The Design and Development of a Mobile Phone Application for STEM based on a Novel Engineering Approach

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***Abstract*—STEM education provides students with interdisciplinary knowledge to improve problem-solving ability and practical ability. The purpose of this study is to explore whether students could achieve the goal of STEM education by mobile learning. This study developed a mobile application which was named *Borrowing Your Enemy's Arrows* to support mobile learning about science, technology, engineering, and math (STEM). According to the textbooks for Grades 5-7, the teaching content of the APP was designed to help students consolidate knowledge and to help teachers save much time in preparing classes. The central narrative, like cartoon or the dialogue of cartoon is used for APP to link the subject knowledge. Therefore, learners can construct a real-life situation by APP. To inspire learners' interest in STEM courses, the APP used games to test how well students did in learning. A shipbuilding task with the narrative background was set to improve learners' skills and interest in engineering learning. The educator could make the assessment of learners based on all their work in the process of learning, including the design sketches, final products, the message from students and the grade of game. For the purpose of improving the APP, teachers and students were interviewed to investigate user feedback in this study.**

***Index Terms*—STEM education, mobile learning, novel engineering**

I. INTRODUCTION

By integrating STEM education in science, technology, engineering, and mathematics, students can see the connection of knowledge between dispersed disciplines. By designing good STEM thematic activities, it is possible to increase students' interests and achievements in related disciplines [1]. However, since STEM education is multidisciplinary, it often takes a lot of time to develop a STEM course. This will prolong the student's study time, and will not achieve the goal of reducing the burden on students. What is worse, it will cause both students and teachers to feel impatient [2]. In the process of improving the STEM curriculum, some scholars have successfully used mobile devices as teaching tools to guide students in autonomous exploration through mobile phones or tablet computers.

In previous studies, many scholars have developed APPs suitable for STEM learning to assist students in learning. Some Italian scholars have developed an application based on artificial intelligence. In the VLE (virtual learning environment), several students form a group and learn through role-play in the style of 3D images. Students in this learning environment will be more interested in participating in the course [3]. In the Science Center, with the help of the staff of the venue, the researchers selected the teaching content and reorganized students into multiple themes. The learners took mobile devices to learn. Not only can they get timely feedback, but they can also learn the science center's fusion of STEM. Knowledge and attention are also more concentrated [4]. Digital game-based learning methods have been proved to be useful in improving students' enthusiasm and promoting learning in a technologically enhanced environment [5].

In order for learners to maintain a sustained focus on STEM courses, stories and novels are often used as one of the forms to guide curriculum progression. The novel engineering integrates engineering education and literacy in school-based curriculum in a new way. When students read materials (such as stories, novels, etc.) in a literature class, the characters in the novel or story will encounter some problems. Based on the situation of the story, the students can use their own knowledge and skills to complete the engineering design in collaboration with the team and the support from the teacher to help the story characters solve the problems [6]. Wilson-Lopez and Gregory [7] pointed out that literacy instruction can be used to think deeply about engineering problems at various stages of the design process. Literacy and engineering are complementary and mutually reinforcing. The way the students design activities when they practice engineering can help them become more experienced readers or writers. Students apply reading comprehension strategies to engineering projects to help them become thoughtful engineers. Through the problems encountered by the characters in the novel, digging out the STEM elements among them makes it possible for the learner and the protagonist to overcome the difficulties and make the course more interesting and more persuasive. Therefore, the purpose of this study is to design and develop a mobile phone application which is called *Borrowing Your Enemy's Arrows* for STEM based on a Novel Engineering Approach.

Borrowing Your Enemy's Arrows was implemented with seventh grade students from a junior high school of Jiaxing, China in March 8, 2018. This research study describes the design of *Borrowing Your Enemy's Arrows* and the results of recording-based interviews of six students and four teachers who had at least five years in their respective fields. We analyze these interviews to address the following three research questions:

RQ1: Is the design of *Borrowing Your Enemy's Arrows* reasonable?

RQ2: Is *Borrowing Your Enemy's Arrows* popular with seventh-grader students?

RQ3: How to improve *Borrowing Your Enemy's Arrows*?

II. Design of Mobile Learning Game Apps

The serious educational games can promote scientific practice and flow experience [8] so the teaching content of *Borrowing Your Enemy's Arrows* was based on the sixth- and seventh-grade teaching materials which is published by Shanghai Education Publishing House in order to foster STEM knowledge and skill (see Table 1). The novel project could help students who were afraid of science and engineering disciplines to overcome psychological barriers in order to improve students' interest in learning and participation, and help students who were not interested in Chinese learning to improve their literacy by solving engineering problems [6]. In the game of educational APPs, it was necessary to design clear knowledge instruction and practice to make the game more effective [9], and the test of knowledge was more helpful to students' mastery of knowledge than practical application [10]. In educational games, clear goals, immediate feedback, and appropriate difficulty were precondition of flow [11].

TABLE I.

Subject	Knowledge	Contents
Science	Gaseous, liquid and solid The effect of force Friction Buoyancy	The formation of fog Deformation of the arch Rolling log Floating boat Wind-blown boat
History	Action and reaction The history of the ship The history of the Three Kingdoms Time	Ancient ship and modern ship
Chinese	Peculiar language of character	Ancient time and modern time
Engineering	The structure of the ship	Shipbuilding

A. Description of the Game APP

Borrowing Your Enemy's Arrows is a serious mobile educational game played with Android mobile devices out of the junior high school. It was designed with Photoshop and developed with APP inventors. The design of interface and character were original.

The content of game APP is divided into five modules: Guide (guide to how to use); Cartoon (knowledge, story background); Think tank (list of knowledge); Shipbuilding (hands-on); Athletics (test). The players gained knowledge through cartoons, and then they built ships and played games. When they encountered difficulty, they could enter Cartoon to relearn or enter the Think Tank to summarize important knowledge (see Figure 1).

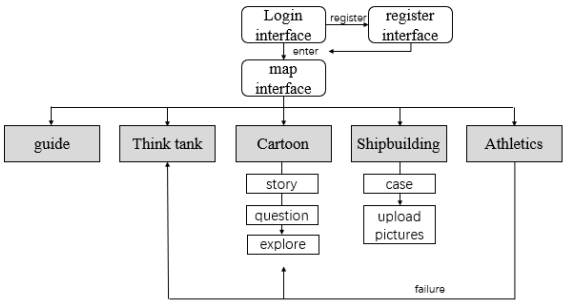

Figure 1. The Structure of Borrowing Your Enemy's Arrows

B. Cartoon

Borrowing Your Enemy's Arrows used a central narrative to link every module together. The core narrative was a story of the Romance of the Three Kingdoms by Luo Guanzhong. This is an episode from the Three Kingdoms. Zhou Yu ordered Zhuge Liang to manufacture 100,000 arrows within ten days, a mission almost impossible, with the hidden purpose of punishing Zhuge Liang in case Zhuge Liang can not fulfill the task in time. Zhuge Liang rode a boat to the enemy's camp for making them believe surprise attack to shoot arrows. Zhuge Liang collected arrows by the scarecrows. The story is presented by comic so the students will be more interested and the relevant questions are set to promote students' thinking (see Figure 2).

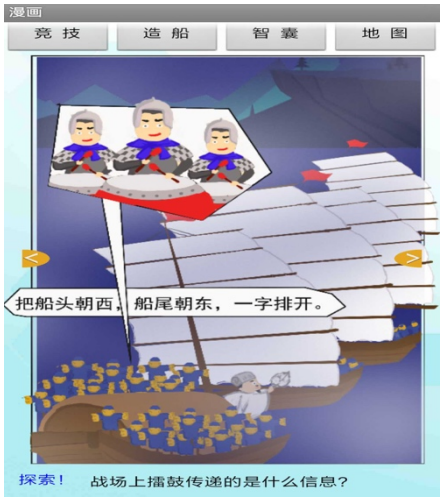

Figure 2. Screenshot of a Cartoon

C. Shipbuilding

In the story of Cartoon, Zhuge Liang needed 20 ships, and thus *Borrowing Your Enemy's Arrows* demanded players to build ships. The task design of the game should follow the small step principle and accord with the requirements of the "zone of proximal development" [12], The virtual character will guide the students through the small tasks step by step. (see Figure 3). And the players were asked to upload a sketch of the design, a picture of artifacts, and their note taking sheets that were scanned into the devices during the production process in order to evaluate students from different dimensionality.

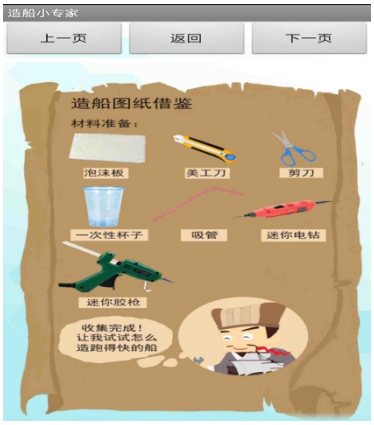

Figure 2. Screenshot of a Shipbuilding that Receives Hints during Gameplay

III. ATHLETICS

The background of the Athletics was the story in Cartoon, and the players played games by role-playing for promoting the engagement. The goal of the game is to borrow 100,000 arrows from Cao Cao. Every time when the player is out of cards, the Athletics would display the number of arrows which the player had borrowed to make the player define the progress of the task (see Figure 4). When the player is at fault, the mobile phone vibrates to provide negative feedback and when the player wins the game, the mobile phone would sound a note of congratulation for the player, more specifically the sound of a firework display, to provide positive feedback.

Figure 4. Screenshot of Athletics

IV. METHODS

A. Setting and Participants

A sample of six seventh-grade students and four teachers was obtained from a junior high school in Jiaxing, China. The school had not a course about STEM or engineering. The six students included three male and three female students and every gender included high, middle and low grades. The four teachers who were at least five years in their respective fields included a computer teacher, a history teacher, a Chinese teacher, and a science teacher.

B. Study Design and Data Collection

This study employed qualitative research method. Date sources included: interviews, field observations, screen recording and the scores of the Athletics.

C. Interviews

Students and teachers were assigned to play *Borrowing Your Enemy's Arrows* for half an hour. Immediately after it was completed, students and teachers participated in the interviews. The interview protocol of the students (see Table 2) included questions about TAM, flow experience, the overall design of the software and the attitude towards the software. Whereas the questions about flow experience were removed from the interview protocol of the teachers. All the interviews were audio recorded and later transcribed by the researcher.

TABLE II. THE INTERVIEW PROTOCOL OF THE STUDENTS

	Dimensionality	Questions
TAM [13]	Perceived usefulness	When you use this APP, have you encountered any problems?
	Perceived ease of use	By using this APP, do you think it is useful for your study? What knowledge have you learned?
Flow experience [14]	No fear of failure	What do you do when you fail?
	Time distortion	Do you think time passes quickly than you realize in the process of using the APP? Do you want to play with it again?
	Loss of self consciousness	Field Observations
	Focused attention	
The overall design of the software.	Module design	What do you think of the modules in the software: Comics, Athletics, Shipbuilding, Think Tanks? Which are you most interested in? Which do you think needs to be improved? Please elaborate your suggestion.
	Art Design	What do you think of the art of software, or do you think it looks good in the software? Where do you think the artists need to change?
	Interaction	Do you think you can get clear and immediate feedback when you use the software? Do you find the interaction in software interesting?
	Teaching content	Do you think the knowledge involved in the software is difficult?
Attitude [15]	Degree of affection	Do you like this software?

D. Field Observations

Two researchers conducted field observations during gameplay by following players. The researchers recorded observations about students' attention and expression to show the flow experience of the students especially in terms of focused attention and loss of self-consciousness.

E. Screen Recording and the Score of the Athletics

When the students were using *Borrowing Your Enemy's Arrows*, the screen recording software recorded the students' operation. And one researcher kept the score of the Athletics by watching screen recording.

V. Results

A. The Score of the Athletics

Table 3 presented the score of the Athletics in the screen recording. After going through the cartoon and the Think Tank for the first time, the students did not complete the task, but most of them were able to complete the task at last. This indicated that the difficulty of the Athletics is appropriate. And the study found that when students failed their first try in the game some of them would go to Cartoon to review or go to Think Tank to learn or both for a second time. Different choices were available to individuals (The full marks is 11).

TABLE III. THE SCORE OF THE ATHLETICS

Student	Gender	Age	Ranking of the School/(N=500)	First Score	Last Score
S1	Female	13	1/500	8	11
S2	Female	14	232/500	8	10
S3	Female	13	411/500	4	8
S4	Male	13	250/500	6	11
S5	Male	14	39/500	8	11
S6	Male	14	451/500	7	10
mean		13.5	230.6/500	6.8	10.2

B. Interviews

1) Technology Acceptance

Students could use the APP easily even without teacher's guidance. They thought that there was no problem with APP usage. Only one girl had a problem with the button, and she thought the problem was with the phone. However, teachers had demanded better APP usage, especially the computer teacher. Below, the computer teacher describes the problems using the APP:

I can play it by myself, but some buttons are too small to recognize at first. Of course, the Icon of the Guide is also so small that I think it is just a picture. So I think you can put it in the middle of the map. And sometimes the button is malfunctions.

(interview, computer teacher, seven years' teaching experience)

In this APP, students and teachers agreed that it could promote students' learning. And they were all aware that this is an interdisciplinary education software, but most people could only recognize science, history, and language.

2) Flow Experience

Most students could have flow experience. They didn't fear failure and thought time passed quickly. They wanted to play it again. On the other hand, five students focused on the APP and one student was distracted when the researchers were taking pictures and walking.

3) The Overall Design of the Software

For the most impressive module, different people had different answers. Students preferred Shipbuilding and Athletics. Teachers' choices were much more dispersed since all four modules were mentioned. For the artistic designing, the requests of the girls were generally more than boys. Girls thought the image of the characters could become more exquisite. The computer teacher put forward her own ideas for the interaction of the Cartoon:

Cartoon is more attractive, but the interaction of the Cartoon is too easy. You can increase the frequency of interaction. For instance, when you touch on the characters, words and sounds then appear.

(interview, computer teacher, 7 years' experience) For the teaching content, researchers asked the students about the difficulty and asked the teachers about its reasonableness. Students thought the difficulty of knowledge was appropriate, because the teaching content had the knowledge they had learned and the knowledge quite unknown to them. The teacher thought the content was accurate.

4) Attitude

The students' attitudes were positive. They thought the APP was very interesting, and they would like to recommend it to their friends. However, on the one hand, the teacher thought that this was a useful tool for the students. On the other hand, the teacher thought that the phone could disturb the students' study and other problems. Chinese teacher's description of the problems of APP is as below:

You should consider which teacher can teach this curriculum. Now none can teach it in our school. And the app just has a story, so the curriculum is just one. It's too little.

(interview, Chinese teacher, 20 years' experience)

VI. Discussion

This paper described a mobile phone application for STEM based on a novel engineering approach to foster STEM knowledge and skills. In this study, researchers introduced the design of *Borrowing Your Enemy's Arrows* and implemented a simple user evaluation in order to find out whether the mobile phone application design was reasonable, weather the teaching content was accurate, and how to improve it.

As a whole, the teaching content of *Borrowing Your Enemy's Arrows* is accurate and conforms to the content of the textbook. The design of *Borrowing Your Enemy's Arro*ws is reasonable and has the following advantages. First, *Borrowing Your Enemy's Arrows* based on a novel engineering approach created a problem-based learning environment to promote students' learning. Second, the method of evaluation was diverse, both competitive and practical. Third, students could personalize their learning based on different knowledge types.

Of course, there were some deficiencies in *Borrowing Your Enemy's Arrows* that needed to be improved. First, add story content, design a series of curriculums to support systematic teaching. Second, increase the forms of interaction and increase the chance of human-computer interaction. Third, improve the design of both the character and the interface to increase visual aesthetics.

VII. Study Limitations

In this study, a STEM educational software on the basis of novel engineering was developed. After interviewing students and teachers, the results showed that the software could stimulate students' interest and help them learn

STEM contents better. However, there were still some limitations. In the study, we only had six samples. Due to the limited time of investigation, the subjects failed to complete the engineering module and further investigation on subsequent memory wasn't able to be carried out.

In addition to the fact that STEM type apps could help improve students' learning motivation, they also had a positive effect on guiding students to complete STEM content. However, researchers still needed to develop learning materials to go with the APP (e.g., textbooks, courses, video, toolkit) to support students in learning STEM contents.

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