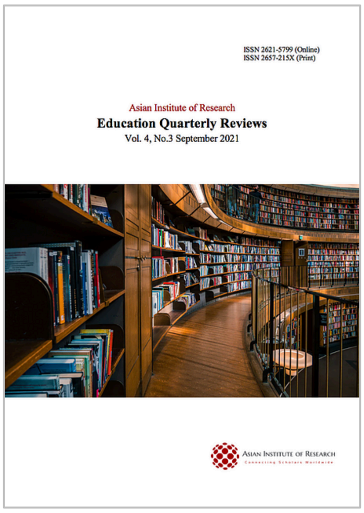

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A Qualitative Analysis of Using Games Learning Programs to Improve Elementary Teachers' Application of STEM Capabilities

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Abstract
This study used CodeMonkey, an online learning platform through which elementary teachers can learn programming while playing games and experience how to integrate STEM into their courses. The study analyzed and examined their experiences using a qualitative research method. According to the research results, learning programming while playing games can encourage beginners to go all in. There are also complete guidelines on the teaching platform, so beginning learners can quickly become familiar with the interactive model, which stimulates their curiosity and changes the traditional learning method of teaching by teachers and received by students. On the whole, learning programming itself is a rigid subject. At the fundamental stage, learners can be greatly interested in learning it. However, if learners cannot understand the learning goals, the advantages gained from their self-confidence and joy of learning will no longer exist. Among beginners to the novel model of learning programming while playing games, there is no obvious difference in learning effectiveness between male and female students. Learners who actively seek to solve problems during the learning process can achieve better learning efficacy.

Keywords: Science, Technology, Engineering, And Mathematics (STEM), Game-Based Programming Learning, Big Six Skills

1. Introduction

In recent years, programming has been incorporated into the elementary school curriculum in many countries. For example, Estonia and Finland encourage students to learn a programming language from the first grade of elementary school. The United Kingdom has launched an education program for children to learn programming. In Asia, Singapore, South Korea, Hong Kong, the Philippines, and Malaysia have launched programs for elementary school students to learn programming. Taiwan's Ministry of Education (2018) promulgated the 12-year National Basic Education Curriculum Outline, which separated the current information curriculum from information technology and life technology, with the expectation that the curriculum objectives in the field of science and technology can create appropriate and friendly teaching situations to enable students to acquire basic scientific and technological literacy in order to bring out children's talents in adaptable and supportive conditions, regardless of gender (Tsai, 2019).

Science and technology are taught via two courses, information technology and life technology, which are expected to train students' operational thinking and design thinking and develop their understanding and logical thinking of science and technology issues. These courses serve the same purpose as science, technology, engineering, and mathematics (STEM) education, which aims to supply the country with excellent manpower in STEM-related fields. Integrating various subjects can motivate learners' willingness to learn the subjects to meet the needs of modern science and technology by enabling students to break away from the traditional way of learning and face future challenges with new ideas and attitudes. However, few teachers feel prepared to integrate STEM into the classroom. Many learning-by-doing courses do not support in-depth learning and apply STEM inappropriately due to a lack of teacher experience, which can impede the achievement of learning outcomes. As educators integrate STEM into courses—a phenomenon becoming more and more required in the field—most certified elementary teachers have no training on how to incorporate new ideas into their courses. Although recent elementary education graduates have been required to take related courses to graduate, they are still unfamiliar with how to integrate the information into lessons for their learners. Thus, the researcher attempts to help elementary teachers experience the STEM course designed for elementary school children learning programming languages. The researcher explores the effectiveness of learning programming that elementary school teachers experience while playing games and then analyzes the efficacy of learning programming.

2. Methods

2.1 STEM Theory

STEM refers to the curriculum integrating science, technology, engineering, and mathematics. The main purpose of STEM education is to train and provide the country with versatile professionals who have acquired applicable competencies integrating science, technology, engineering, and mathematics. Through the interactive application of various disciplines, STEM education motivates learners' interest in integrated courses so they can combine what they have learned from science and technology into their daily lives. STEM education originated in 1986, when the U.S. National Science Board released its *Undergraduate Science, Mathematics, and Engineering Education*, which put forth the programmatic proposal of STEM education integrating science, technology, engineering and mathematics and recommended cultivating high-quality scientific and technological talents, engineers, scientists, and mathematicians to enhance the country's competitiveness. In 2007, it released the *National Action Plan*, which proposed that the United States should strengthen the dominant position of STEM education at the K–12 and undergraduate stages, improve the quality of teachers, and increase the amount of resources allocated to addressing this issue. In 2009, in the *Ten-Year Plan for Innovation in Education*, USD 400 million were budgeted for training 100,000 STEM teachers to improve their students' science and mathematics skills; it was recommended that teachers make science practical and interesting through hands-on courses. In 2014, in the *National Integration Strategy for STEM Talent Development*, USD 450 million were budgeted to establish the STEM Innovation Network Program, STEM Virtual Learning Network, Group of Expert STEM Teachers, STEM Teacher Professional Development, STEM Efficient Teaching and Learning Program for elementary and secondary schools, and the Improvement Education Fund (Lin, 2014).

Since 1990, many analysis reports in the United States have noted that the traditional way of teaching STEM subjects in disaggregated categories is obviously insufficient for students' learning, resulting in students' inadequate problem-solving skills (Bybee, 2013; Thomasian, 2007); National Academy of Engineering & National Research Council, 2014). Over time, the United States has been alert to the continued decline in student performance in STEM subjects and the decreasing number of students becoming employed in the engineering field after graduation, leading to a series of changes to STEM teaching (Toulmin & Groome, 2007). Such ideas have also quickly attracted the attention and emulation of various countries (Fan & Yu, 2016; Ritz & Fan, 2015).

In order to reverse the decline in American competitiveness, the United States released the American Competitiveness Initiative (ACI) in 2006. In view of the close correlation among competitiveness, creativity, and mathematics and scientific literacy, ACI listed the enhancement of students' mathematics and science literacy as one of the main initiatives. In addition to encouraging students to study science, technology, engineering, and mathematics in various ways, ACI attached greater importance to the cultivation of students' STEM literacy in integrating STEM knowledge and developing innovation and problem-solving skills. In the following year, the National Governors Association (NGA) released a joint research program, Innovation America: Building a Science, Technology, Engineering and Math Agenda, to effectively implement STEM education in each state of the United States. For example, in terms of STEM curricula, the NGA believes that states should integrate K–12 STEM education, align state K–12 STEM standards and assessments with postsecondary and workforce expectations for what high school graduates know and can do, and develop high-quality STEM curricula for voluntary use by various regions. In 2011, the United States National Research Council released a research analysis entitled *Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics*, which noted that increasing STEM literacy for all students should be the main goal.

Not all STEM-related jobs require candidates who have received a higher education or even a university degree. Less than half of the rudimental STEM jobs require a bachelor's degree or above. STEM education begins when the students are young:

- Elementary schools focus on introducing STEM courses so that the students can develop an understanding of STEM fields and occupations;
- Secondary school curricula are more rigorous and challenging, and the goal of STEM education is still to enable students to develop an understanding of STEM fields and occupations; and
- Senior high schools focus on challenging and rigorous tasks, reducing STEM opportunities both inside and outside the school.

Kelley (2010) noted that the STEM curriculum framework of science and technology education should be geared with "contextual learning" and provide students with a systematic problem-solving model through "engineering design" so that the students can solve real-world problems through "scientific inquiry." Fan and Yu (2016) conducted in-depth interviews with several scholars related to science teaching in the United States for the purpose of understanding their teaching, and their study reached the following conclusions:

- The STEM teaching model should be an integrated way of teaching and learning.
- In addition to practical teaching, STEM teaching courses must also consider intellectual learning.
- STEM teaching courses must consider such aspects as science and engineering issues, engineering design, scientific inquiry, mathematical analysis, and scientific and technological tools, applying and integrating them.

The STEM teaching philosophy takes creative design as the goal and uses technological techniques and thinking to deal with the problems encountered. The overall competencies to be trained and developed cover science, technology, engineering, and mathematics literacy (Liu, Wu, Xie, & Shen, 2013). According to Becker and Park (2011), compared with the traditional single-subject teaching approach, integrated approaches in STEM teaching improve students' interest and learning in STEM.

2.2 CodeMonkey Course

CodeMonkey enables learners to get a sense of programming. In addition, CodeMonkey has a set of complete and step-by-step game levels for individuals to learn programming languages; these levels are suitable for children and beginners to slowly learn from scratch, so they can start learning programming in a relaxed and interesting situation. This study adopts the CodeMonkey game programming as the experimental platform.

CodeMonkey game software was launched by Israel in 2014 to teach children to code online. The programming language used in CodeMonkey is called CoffeeScript, and the method adopted is to code in JavaScript, which is mainly used for web-based applications. CodeMonkey hopes to combine games and learning in education to enhance students' motivation to learn to program through game-based digital learning.

CodeMonkey is suitable for children over 9 years old and beginners, and the way of learning is similar to that of real programming. Coding in hand allows children to have a more authentic feeling of writing the program. Of course, the higher the game level is, the more difficult the corresponding programming is, such as logic loops. In terms of learning outcomes, education through entertainment can develop children's logical thinking and provide fundamental training to learn engineering mathematics in the future. The game involves a baby monkey who wants to eat bananas, and the player helps the virtual monkey partner get mouth-watering bananas by writing real lines of code.

The basic levels of CodeMonkey are called "Story Mode" and can be challenged one by one. Each level includes many graphic buttons to tell learners the meaning of the main commands. It is a very good guiding process for people who have never learned a programming language. Moreover, after each level is passed, the program logic designed by the learner will be scored, and the learner will even be prompted with a better way to write it.

CodeMonkey also has some more advanced practice courses, such as practicing creating a small game. Once the player acquires some basic program concepts, they can try such exercises. At these levels, players are challenged to create more interactive effects as well as make characters' interactions successful and complete tasks. The many checking mechanisms in the course help learners identify the wrong lines of code they wrote. This is a very convenient self-study exercise for beginners (Etemadi, Kharma, & Grogono, 2013).

2.3 Theoretical Framework of Big 6 (Big Six Skills)

This study intends to implement the theoretical framework of Big 6 (Big Six Skills), which is a teaching method that adopts the problem-solving model. Big 6 was proposed by Eisenberg and Berkowitz in 1990. It consists of six stages: facing the problem, analyzing the problems, acquiring the data, using the data, synthesizing useful data, and evaluating the results.

Big 6 is the most promoted curriculum activity in American school education. It is a teaching model focusing on solving information problems. In recent years, many experts have recommended integrating this model into the teaching of various subjects. Big 6 was originally a method through which school librarians and subject teachers plan the curriculum together so that the students can learn by seeking information and using information in the process of problem thinking, data collection, and report completion. Through the Big 6 teaching strategies, teachers develop problem situations suitable for students' level and help students use systematic steps to complete the course step by step in order to develop their problem-solving skills in areas such as critical thinking, information seeking, and information synthesizing. These are usually the abilities that students find more challenging to acquire. Following the Big 6 strategic steps will effectively assist students in developing an active and participatory learning process and becoming self-directed learners. Students who want to improve STEM professional knowledge and competencies must have this learning attitude to avoid confusion and disorientation (Eisenberg & Berkowitz, 2000).

The Big 6 strategic steps go through six stages:

1) Understand the problem (task definition): Define the problem and identify relevant information needed to solve it. Students must first know the form of the problem to be solved, understand the amount of information needed to solve the problem, and confirm the processing method.
2) Identify sources of information (information seeking): Determine the scope of resources and select the best resources. Students must use their imagination or an innovative way to come up with all possible sources of information and areas covered. They then identify and select the appropriate data sources from the

information sources.

3) Gather relevant information (location and access): Find the sources of the information, acquire the information, identify where the information can be found to solve the problem, and find and acquire the required data oneself.
4) Select a solution (use of information): Read and summarize the information. After searching out the necessary data, understand, analyze, and classify the data acquired and classify the necessary data.
5) Integrate the ideas into a product (synthesis): Organize a variety of information from different sources and present the information. Students must sort and analyze the information that meets actual needs and choose the most appropriate way to publish and present the results of the research.
6) Examine the result (evaluation): Judge the information-processing process and evaluate the works. Students should be able to assess whether they have solved the problems they faced in the whole process as well as reflect on and review whether the whole process is effective.

In sum, the Big 6 model focuses on different priorities for solving the problem at each stage. Students should constantly think about ways and channels to solve the problem, learn to seek the information needed and synthesize it, and then develop the ability to solve the problems. The purpose of the Big 6 model is to provide the framework for teachers to work out a series of systematic teaching activities to strengthen students' ability to think critically.

When analyzed according to the problem-solving method proposed by Lai (2000), the Big 6 involves a series of tasks or needs to be dealt with, which are combined with data through a series of processes, from data-searching methods and tools to how to use, apply, and evaluate the data. The details are broken down into six major steps: (1) definition, including defining the problem and identifying the information need; (2) searching, including determining the scope of resources and listing priorities; (3) acquiring, including finding information resources and acquiring the information; (4) use, including reading and summarizing the information; (5) synthesis, including organizing and presenting the information; and (6) evaluation, including appraisal work and process. Therefore, the use of Big 6 combined with the implementation of game programming can systematically link the theoretical knowledge of STEM with practical applications.

2.4 Research Methodologies

This study combines program design with STEM and Big 6 teaching modes while using exploratory teaching. Through a student-centered learning approach, trainers serve as facilitators, encouraging elementary teachers to raise inquisitive questions independently or in groups and then to search, read, analyze, and compare relevant information before finally reaching conclusions for solving the problem.

The research participants are 10 elementary school teachers who do not have any programming background. According to the six steps of the Big 6 model, which were matched to the course topics of CodeMonkey, the elementary school teachers were helped to learn the basics of programming.

The research design combined the plan with programming and the Big 6 teaching model to train teachers' how to apply STEM into their courses. It formulated specific teaching strategies for each stage. Elementary teachers' learning processes are described as follows:

1) Defining the problem: Trainers encourage elementary teachers to discuss ideas in class to pool collective wisdom, conduct brainstorming sessions and discuss ideas with each other on the spot, and solve problems by drawing upon all useful opinions.
2) Employing information-seeking strategies: In this teaching activity, trainers guide elementary teachers to achieve the aforementioned goals, provide pre-screened and appropriate teaching units, and require elementary teachers to seek the necessary information.
3) Acquiring information: In this teaching activity, trainers require and instruct elementary teachers to read or watch the information found in the previous step, mainly allowing elementary teachers to spontaneously

understand the teaching units provided.

4) Using information: In this teaching activity, hosts require elementary teachers to understand every piece of information, figure out useful information, and record the key points of the information.
5) Synthesizing information: In this teaching activity, trainers encourage elementary teachers to try to synthesize the commands at different game levels in order to achieve the goal under the condition of restricted program commands. Therefore, elementary teachers not only need to fully understand STEM-related teaching units, but also must try to solve the problems that may be encountered in the process of synthesizing program commands.
6) Evaluating: elementary teachers use the knowledge learned and experience from the previous stages to achieve the goal set in the concept development stage—namely, creating a product. In this teaching activity, elementary teachers evaluate the effectiveness of the product through the program commands actually completed by elementary teachers.

This study refers to Sung's (2017) interview outline as the interview questionnaire for the research. After the course finished, the structured interviews were conducted with the elementary teachers. The research questionnaire is shown in Table 1.

Table 1: Interview questionnaire for application programming for improving learners' STEM professional knowledge and competencies

Theoretical Foundation	Big 6 Stage	Interview Questions	Interview Record	Notes
Thinking about the problem	I. Define the problem	What have you learned in this study? Have you encountered any problems? How would you solve the problem(s)?		
Identify the problem	II. Employ information-seeking strategies	How will you find useful information?		
	III. Find information	Will you use the computer or mobile phone or ask other people?		
Use information	IV. Use information	How do you find out what you want from the information collected and categorized?		
Solve the problem	IV. Synthesize information	Is there any information for solving your problem?		
	VI. Evaluate	What have you learned?		

The participants of this study were elementary teachers who played CodeMonkey. Using the levels designed for the game, this study observed whether elementary teachers could learn by doing via playing the game, cultivating their self-confidence and creativity in the games. Each elementary teacher in the course had a computer. By understanding and writing the program logic, elementary teachers were continuously encouraged to try to design and observe details and problems. For problems encountered in the course design, elementary teachers were allowed to find solutions to problems on their own in order to cultivate their abilities and self-confidence.

3. Result

A total of 10 elementary teachers (7 males, 3 females) who do not have any programming background were interviewed in this study.

3.1 Define the Problem

3.1.1 What Have You Learned from This Study?

In the part of thinking about the problem, only three elementary teachers did not pass all the preset game levels. Most elementary teachers could pass all the preset 75 game levels.

3.1.2 What Problems Have You Encountered?

Among the 10 participants, five were able to quickly solve the problems they encountered. Three struggled a bit in learning in the second half of passing the preset game levels and felt that the program logic was a bit difficult to understand; two were obviously weak in learning the program logic as it was relatively difficult for them to pass all the game levels by themselves, perhaps because it was the first time that they had participated in such a course.

3.1.3 How Would You Solve the Problem?

In the last part of defining the problem in Big 6, when encountering a problem, regardless of the stage of the course, participants generally tended to ask classmates or the trainer instead of trying to solve the problem themselves. Four participants were willing to find a solution on their own during the learning process, and they were considered to be quite outstanding participants. When two of the participants encountered a problem, apart from watching what their classmates would do, they were less likely to ask the trainer or actively search for a solution, so their learning results were relatively poor in the later stages.

3.2 Employ Information-Seeking Strategies

Four participants were very comfortable in the context of self-learning game programming, and another one was willing to seek information from other places to solve the problem. These five participants were also able to show a positive attitude and overcome the problems encountered in the relatively difficult program logic in the later stage of passing the game levels.

3.3 Find the Information

In existing Big 6 literature, the main way to find information was to use computers and ask other people (hosts and classmates). In this study, because the learning platform provides prompt guidance before passing the level, most participants could find information from the guidance. Two participants gave priority to asking the hosts, another two gave priority to asking their classmates, and four gave priority to finding solutions to the problems on their own.

3.4 Use Information

In terms of using information, this study mainly observed how participants used information. Four participants acted in accordance with the source of the information, while six categorized the information according to the problem. As previously discussed, each game level of the learning platform offered some problem points for consideration. The learners also adapted to the learning model. They would first think about how they wanted to solve the problem before acting so they could develop the skills for first collecting, categorizing, and finding the information they wanted and solve the problem themselves.

3.5 Synthesize Information

Most of the participants could successfully solve the problems through the process of collecting and categorizing information, especially the basic logical problems in the first half, which could be successfully solved in accordance with the information. However, the second half included more complicated game levels, which led participants to conclude that "the program is difficult" and ask "Why is it that? I cannot understand it."

3.6 Evaluate

As they learned to code while playing games, the participants generally found the activities novel and fun. On the whole, all of them liked the process of learning by playing games.

Passing game levels can encourage participants to go all in. In addition, some guidance is provided before entering each level, and learners are able to complete the tasks to complete each level. After acquiring a basic understanding of the game in the initial stages, learners enter more complex game levels; if mistakes continue to occur, Dr. Monkey provides some guidance on the learning platform, which greatly reduces learners' frustration. The learners can get complete step-by-step guidance and feel a sense of accomplishment by passing the game levels, thereby stimulating their curiosity and generating a strong impulse to pass the game levels and even create their own game levels to challenge others.

Participants are more willing to accept different learning tools to collect and analyze information. The process of this study lasted only 32 hours of research time total over 8 weeks. Throughout the classes, participants were very focused on such courses for learning programming, which could improve their abilities to collect, analyze, and synthesize information. As the trainer could not answer different participants' questions at the same time, those participants eager to pass the game levels used other information to solve the problem, including repeatedly reading the prompts of the topic to search for data, discussing ideas with each other, and reviewing the information that the trainer had already provided.

Programming is a relatively rigid subject that involves commands, logic, mathematics, programming, etc. In the expanded scope, it also involves source materials from science, technology, and mathematics. Through game-based learning, at the fundamental stage, participants can learn it with great interest. However, when the application of logical and loop concepts is involved, participants must have the ability to use abstract thinking to deconstruct concepts. If the participants cannot understand the learning goals, their self-confidence and joy of learning will be weakened.

4. Discussion

With respect to the performance of elementary teachers who participated in the course CodeMonkey Learning Programming while Playing Games, no significant difference was found between male and female participants' expectations of the course teaching, game levels passed for the course, programming skills, and learning attitude. This is different from the general perception that male participants would do better than female students. When participating in the course, the proportion of participants who actively solved problems was higher than that of participants who waited for help. Thus, participants who actively seek to solve problems can achieve better learning efficacy.

Regardless of whether they had completed Lesson 6, most participants agreed that learning CodeMonkey is not difficult; the operation for passing the game levels is easy, and CodeMonkey is helpful for learning programming and can improve the learning efficiency. In the learning process, most participants thought that CodeMonkey was interesting, and they would continue to learn programming. The research results show that participants were highly satisfied with the CodeMonkey programming teaching course, which successfully aroused their interest in programming. For both male and female students who are relatively passive in learning, when they learn CodeMonkey programming courses, the teacher should provide more guidance to eliminate their differences in learning. Logical thinking is an important ability for programming. If participants can study the CodeMonkey programming courses for at least half a year, it would be helpful for the researcher to observe the participants' differences in logical thinking ability after they receive the CodeMonkey programming teaching.

This study confirmed that CodeMonkey is suitable for beginners and can enable them to develop an interest and maintain that interest in information technology since first becoming engaged in information courses. The study can serve as a guide for elementary teachers to improve their Application of STEM Capabilities

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