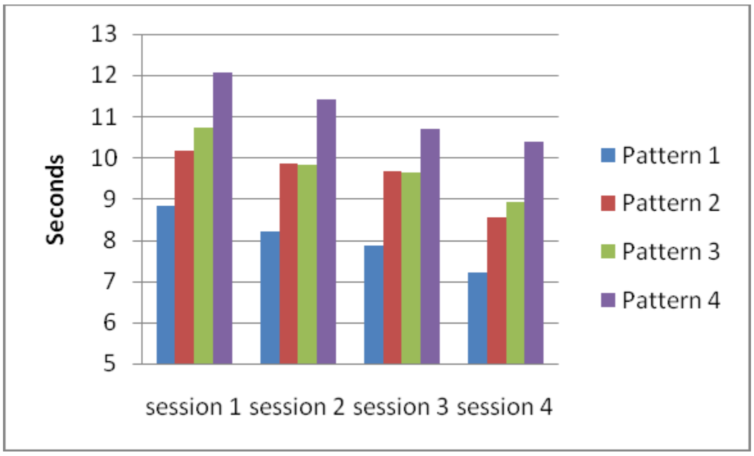

Figure 6. Response time of 3 digit numbers divided by 2

Figure 6 shows the average response time (from the question appeared in the screen to the answer was submitted) in different pattern numbers of the same unit. The response time is getting shorter from session 1 to session 4. Data in response time only included correct responses.

A surprisingly encouraging result was that the teacher of the class found that the average score of midterm mathematics exam of the class raised 10 points, while other classes of the same school remain about the same. In addition, the teacher found that the number sense of most of the students was improved. Students were observed to perform mental calculation instead of performing traditional algorithm on paper frequently. Of course, we cannot ascertain this improvement is caused by extensive practice. We need further investigation to find out whether extensive practice of mental calculation had made contribution to students' improvement in math exam.

5. Discussion

According to the observations and the experimental results, students were engaged in extensive practice of mental math and in game-based environment brings positive effect on both accuracy and response time. And most important, students are engaged in it. Compared to paper based practice, no one complains in this game-based setting. Game is a good factor to motivate students to do extensive practice and concentrate on the task. Although we only reported students' performance in "divided by 2" unit in this paper due to limitation of space, actually, all four units carried out in this study have similar patterns: accuracy is getting higher and higher and response time is getting shorter and shorter in extensive practice.

Although we got some positive effect in this study, some problem emerges with the execution of our study.

In this study, 20 minutes practice seems to be ok for students, they kept their concentration on their task till we terminate the program. However, we should ask what quantity of practice is most appropriate for each individual? Ability difference exists among students, some of them may achieve mastery of the skill after practice 50 questions, and some of them may need to practice 100 questions to attain mastery. Even high ability students still engaged in practicing the skill after they had mastered the kill, over practice seems not providing more positive effect to proficiency. [4] So, how much a student should practice on a skill that ensures she or he has attained mastery? That's the next step we are going to find out according to collected data in this study.

Practice brings improvement but it may also bring boredom and fatigue especially when the student has mastered the skill. If we can detect when the student has reach the mastery point, we can interrupt the practice, and the student can utilize the remained time to carry out other learning task, these saves much time compared to traditional style.

Another problem observed in this study is the arrangement of content. Although students gain improvement in each unit, and it seems that they had mastered those skills. Some students tend to follow patterns to calculate, they don't try to discriminate the questions when we gave them a mix practice. Actually, it was a dilemma when we want to collect clean data of a single skill. If we use mixed questions, we might not collect clean data of each skill, different skills may interfere mutually. In our next study, the arrangement of content will be an important work for students can review what they had learned and develop sense to discriminate what skill is appropriate for a question.

6. Conclusion

In conclusion, game is a good factor to engage students in extensive practice and brings positive effect. After 20 sessions of game-based practice, students still like this style of practice, they don't care whether they have to do many questions in it. Games used in this study are simple games; they support enough game elements but not fancy enough to cause addiction.

Students also gain improvement in accuracy and response time after extensive practice in game-based environment, and this also enhance students' number sense. Although there are many positive effect of game-based extensive practice, other problems emerge at the same time, such as the arrangement of content, ability difference, quantity of practice; we need further investigation to solve these problems.

Acknowledgements

The authors would like to thank the National Science Council of the Republic of China, Taiwan, for financially supporting this study under Contract No. NSC 96-2524-S-008-001.

References

[1] Carini, R. M., Kuh, G. D., & Klein, S. P. (2006). Student Engagement and Student Learning: Testing the Linkages. *Research in Higher Education , 47* (1), pp. 1-32.
[2] Chan, T.-W., Roschelle, J., Hsi, S., Kinshuk, Sharples, M., Brown, T., et al. (2006). One-to-One Technology-Enhanced Learning: An Opportunity for Global Research Collaboration. *Research and Practice in Technology Enhanced Learning , 1* (1), pp. 3-29.
[3] Cen, H., Koedinger, K., & Junker, B. (2006). Learning Factors Analysis – A General Method for Cognitive Model Evaluation and Improvement. In M. Ikeda, K. Ashley, & T.-W. Chan (Eds.), *Intelligent Tutoring Systems* (pp. 164-175). Springer.
[4] Cen, H., Koedinger, K., & Junker, B. (2007). Is Over Practice Necessary? – Improving Learning Efficiency with the Cognitive Tutor through Educational Data Mining. Retrieved from http://www.learnlab.org/uploads/mypslc/publications/lfa%20efficiency%20study%203.61%20use%20the%20official%20template.pdf
[5] Hope, J. A. (1987). A Case Study of a Highly Skilled Mental Calculator. *Journal for Research in Mathematics Education , 18* (5), pp. 331-342.
[6] Kilpatrick, J., Swafford, J., & Findell, B. (Eds.). (2001). *Adding It Up: Helping Children Learn Mathematics.* Washington, DC: National Academies Press.
[7] Klawe, M. (1998). When does the use of computer games and other interactive multimedia software help students learn mathematics? In *Proceedings of the Technology and NCTM Standards 2000 Conference*. Arlington, VA.
[8] Malone, T. W. (1981). Toward a theory of intrinsically motivating instruction. *Cognitive Science , 5* (4), pp. 333-369.
[9] Minsky, M. (1986). Position Paper about AMT's Future. MIT.
[10] Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 1-55). Hillsdale, NJ: Erlbaum.
[11] Pauli, P., Bourne, L. E., & Birbaumer, N. (1998). Extensive practice in mental arithmetic and practice transfer over a one year retention interval. *Mathematical Cognition , 4* (1), pp. 21-46.
[12] Prensky, M. (2001). *Digital Game-Based Learning.* New York: McGraw-Hill.
[13] Randel, J. M., Morris, B. A., Wetzel, C. D., & Whitehill, B. V. (1992). The effectiveness of games for educational purposes: A review of the research, *Simulation and Gaming, 25*, 261-276.
[14] Reys, R. E. (1984, May). Mental Computation and Estimation: Past, Present, and Future. *The Elementary School Journal, Special Issue: Mathematics Education , 84* (5), pp. 546-557.
[15] Rosas, R., Nussbaum, M., Cumsille, P., Marianov, V., Correa, M., Flores, P., et al. (2003). Beyond nintendo: Design and assessment of educational video games for first and second grade students. *Computers & Education, 40*(1), pp. 71-94.
[16] Soloway, E., & Norris, C. (2004). Having a Genuine Impact on Teaching and Learning – Today and Tomorrow. *Keynote speech in Intelligent Tutoring Systems 2004* .
[17] Thompson, I. (1999). Getting your head around mental calculation. In I. Thompson (Ed.), *Issues in Teaching Numeracy in Primary Schools* (pp. 145-156). Buckingham: Open University Press.