Developing a Mobile-based Digital Math Game for Learning Number and Calculation in Elementary School

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ABSTRACT
The main purpose of this study was to develop a mobile game-based math learning APP for the learners of elementary school. The study adopted gradual prompting of dynamic assessment to design a digital role-playing game for the students to learn number and calculation concepts. The learners have to solve the math problems for finishing the challenging mission in the process of this digital game playing. When they encounter difficulties in the game playing, the APP will offer real-time intervention gradually for assisting them to break through the challenge. After finishing the system, this study conducted an expert evaluation and learning experiment. The evaluation results revealed that the experts showed high appraisal toward this APP and the learners expressed their high interest and willing to use it.

CCS Concepts
• Applied computing → Education → E-learning • Applied computing → Education → Collaborative learning

Keywords
Digital game-based learning; Number and calculation concepts; Elementary school; APP development; System evaluation

1. INTRODUCTION
Games can offer a kind of meaningful learning context [6]. Digital game-based learning is a kind of learning strategy by providing real or virtual learning context. It can be used for promoting learning motivation and cultivating high order thinking skills [7, 8]. Some of e-learning researches tried to develop digital games for education in different learning domain, including information technology [9, 10], math [11, 12], and language learning [13]. Some empirical studies revealed the positive effect of digital game-based learning, such as promoting the learners' learning interest and motivation [14-18], and enhancing learning achievement and problem-solving skills [6, 19-21].

Math is the most difficult subject for the elementary schools' students due to its complexity of solving math problems and abstract features. Many learners lost their interest in math gradually. How to enhance their learning interest and motivation is an important task for educationalist. Based on aforementioned study, digital games have potential for promoting the learning motivation and achievement. As a result, this study is to develop a role-playing game for the learners of elementary school to learn math, and to investigate its suitability through evaluation and its impact on math learning effect.

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2. LITERATURE REVIEW
Learning by playing or game is the most nature approach for the learners to construct knowledge and skills, especially for kids and digital natives [4]. Kinzie and Joseph (2008) [22] defined game as an immersive, voluntary and enjoyable activities for chasing challenging goals under agreed-upon rules. Due to widespread and rapid computation of computer and Internet, many digital entertainment games were developed. Nevertheless, the use of games in education is still limited [23]. One of the factors is mismatch of learning objectives and game objectives. In other words, how to embed learning content into digital game is the key task in educational game design. From constructivist perspectives, the games elements should contain scaffolds to support learners when challenges are too great, construct context for the learners engaging in the problem-solving activities, and strategically provide challenging problems [24]. A well-designed game for educational purposes need to provide guide for the learners to develop their skills or knowledge [1].

Static assessment is an outcome-oriented assessment, completely neglecting individual assessment of the dimension of modifiability. Based on Vygotsky's zone of proximal development (ZPD for abbrev.), dynamic assessment can assess the students' learning potential which cannot be achieved by traditional static test, and it has the specific functions of the learning diagnosis and remedial instruction [2, 3, 5, 25]. In the process of dynamic assessment, real-time intervention is provided after directly evaluating the students' learning potential and learning problems. Gradual prompting assessment proposed by Campione and Brown [2] in 1987 is a type of dynamic assessment. Gradual prompting assessment is a form of test- intervene–retest, offering intense gradual intervening teaching opportunities from abstract level to concrete level [5]. The purpose of gradual prompting assessment is to provide real-time scaffold to help the test-takers to improve their performance and potentials. In order to promote the learners' ZPD, this study integrated gradual prompting assessment approach into digital math game. In other words, in the digital game playing, when the learners cannot solve the questions for breaking through some challenging stage, the APP of this study will offer real-time intervention for promoting

the learners' problem-solving potentials, from keywords hint to direct teaching by animation gradually.

In other words, to offer systematic scaffolds to support learners for challenging and engaging the learner in the math problems, this study employed dynamic assessment for developing the digital math game.

3. SYSTEM DEVELOPMENT AND ITS FRAMEWORK

3.1 System Development

This study adopted ADDIE (analysis, develop, design, implement, and evaluate) model for developing a digital math game for the students to learn number and calculation concept. In the analysis phase, the study reviewed the literature about the misconceptions in number and calculation concepts, and discussed with experienced math teachers in elementary schools for grasping the teachers' requirement, the students' math learning dilemmas and available supporting learning environments including mobile devices. In the development phase, the study divided the system into client side for mobile devices and server side for the teachers, based on requirements analysis. The math games were developed for executing in Android-based mobile devices, and all of learning behaviors will be recorded for further analysis. In the design phase, the mobile-based game modular with gradual prompting approach and learning behavior recording function were written in C# and by using Unity game engine, and teaching management functions were designed in php and javascript. Apache was used for web server, and MySQL is adopted as data base for recording the learners' behaviors. In the implementation phase, the study conducted a learning experiment by quasi experiment design methodology in an elementary school. In the evaluation phase, the study developed evaluation questionnaires for examining the suitability of this math games and system, and conducted a learning experiment for examining its impact on learning effect. After the system was finished, the study invited the experts to assess the developed system. In addition, the acceptance survey was explored by asking the students for filling out the questionnaire after learning experiment.

3.2 System Framework

The mobile-based games were design as kind of role-playing games, and it will ask the students to complete a series of missions with challenging math questions. These digital games consist of "Let's open lock", "Let's fish", "Let's stamp", "Let's balance it", "Let's buy candies", and logical inference game. In the "Let's open lock" game, shown as Figure 1, the students were asked to complete integer calculation problems. In the "Let's fish" game, shown as Figure 2, the mission of this game is to form the calculation list for solving math word problem by clicking fishes. When the students cannot respond it correctly, the game will offer a prompt gradually. Based on dynamic assessment theory, the gradual prompts in these games will be depicted from keywords to direct teaching by animation when the student fail to solve the question. In the "Let's balance it" game, shown as Figure 3, the students is to solve the calculation problem for balancing the weighing scales. This game can be used for examining the students' misconceptions about calculating rules and two-step calculating method. The "Let's buy candies" game, shown as Figure 4, is used to assess the students' ability of listing math expressions for solving problems. In this game, the students have to select the candies from purchase lists by considering the discount of each candy and final target budget. The gradual prompts are embedded in this game for facilitating the learner solve the math question as well.

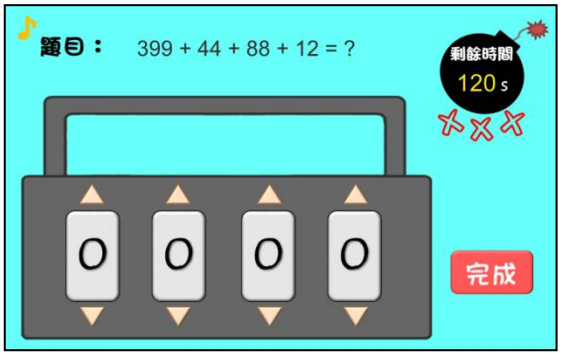

Figure 1. Snapshot of "Let's open lock" game

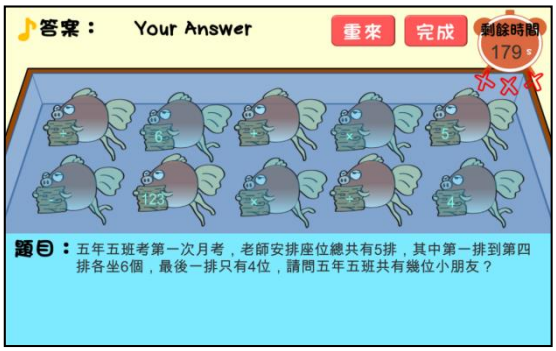

Figure 2. Snapshot of "Let's fish" game

In server side, the teachers can look up the students' learning profile and performance for grasping the learners' learning status. The individual and total statistical charts can be used for understanding the students' performance and encountered misconceptions, shown as Figure 5 and 6.

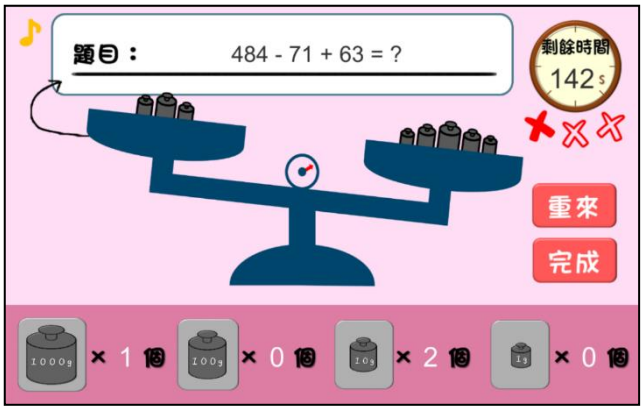

Figure 3. Snapshot of "Let's balance" game

Figure 4. Snapshot of "Let's buy candies" game

Figure 5. Snapshot of students' learning profiles

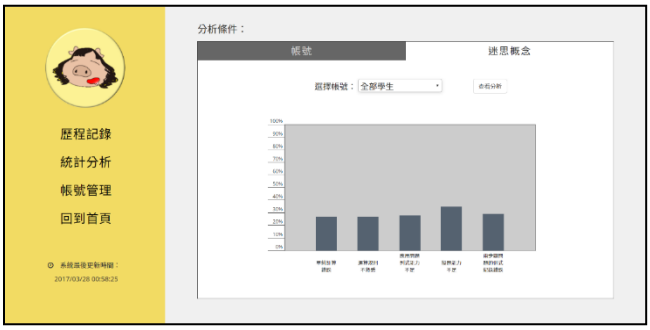

Figure 6. Snapshot of misconception analysis of on-line drill in game-playing

3.3 System Evaluation

In order to examine the suitability of this mobile-based game and web-based management system, the evaluation inventory was designed by Likert 5-point scale in this study. The inventory is comprised up of three facets including perceived usefulness, perceived interest, and willing to use. The Cronbach alpha coefficient of each facet is over .8, depicting that this instrument is reliable. The study employed eleven experienced math teachers of elementary schools for assessing the system, and filling out the inventory after testing the system. The collected data was analyzed by descriptive statistics and one-sample t test by adopting 3 as test value. The evaluation results revealed that the strongly agree and agree percentage of each question are over 85%, the average value of all items is over 4. In addition, t value of each item is over 2.67, shown as Table 1 and Table 2, which reach significant level for all items, $p<.05$, indicating that the math teachers and experts show high appraisal toward this math APP and web-based management system.

Table 1. The descriptive statistical and one-sample t test results of expert evaluation about APP

items	A (%)	B (%)	C (%)	D (%)	E (%)	M	SD	*t*
This APP is helpful in learning math for the students.	9.1	90.9	0	0	0	4.09	.302	12.000***
This APP can promote the students' learning interest.	27.3	63.6	9.1	0	0	4.18	.603	6.500***
This APP can enhance the students' learning motivation.	18.2	72.7	0	0	9.1	3.91	1.044	2.887*
This APP can promote the students' learning achievement.	18.2	72.7	9.1	0	0	4.09	.539	6.708***
This math APP is easy to operate.	36.4	45.5	18.2	0	0	4.18	.751	5.221***
The intervened content in this game is interesting.	27.3	63.6	9.1	0	0	4.18	.603	6.500***
The intervened content in this game is helpful.	18.2	45.5	27.3	9.1	0	3.73	.905	2.667*
The intervened content can improve the students' math misconceptions.	36.4	54.5	0	9.1	0	4.18	.874	4.485**
The game arrangement if this APP is attractive.	27.3	45.5	27.3	0	0	4.00	.775	4.282**
The content of this game can attract the students.	45.5	27.3	18.2	9.1	0	4.09	1.044	3.464**
I am willing to recommend this APP for my students.	27.3	63.6	9.1	0	0	4.18	.603	6.500***
I am willing to apply this APP in my course.	45.5	36.4	9.1	9.1	0	4.18	.982	3.993**

*$p<.05$, **$p<.01$, ***$p<.001$ (A: strongly agree, B: agree, C: medium, D: disagree, E: strongly disagree)

Table 2. The descriptive statistical and one-sample t test results of expert evaluation about management functions

items	A (%)	B (%)	C (%)	D (%)	E (%)	M	SD	*t*
The web-based management for the teachers is easy to use.	18.2	72.7	9.1	0	0	4.09	.539	6.708***
The web-based management for the teachers is suitable.	9.1	81.8	9.1	0	0	4.00	.447	7.416***
The web-based learning profile management is easy to use.	18.2	72.7	9.1	0	0	4.09	.539	6.708***
The web-based learning profile management is suitable.	18.2	72.7	9.1	0	0	4.09	.539	6.708***
The web-based learning profile analysis function is suitable.	45.5	45.5	9.1	0	0	4.36	.674	6.708***
The web-based learning profile analysis function is helpful.	36.4	54.5	9.1	0	0	4.27	.647	6.528***
The web-based management functions can facilliate the teachers grasp the students' learning behaviors.	54.5	36.4	9.1	0	0	4.45	.688	7.016***

*$p<.05$, **$p<.01$, ***$p<.001$ (A: strongly agree, B: agree, C: medium, D: disagree, E: strongly disagree)

4. LEARNING EXPERIMENT

4.1 Learning Experiment Design

To assess the learning effect, this study conducted a learning experiment by adopting quasi-experiment design in an elementary school. The experiment design is depicted as Table 3. The subjects are 60 fifth graders from two classes in Taipei city, and they divided into experimental group and control group. The experimental group accepted digital game-based learning method while control accepted traditional math learning activities. The main instruments are pretest and posttest of number and calculation concepts with different difficult level, validated by experienced elementary math teachers. Before experiment, all of them accepted pretest of number and calculation concepts. The learning experiment lasted for two hours. Afterwards, they took a posttest of number and calculation concepts. In addition, the experimental group was asked to fill in the acceptance

questionnaire of digital game-based learning activities after experiment.

Table 3. The experiment design

group	pretest	treatment	posttest
Experiment group	O_1	X	O_2O_3
Control group	O_1		O_2

O_1: all of subjects accept pretest of number and calculation concepts

X: experimental group accept digital game-based learning activities while control group accept traditional math learning activities

O_2: all of subjects accept posttest of number and calculation concepts

O_3: experimental group fill in the acceptance questionnaire

Figure 7. Snapshot of learning experiment of experimental group

4.2 Result of Learning Effect

In order to examine the learning effect, this study employed descriptive statistics and independent t test for analyzing the pretest and posttest of experimental group and control group. In Table 4, the descriptive statistical results reveal that the pretest of control group is better than that of the experimental group slightly, on the contrary, the posttest of experimental group is better than that of control. In Table 5, the independent t test statistical results of pretest show that there is no significant difference between two groups, p>.05, indicating that the students' math competence of two groups are not different before experiment. Nevertheless, the independent t test statistical results of posttest is same as that of pretest, p>.05, depicting that the learning effect of digital game-based learning method is not significant.

Table 4. Descriptive statistical result of pretest and posttest

achievement test	group	N	M	SD
pretest	experiment group	24	8.21	1.693
	control group	23	8.22	1.476
posttest	experiment group	26	7.77	2.355
	control group	27	7.70	1.977

Table 5. Independent t test of pretest and posttest between experimental group and control group

achievement test	Levene homogeneity test		t	df	Sig.
	F	Sig.			
pretest	.422	.510	-.020	45	.985
posttest	.068	.796	.110	51	.913

Table 6. The descriptive statistical and one-sample t test results of learners' acceptance

items	A (%)	B (%)	C (%)	D (%)	E (%)	M	SD	t
The game of "Let's open lock" is fun.	44.4	22.2	16.7	5.6	11.1	3.83	1.383	2.557*
The game of "Let's fish" is fun.	38.9	38.9	11.1	0	11.1	3.94	1.259	3.183**
The game of "Let's stamp " is fun.	22.2	38.9	22.2	5.6	11.1	3.56	1.247	1.890
The game of "Let's balance" is fun.	38.9	27.8	16.7	0	16.7	3.72	1.447	2.117*
The game of "Let's buy candies" is fun.	27.8	27.8	11.1	5.6	27.8	3.22	1.629	.579
The math APP is easy to use.	55.6	11.1	22.2	0	11.1	4.00	1.372	3.092**
This math APP is helpful.	44.4	27.8	16.7	0	11.1	3.94	1.305	3.071**
I am willing to use this game for mastering math questions.	38.9	22.2	27.8	0	11.1	3.78	1.309	2.522*
The learning profiles are helpful.	44.4	27.8	16.7	0	11.1	3.94	1.305	3.071**

**p<.05, **p<.01 (A: strongly agree, B: agree, C: medium, D: disagree, E: strongly disagree)*

4.3 Result of Acceptance Evaluation

In Table 6, the descriptive statistical result and one-sample t test result reveal that the students regard that three of these games are fun, including "Let's open lock" (M=3.83, SD=1.383, *p<.05*), "Let's fish" (M=3.94, SD=1.259, *p<.01*), "Let's balance" (M=3.72, SD=1.447, *p<.05*). The three dimensions of acceptance are significant through one-sample t test, including easy to use (M=4.0, SD=1.372, *p<.01*), useful to use (M=3.94, SD=1.305, p<.01), and willing to use (M=3.78, SD=1.447, *p<.05*). As a result, the evaluation result show that the students accepted this digital math game positively. In addition, we made learning observation during experiment and interviewed some of the students of experimental group after experiment. The quality results show that they had strong interest and flow in this game, such as "*I like to play this APP even if the math question is not easy to solve*", "*This APP is so fun that I cannot stop playing it*".

5. CONCLUSION AND FUTURE WORKS

This study adopted ADDIE approach to develop a digital game-based math learning APP for the students of elementary schools. After surveying the math misconceptions of number and calculation concepts, gradual prompt of dynamic assessment was integrated into game design in this APP. Therefore, the game players can be supplied intervening content for solving math questions in the digital game-playing process. After the development of APP, this study invited experienced math learning experts to assess its suitability. The evaluation results show that experts show high appraisal towards this APP. To examine the learning effect of this APP, this study conducted a quasi-experiment in an elementary school. Although the learning effect is not significant, the students of experimental group show high willing, interest and motivation toward this APP. Because of the short-term experiment, its impact on learning will not be significant. As a result, this study will launched a long-term

experiment for surveying its learning effect including math learning achievement and motivation.

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