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The Development of a Game-Based Formative Assessment Mathematical Algebra Tutorial App

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Abstract: Algebra plays an important role in the domain of mathematics learning. During the process of solving, not only was it to deepen the basic knowledge of mathematics, but it was also to promote learners' ability of analysis and answering questions. However, during the process of solving an unknown quantity, some researchers mentioned that the learners often made some mistakes such as misunderstanding the meaning of algebra, and it could result in a poor learning of mathematical algebra. In addition, it was also proposed in past studies that the technology integration into learning was helpful to improve the learning effectiveness if employing appropriate teaching strategies, such as game-based learning, formative assessment, and mobile learning. Therefore, the technology of mobile application (abbreviated as "app" in the following) incorporating with the strategies of game-based learning and formative assessment is adopted in this study to develop a game-based formative assessment mathematical algebra tutorial app, and it is expected to enable learners' active learning and improve their learning effectiveness.

Keywords: Game-based learning, formative assessment, mathematical algebra, mobile learning, mobile application

1. Introduction

The learners often had some difficulties in answering the questions of mathematical algebra. For example, learners could not understand the setting of questions or the point of words; they could not make connection of concepts of two words or understand the concepts of unknown quantities (Chiu & Mao, 2002). Hence, some learners progressively began to generate exclusion in learning mathematics. However, due to the progressive process of learning mathematics, the exclusion phenomenon would lead to the learners' difficulties of learning mathematics. Voinea and Purcaru (2014) had explored the effectiveness of learning mathematics at different learning levels, and it is found that the interest of learning mathematics is getting declining for the learners at higher grade. Therefore, how to effectively conduct learners to understand the process of answering the application questions is taken into account in this study.

With the advance of information technology, subsequent scholars increasingly discussed the technology integration into mathematics learning and the possibility to improve the learners' interest of learning mathematics. For example, Wu and Meng (2005) had integrated information technology into teaching with the strategy of question answering, and they explored the effectiveness of question answering on learners in elementary school with mathematics learning disabilities. The results show that it could reduce learners' errors in historical process of answering the questions and improve their attitude of answering the questions. Lwo, Laurence and Liu (2012) developed a personalized computer-assisted instruction (CAI), and they explored the effect of this system on learners learning mathematics algebra questions in elementary school. The results indicate that the learners behave more positively while learning mathematics algebra questions. Lin, Hung, Chang and Hung (2014) proposed a problem-solving learning system (PSLS), and the results show that PSLS is appraised well by 95% teachers and learners. Meanwhile, the learners considered PSLS an effective learning tool as learning contents of problem-solving, and they behave more positively.

However, there were a lot of technology-assisted teaching tools, such as audio-video equipment, teaching compact disc (CD), computer software, network communication, and mobile

application (abbreviated as “app” in the following) which was popular recently (Chung & Cheng, 2005). Some researchers appropriately combined app and learning, and it also created more possibility of teaching and learning. For example, Lo (2013) had successfully established cloud app of language learning, and it could be used to provide users to learn the "classical poetry". Due to the availability of app rating at app store, Zhang and Huang (2014) had organized and analyzed the rating of education apps at app store. The results indicate that the number of education apps with 5 stars which is the maximum is still less than the half of those with 2 stars. Accordingly, the education apps at app store were considered to be still not complete and need improvement by customers. Moreover, it was also conducted to compare free apps with commercial ones; the results show that the customers were willing to pay for commercial apps if their qualities were good enough. Therefore, it is found that user’s intention to use be affected by the apps quality. Zhang and Huang (2014) also suggest that the mechanisms of feedback and scoring should be established during the development of education apps, and it could enable the learners to review their learning portfolio and promote their learning effectiveness. Therefore, in this study, the technology of app is adopted, and the suggestion of Zhang and Huang (2014) are also taken into account to increase the integrity of system.

Although the technology integration could attract learners’ interest and improve learning effectiveness, it is insufficient to promote learners’ interest and learning effectiveness only with the technology integration. Chou and Wu (2014) discussed the learners’ effectiveness while learning the surface area of composite solids of mathematics with three teaching modes; one mode was an instruction assisted by Google SketchUp with push-and-pull function, another mode was an instruction assisted by Google SketchUp without push-and-pull function, and the other mode was traditional lecture. Push-and-pull function enabled learners to change the surface area of composite solids. The results indicate that the learners’ effectiveness using the mode of an instruction assisted by Google SketchUp with push-and-pull function is better than those using the other two modes, and there is no significant difference for learning effectiveness between the mode of an instruction assisted by Google SketchUp without push-and-pull function and the mode of traditional lecture. Accordingly, there would be impact on the learning effectiveness when information technology integration into mathematics teaching if insufficient influence of information technology (Chou & Wu, 2014). Chung and Cheng (2005) pointed out that making good use of the technology and incorporating with the teaching strategies during the process of teaching and learning would be helpful to the effectiveness of information technology integration into mathematics teaching.

However, there are a lot of teaching strategies, and game-based learning is considered a helpful teaching strategy to attract learners’ interest and enable learners to enjoy learning (Huang, 2006). Moreover, Chen and Chen (2009) also suggest that the feedback mechanism of formative assessment is helpful to assist learners’ mathematics learning, and it could enhance their mathematical ability and promote learning interest. Consequently, it is intended in this study to develop a game-based formative assessment mathematical algebra tutorial app, and it is expected that the intentional app is helpful to facilitate learners’ active learning and promote learning interest and effectiveness.

2. Literature Review

2.1 Game-Based Learning

A virtual environment was provided to game players, and they had to use their own knowledge to solve the questions encountered under a virtual environment (Huang, 2006). Game-based learning was to proceed learning by the way of a game, and teaching would serve as game playing in order to attract learners’ interest and enable learners to enjoy learning (Huang, 2006). Many scholars had combined a lot of fields with a game, and they found that game-based learning could really promote the learning interest (Chen, Chiou, Chen, & Chang, 2013; Chen, Ho, Wu, Wang, & Yan, 2010). Chen et al. (2010) had integrated the mechanism of game level into the natural science learning in elementary school, and the results showed that the majority of learners considered game-based learning to be more interested and helpful for learning. Chen et al. (2013) integrated a game into mathematics learning to help learners to understand the concept of mathematical division. The results indicated that it could effectively promote the learning interest and facilitate positive learning.

In addition, Chen et al (2010) found that the rank of system components to impress learners was scenario, way to play game, subject knowledge, display, and sound effects. Therefore, it was suggested in game design to avoid too much learners' focus on interesting parts and stimulus brought by game playing, and thus the objectives and the contents of teaching were ignored. Consequently, the strategy of game-based learning is employed in this study to develop an app based on the game level, and the suggestions by Chen et al. (2010) are also adopted to avoid more attentions on game playing than on the teaching contents.

2.2 Formative Assessment

Formative assessment was able to facilitate teachers and learners to understand the learning process and improve learning effectiveness (Cowie & Bell, 1999; Scriven, 1973), and it would play an important role in learning (Bell & Cowie, 2001; Black & Wiliam, 1998). Buchanan (2000) also pointed out that an assessment-centered teaching design could correct learners' wrong directions of thinking by the provision of continuous feedback information to learners. Pan (2008) combined the network multimedia and formative assessment to discuss whether or not to enhance learners' motivation. The results showed that the learners presented higher motivation by the combination of the network multimedia and formative assessment. Hwang and Chang (2011) combined the mobile learning and formative assessment, and the results indicated that the learning effectiveness of learners with formative assessment involved was better than those without formative assessment involved.

Moreover, some scholars had pointed out that it was necessary to incorporate some teaching strategies into formative assessment so as to enhance the learning effectiveness of learners (Wang, 2008; Wang, Wang, Wang, & Huang, 2004a; Wang, Wang, Wang, & Huang, 2004b). Buchanan (1998) suggested that "repeat the test" and "correct answers are not given" could be included in the design of formative assessment; when a learner's answer was wrong, an instant feedback was provided to guide the learner to find out the correct answer; using this method was able to facilitate learners' proficiency of answering the questions during the process of practice and actively finding out the answers, and then promote the learning effectiveness.

Incorporating some modules into the Web-based Assessment and Test Analysis system (WATA), Wang, Wang, Wang and Huang (2004a) discussed the impact of three different types of formative assessment strategies on the learning effectiveness of students in junior high school; one was the Formative Assessment Module of the WATA system (FAM-WATA) which included "repeat the test", "correct answers are not given", "all pass and then reward", and "monitor answering history"; another one was the Normal WATA system (N-WATA) which included "repeat the test", and "correct answers are given"; the other one was the Paper-and-Pencil Test system (PPT) which included "answer once" and "correct answers are given". The results indicated that there were significant differences on the learning effectiveness among different formative assessment strategies, and the average score with FAM-WATA was higher than those with N-WATA and PPT. Wang, Wang, Wang and Huang (2004b) also pointed out that the design of self-assessment teaching strategies implemented in FAM-WATA enabled good learning effectiveness.

Moreover, Wang (2008) discussed the impact of three different types of formative assessment strategies on the learning effectiveness; one was the Game Assessment Module of the WATA system (GAM-WATA) which included "repeat the test", "correct answers are not given", "instant hints are given", "monitor answering history", and "all pass and then reward"; another one was the Normal Web-Based Test system (N-WBT); the other one was the Paper-Pencil Test system (PPT). The results showed that the learning effectiveness with GAM-WATA was better than those with N-WBT and PPT, and it also suggested that teaching strategy integration into formative assessment was necessary to promote the learning effectiveness. Consequently, the formative assessment strategies of "repeat the test", "correct answers are not given", "instant hints are given", "monitor answering history", and "all pass and then reward" will be implemented in this study, and it is expected to promote the learning effectiveness.

3. System Structure

3.1 System Architecture

The intentional system is designed for learners and for teachers; a learner can use a smart phone or a tablet to learn the mathematical algebra, and a teacher can use a smart phone or a tablet to query the learners' learning history. The system architecture is shown in Figure 1.

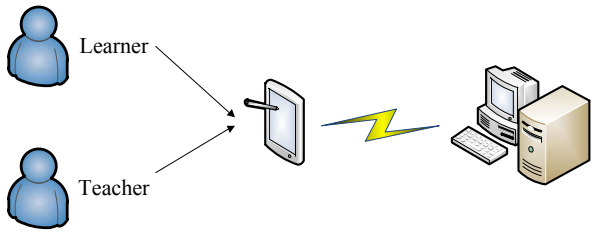

Figure 1. System Architecture.

3.2 Teaching Materials

The contents of teaching materials are selected from a mathematics textbook for sixth grade students in elementary school, and there are eight topics included: "warm-up practice", "average question", "age question", "chickens-and-rabbits question", "catch-up question", "flow rate question", "total review", and "advanced question". Corresponding to these eight topics mentioned above, the intentional App in this study is developed and expected to help learners learning mathematical algebra.

3.3 Game-Based Learning Strategy

The game-based strategy proposed by Chen et al. al (2010) is used in this study, and there are eight game levels designed to correspond to eight topics of teaching materials mentioned above. The learning activities mainly follow the assigned order of game levels, and thus a route animation is designed to inform the learners to click the target game level to advance learning. Therefore, it is illustrated on the map as shown in Figure 2. The inactivated game levels are displayed in gray color; the sphere-like objects denote basic game levels; the pentagon-like object corresponds to the topic "total review"; the six-pointed star corresponds to the topic "advanced question". Furthermore, a toolbar is provided in the upper right-hand corner of the screen, and its appearance can be toggled by mouse click. There are a "Help" button (denoted as a question mark and expressed in text and voice) and a "Close" button (denoted as X) listed on the toolbar.

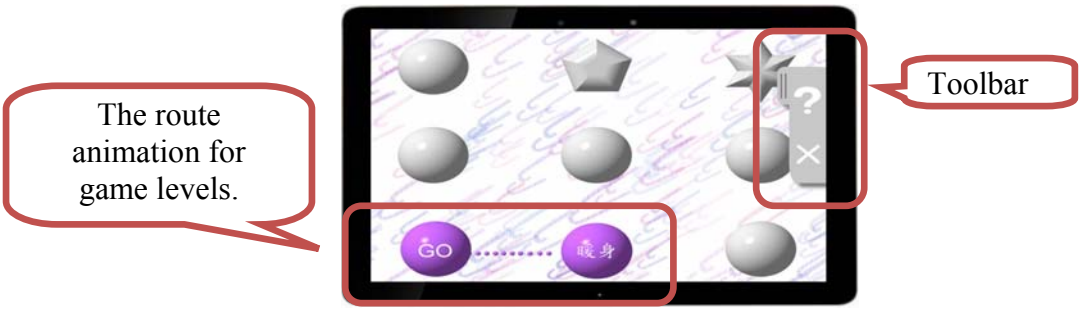

Figure 2. The map of game levels.

The game level named "warm-up practice" is taken as an example, and there are five game sub-levels corresponding to five questions for this topic. The learners have to follow the assigned order to learn, and they cannot advance to the next game sub-level if not finishing previous ones as shown in Figure 3. The toolbar with the "Help" button and the "Return" button is still arranged in the upper right-hand corner of the screen. Furthermore, the star collection activity is employed in the system to inspire the learners' motivation. All stars will be obtained if the correct answer is given without hints at the first time, but it will result in a one-star loss when the hint is provided after entering a wrong answer.

Figure 3. An example of a game level.

Furthermore, the number of stars within a game level on the map will correspond to the number of its sub-levels as shown in Figure 4. For example, the game level named "warm-up practice" contains five stars corresponding to its five sub-levels. A one-star will be obtained if the correct answer is given without the hints at the first time, but a one-half star will be given if the hints are once provided after entering wrong answers. However, the pentagon-like game level named "total review" will be activated if previous ones are all conquered. The function to access the learner's personal answering history is also provided by real time recording in the system. Finally, the animation as a reward will be launched to celebrate all pass as shown in Figure 5.

Figure 4. The map of game levels with the star collection activity.

Figure 5. The animation as a reward for all pass.

3.4 Formative Assessment Strategy

A game sub-level within the "average question" level is taken as an example to demonstrate the system design. The question description of a word problem is displayed in the top of the screen, and a toolbar appears in the right-hand side of the screen as shown in Figure 6. There are a lot of buttons on the toolbar, and the function description of buttons is shown in Table 1. Moreover, the area under the question description is available to support handwriting function for the computation details by learners, and its scope is extendable by scrolling up and down. The area to enter the answer is located in the lower right-hand corner of the screen.

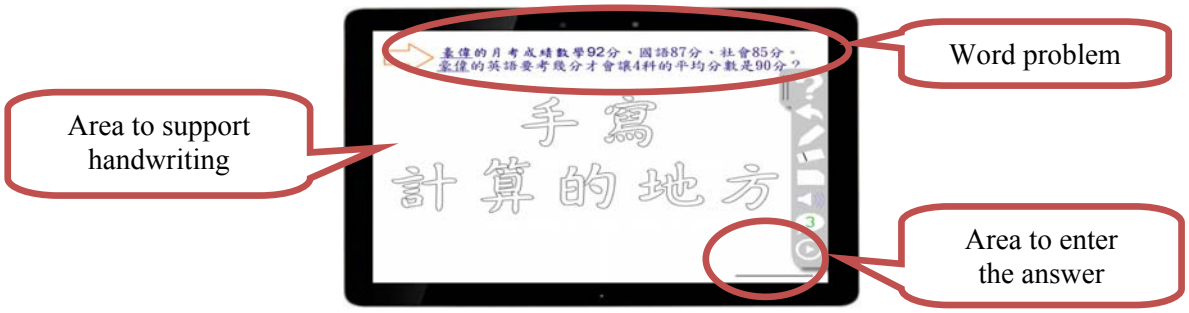

Figure 6. An example of the game sub-level within the "average question" level.

Table 1: The function description of buttons on the toolbar.

Button	Function description
	Provide the operation help expressed in text and voice
	Return to the corresponding game level
	Support handwriting and changing color (the default color is blue)
	Eraser
	Return to the map of game levels
	Speak the question description in voice or turn off the function (the default mode is "on")
	Provide the hint on demand within three times at most
	Provide the solution with a video after giving the correct answer or three wrong answers

Zhang and Huang (2014) had suggested that the mechanism of feedback and scoring should be established when developing an app, and it could enable the learners to realize their own learning history and promote the learning effectiveness. Accordingly, during the process of learners' answering the question, the text as a hint is given after entering a wrong answer for the first time as shown in Figure 7; the computation formula as a hint is displayed after entering a wrong answer for the second time as shown in Figure 8; finally, after entering a wrong answer for the third time, the solution video is displayed to guide learners without giving the correct answer as shown in Figure 9. In addition, the animation as a reward is displayed after giving the correct answer as shown in Figure 10. The hints mentioned above are also provided in voice as well as the animation, and their contents are formulated after discussing with the mathematics teachers in elementary school.

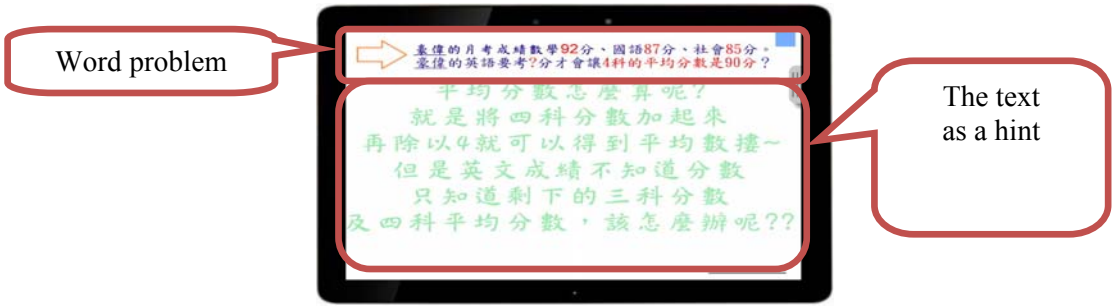

Figure 7. The text as a hint.

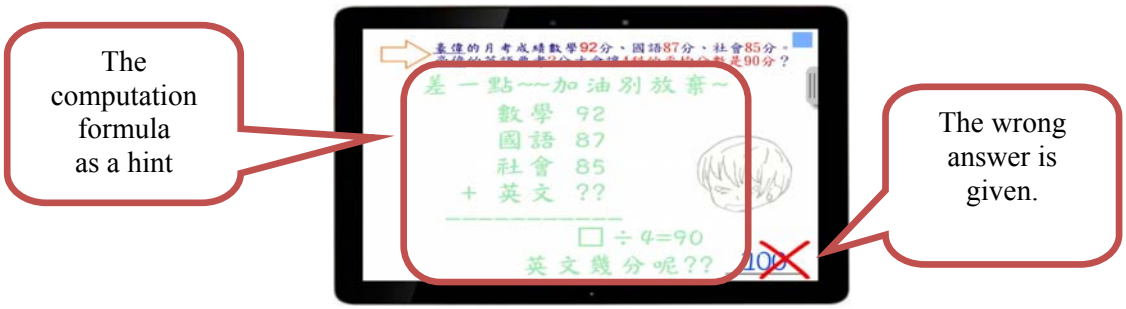

Figure 8. The computation formula as a hint.

Figure 9. The solution video.

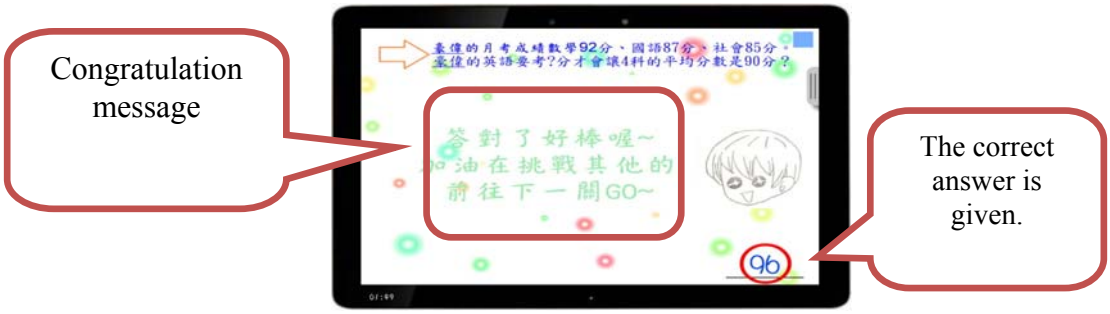

Figure 10. The animation as a reward

Furthermore, the app with the query function for the teachers is also developed to allow them to use a smart phone or a tablet to query the learners' learning portfolio. The learners' current score is illustrated with a bar chart as shown in Figure 11, where the learners' seat number as well as their name is labeled along the horizontal axis and their current score is labeled along the vertical axis. The highest score is 100, and the score computation for each game level is described as follows. There are five questions for the "warm-up practice" level, and their goal is to allow the learners to review the basic mathematical operation. Thus, the score gain is 2 for each question. For five game levels including "average question", "age question", "chickens-and-rabbits question", "catch-up question", "flow rate question", there are four questions respectively for each game level, and the score gain is 3 for each question. For two game levels including "total review" and "advanced question", there are five questions respectively for each game level, and the score gain is also 3 for each question. The score loss is 1 for every time using a hint during the process of answering a question. The score ranking for the learners is shown in Figure 12, and the column titles in the left-to-right order are "Ranking", "Seat number", "Name", and "Score".

Figure 11. The learners' current score illustrated with a bar chart.

Figure 12. The score ranking for the learners

The personal answering history for a learner is demonstrated in Figure 13, and the column titles in the left-to-right order are "Game level", "Game sub-level", "The n-th time to repeat the test", "Date", "Start time", "Stop time", "Duration", and "Frequency to use the hints". As shown in Figures 11, 12, and 13, the "Refresh" button is arranged in the upper right-hand corner of the screen, and it can be used to refresh the page and update the information on the screen. The update time is also displayed in the top of the screen.

Figure 13. The personal answering history for a learner.

In order to allow learners and teachers to use the proposed system no matter the Internet is offered or not, two switched modes including the offline mode and the online mode are provided in the proposed system. The offline mode can be switched if the Internet is not available or a serious lag, and the learning portfolio for the learners can be temporarily stored in the portable device. When the Internet is available, the online mode can be switched to upload the data temporarily stored in the portable device to the server to update the database and backup. The teachers can download the learners' data from the server to refresh and update the data stored in the portable device by switching to the online mode when the Internet is available, and they can still query the learners' data stored in the portable device under the offline mode when the Internet is not available or a serious lag.

4. Conclusion and Future Work

The game-based formative assessment mathematical algebra tutorial app is developed in this study. During the process of development, the suggestion of Zhang and Huang (2014) is adopted in this study. The mechanisms of feedback and scoring should be established during the development of education apps, and it could enable the learners to review their learning portfolio and promote their learning effectiveness. The suggestions by Chen et al. (2010) are also adopted to avoid more attentions on game playing than on the teaching contents, and the game levels are used to inspire the learners' motivation. In addition, some strategies suggested by Buchanan (1998), Wang (2008), Wang, Wang, Wang, and Huang (2004a), and Wang, Wang, Wang, and Huang (2004b) are incorporated into the formative assessment. The strategies include "repeat the test", "correct answers are not given", "instant hints are given", "monitor answering history", and "all pass and then reward".

The future work is to invite at least two mathematics teachers to test this system, and an interview with the invited teachers will be conducted for forty minutes after the test. The suggestion of

the invited teachers will be used to improve and revise the system. Then the teaching experiment is intended to invite two classes of sixth grade students taught by the same mathematics teacher in elementary school. Participants in the experiment are totally 50 students and divided into two groups, the experimental group and the control group. The experimental group uses the proposed app with the strategy of game-based learning and formative assessment to learn, and the control group uses the game-based app without the strategy of formative assessment to learn. The experiment is intended to be conducted in the mathematics course for three weeks, two days a week, and two periods per day. The purpose of this study is to explore the effect of formative assessment strategy on the learners' learning effectiveness.

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