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The Design and Evaluation of a STEM Interdisciplinary Game-based Learning about the Great Voyage

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Abstract: In recent year, STEM education has been widely practiced with computational thinking since it encourages students to be immersed in the problem-solving process which also requires interdisciplinary knowledge. This study presented a 21-hour game-based learning course in the context of Great Voyage with the integration of STEM and robots, called <STEM Port>. Students programmed the robots to play the classroom-size spice-trading game. The results show that students can effectively learn to use programming block editor to control mBot in this course. From the course evaluation and learning motivation survey, it is shown that students are highly motivated to learn knowledge and skills in different fields including science, technology, engineering, and math, and can show significant improvements in all these subject areas.

Keywords: STEM, computational thinking, mBot, game-based learning, Great Voyage

1. Introduction

The 21st Century Skills has been the focus of educational reform in the last decade in several countries including the U.S., Australia, Finland and Singapore. The 21st Century Skills reinforces 5C skills including critical thinking, creative thinking, complex problem solving, communication, and collaboration. Students would not only have to learn the knowledge content in the textbooks but also use multiple abilities to adapt to future society. Therefore, interdisciplinary education is essential, such as STEM education has integrated science, technology, engineering and mathematics into one thematic curriculum. Current STEM practices are educational applications done with 3D printings, robots, tele-controlled aircraft, just to name a few. MIT also has created code.org which use block editor and mini-games to let primary school students to learn basic coding concept.

However, game-based learning can intrigue students to learn in the interesting way which can enhance their learning motivation. The gamification mechanism, such as levels, collective points, badge system, and ranking board, can turn the classroom lectures into a more competitive and activity-based learning so that students can be more autonomous in their own learning, acquire and apply what they learn in the process. Games have enriched students' learning environment, and gaming tasks have given them clear learning goals. Through either cooperative or competitive ways, students learn from their peers in the positive interactions. They would also enhance their social abilities, train communication skills, and nurture negotiation habits. Student groups would not just be work-sharing groups, but a collaborative team with common goals in which group members know when and how to support each other.

This research describes the design and evaluation of the game <STEM Port> about the spice trades in the Age of Discovery and the complete game-based learning course with the integration of STEM interdisciplinary concepts. In the 21-hour summer camp, twenty primary students aged from 8 to 11 participated the STEM course. They learned coding with block editor to control the robot, mBot; they learned astronomy to be able to define directions without compass; they learned the history of the Age of Discovery to understand how and why the European countries do trading with the Asian countries.

In the study, both quantitative and qualitative data were collected for analysis in order to answer the following research questions.

1. What is the students' learning achievements in the STEM game-based learning course?
2. What is the students' learning motivation in the STEM game-based learning course?

2. Related work

2.1. Game-based learning

Game is interactive, interesting, and lively (De Lisi & Wolford, 2002; Mayer, 2003). With proper integration with instructions, students can be immersed in the pleasure learning environment. In the past studies, students' learning motivation and effectiveness were positively improved (Huang, Huang, & Wu, 2014; Jacob, 1999; Johnson & Johnson, 1990; Lin & Shih, 2017; Shih & Hsu, 2016).

Students are situated in the virtual learning context in the classroom instructions and the theoretical concept of learning-by-doing can be practiced. Students are immersed in the learning situations that are instructional structured which encourage student cooperation in the authentic learning environment (Druckman, 1995; Eskelinen, 2001). Students' learning was achieved through the communicative interactions, manipulative experiences, feedbacks, in both individual and group activities (Mayer, Mautone, & Prothero, 2002). Therefore, in order to have positive learning effects, games have to provide challenges and instant feedbacks in the process (Prensky, 2003).

Rosas (2002) mentioned that game-based learning is meaningful to students which allow them to make connections to real life. Also, students favor it since digital games can bring positive effects to them such as learning achievements, cognitive ability development, learning motivation, and attention span. Pepler and Ross (1981) discovered that children could solve problems in the static games, and can think about various solutions to the problem. Bruner (1960) said children's problem solving skills can be improved through their behavioral choices.

However, games are interesting and attractive by nature. Students can learn in the joyful environment and have effective learning. Kirriemuir and McFarlane (2004) and Yang (2012) said that students generate strong motivation when they are playing games. They participate in the hands-on process. Games have become good learning tools in learning. Moreover, games provide challenges in learning so students pay much attention in the process and have high motivation (N. Vos, D. M. H. Van & E. Denessen, 2011). In the process, students are active and creative.

2.2. STEM

United States government launched "Educate to Innovate" initiative in 2009 to support STEM educational movement which nurture students to reach excellence in subject areas of science, technology, engineering, and mathematics, thus enhancing science literacy. Since STEM refers to the above subjects, interdisciplinary instructional design should be carried out.

By situating students in collaborative hands-on tasks, they are more immersed in complex problem-solving process and learning by trying, designing, discovering, and experimenting. Students would be motivated to expand their knowledge in the wide array of learning content, discuss with peers, and take multiple perspectives, and try to use the knowledge in any way they can to resolve the given issues.

In the aspect of educational policy, STEM education focuses on talent education and award; in the aspect of teaching, STEM course focuses on improving K-12 STEM course design, teaching strategies, and teaching practices in order to allow students to synthesize what they have learned (Bybee, 2010).

Computational thinking is a kind of analytical thinking, and is a process from defining problems to finding solutions with mathematical thinking and systematic scientific thinking, which gives computers or robots commands for effective execution (Wing, 2006; Wing, 2008; Wing, 2014). Learning to control robots has brought to the students high sense of achievement.

3. Course design

In this study, the game uses the Age of Discovery in 17th century as its context, with learners representing different countries that conduct spice trading. The interdisciplinary course integrates game-based learning, technology and coding for the students to learn history at one time. The course structure is shown in Figure 1.

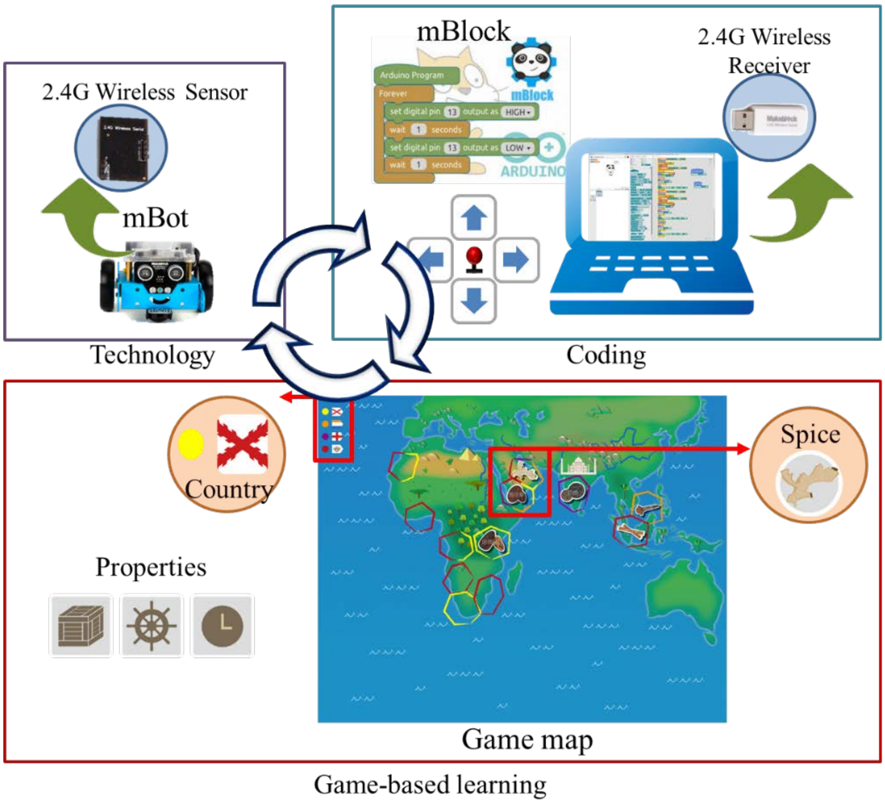

Figure 1. Course structure

In the course, students were divided into four groups for the game <STEM Port>. The game has three parts: technology, coding and game-based learning.

- Coding: Students learn coding using mBlock editor. With 2.4G wireless receiver connecting to notebook, students can send their commands to mBot (Figure 2). Class time for unplugged coding is 3 hours. Class time for plugged coding with code.org is 3 hours.
- Technology: mBots are used as ships for the game <STEM Port>. Class time for mBot is 6 hours.
- Game-based learning: the game <STEM Port> is based on the historical context of Great Voyage. A big map in 600x400 cm shows the area covered in the Age of Discovery in the 17th century (Figure 3). mBots represent ships of different countries, namely England, Netherland, Portugal, and Spain. Each country can choose ship parts such as hull, oar, mast, and weapons which would influence their total ship power, including Propulsion Power, Cargo Capacity, Deceleration, Firing Distance, Arm Force, and Sailing Duration. With the self-set parameters, all groups start up with different strength and weakness. Then, they take turns to move their ships by coding. Whichever country completes its spice task wins. Class time for table game is 3 hours. Class time for big <STEM Port> game is 6 hours.

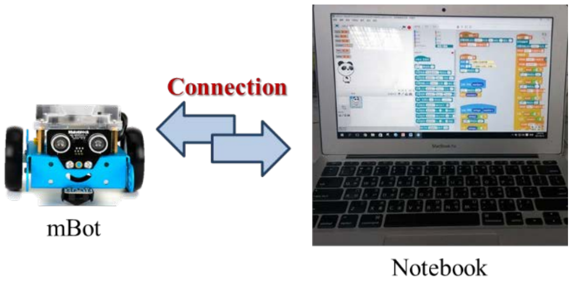

Figure 2.

Figure 3. 600x400cm world map

In the gaming process, students need to use mathematic concept such as angle, distance, direction, and calculation; computational thinking for coding and control robots, as well as geographical concept to do spice trading (Figure 4).

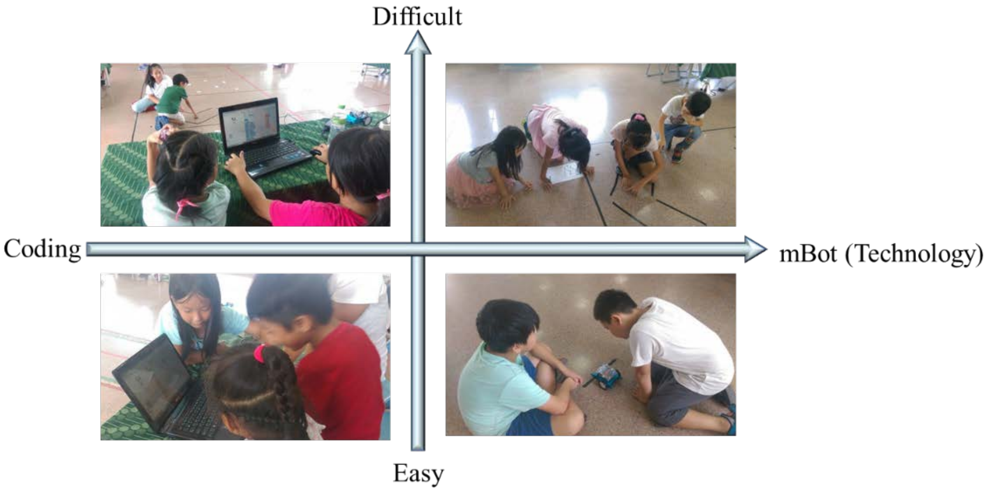

Figure 4. mBlock programming training

In the game, students were involved in the within-group cooperation and inter-group competition so they need to think of good gaming strategies to complete the task and win the competition. At the same time, students were immersed in the social cultural context of the history of

Great Voyage (Figure 5). In order to successfully win the final game, the students were motivated to learn the course content.

Figure 5. <STEM port> Game

4. Research design

4.1. Research process

The participants of this research were 20 primary school students in grade 3 to 6, aged 8 to 11. Students were randomly divided into 4 groups with four to five students in a group, but each group would intentionally place in with a couple of older kids. At the same time, in-class practice assignments were required to be done individually so that the little ones won't be left aside.

In the beginning of the course, a pre-test of math, coding, and game-related history concepts were conducted so the teacher knows how much course content should be included.

During the course, teacher observation were taken about students' behaviors, group interactions, and gaming strategies. After every section of the course, science, technology, engineering, and math would be evaluated from their in-class assignments and practices.

At the end of the course, a post-test of similar questions were conducted.

The research process is as Figure 6.

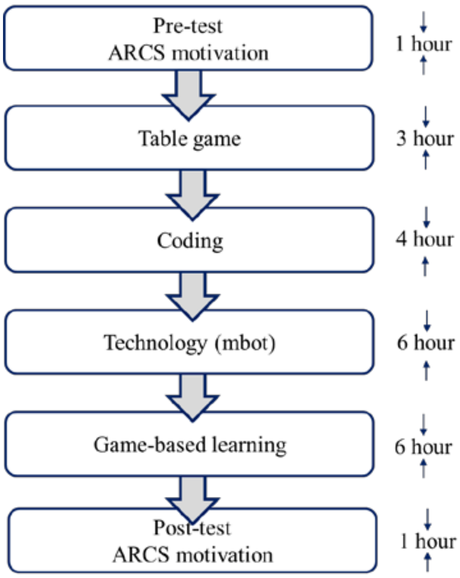

Figure 6. Experiment process

4.2. Research tools

In order to evaluate learning motivation and learning effectiveness, quantitative research tools were used.

Learning effectiveness: Pre- and post-tests were done by tests that took students 20 minutes to complete. The testing content includes the history, mathematic and logistics of coding using coding blocks. Fifteen questions with a total of 100 points. SPSS statistics 19 were used; and nonparametric Wilcoxon signed rank test statistics method were performed to see the students' learning improvements.

Learning motivation: At the same time, students' learning motivation before and after the course is also assessed through ARCS questionnaire including four aspects such as Attention, Relevance, Confidence and Satisfaction. ARCS questionnaire for learning motivation uses a 5-point Likert scale from 1 as Strongly Disagree to 5 as Strongly Agree with total of 36 questions. The reliability estimates (Cronbach's α) for each aspect were as follow: Attention: 0.89, Relevance: 0.81, Confidence: 0.90, Satisfaction: 0.96 and total: 0.96 (Keller, 1987).

5. Result analysis

5.1. Learning achievements

From the survey before the course, it is known that the student participants in this course were in 2 to 5 grade levels, aged from 8 to 11 years old. 70% of students did not have coding experience (Table 1) so this course was their first time getting in touch with coding. They have large age and experience gap. Therefore, the course started with unplugged coding game to give students' basic coding concept.

Table 1: Student programming experience of difference level

Programming experience	N (%)
No experience	12 (67%)
Less than 1 year	5 (28%)
Between 1 and 3 years	1 (5%)
Total	18 (100%)

The pre-test and post-test results of the learning achievements have reached significant difference (z = -2.78, *p*<.05) (Table 2). It is shown that the STEM interdisciplinary course can effectively enhance students' learning in STEM subjects.

Table 2: Pre and post-test nonparametric Wilcoxon signed rank test

Subject	Test	N	M	SD	z
All	Pre-test	20	44.25	18.94	-2.79^{**}
	Post-test	20	19.25	15.92	
History	Pre-test	20	68.95	29.64	-3.10^{**}
	Post-test	20	22.63	31.75	
Mathematic	Pre-test	20	51.25	27.48	-.92

	Post-test	20	52.50	30.24	
Programming	Pre-test	20	4	10.46	-2.68**
	Post-test	20	24	28.72	

**p<.01

Among all, history about the Age of Discovery has the most improvement, and has reached significant difference (z = -3.10, p<.05). Although the course did not give lectures on the history, the students learn about the concept of the Age of Discovery in the game without being taught.

Otherwise, students' pre-test programming scores were low (M = 4, SD = 10.46) showing that they had little coding experiences before the course. More than 70% (14 students) did not know how to answer most of those questions. After the course, students' post-test score was much higher than pre-test (pre-test SD = 10.46 and post-test SD = 28.72). It is shown that the students can learn coding effectively in this course. However, the standard deviation was large because the student participants had great age differences, that their learning paces had great gap. Older students had more improvements than younger students. The nonparametric Wilcoxon signed rank test result (z = -2.68, p<.05) shows significant difference between the pre- and post-tests.

From the results, it is seen that students' do not have significant improvement in math (z = -.92 p>.05), but slightly went down. It is supposed that math tests were 2D concepts, and in the mBot game, students need spatial concept to solve the angle problems. Therefore, it might be the difference that caused their confusion. It is also a reminder to us that the flat and dimensional concepts were to be verified to the students.

5.2. Learning motivation

The ARCS learning motivation uses a 5point Likert scale from 1 as Strongly Disagree to 5 as Strongly Agree with total of 36 questions. The Cronbach's α for both groups was above 0.7 and shows high response validity. The pre- and post-test questionnaire results of the four aspects considered (Attention, Relevance, Confidence, and Satisfaction) are shown in Table 3.

A nonparametric Wilcoxon signed rank test was conducted to see the differences. The results of the four aspects pre- and post-tests comparison of the learning motivation have all reached significant differences. Among the four aspects, the means of attention, relevance and satisfaction aspects were close to 4 which show that the course can effectively attract students' attention, connect concepts with what they learn before, and feel satisfied with the course. However, confidence aspect is the lowest. From the interview, it is known that the course content is rather difficult to younger students which require a combination of all subject knowledge. Furthermore, the mBot game is done in groups. When only one computer is provided, lower graders have little chance to do coding. Thus, they had less confidence to themselves.

Table 3: The nonparametric Wilcoxon signed rank test of learning motivation

Aspects	Test	N	M	SD	Cronbach's α	z
Attention	Post-test	20	4.058	.751	.853	-2.78**
	Pre-test	20	3.536	.494	.946	
Relevance	Post-test	20	4.078	.776	.883	-2.11*
	Pre-test	20	3.705	.659	.959	
Confidence	Post-test	20	3.791	.735	.746	-2.72**

	Pre-test	20	3.333	.332	.843		
Satisfaction	Post-test	20	3.939	.797	.83		-3.33^{**}
	Pre-test	20	3.249	.500	.885		

$^{*}p<.05$, $^{**}p<.01$

Overall speaking, students have generally positive feedbacks to the course. They liked the activities and liked the process arrangements of the course. They enjoyed learning history, math, and coding in the game. They hoped to have similar interdisciplinary activities in the future.

6. Conclusion

STEM education has been a global trend. Students' computational thinking has been emphasized in the STEM course which is used to solve life problems. It is an interdisciplinary education gives students an overall literacy to adapt to future society

Therefore, this study designed a STEM interdisciplinary course with game-based learning in the context of the Age of Discovery. Students learn about math, coding, and history in the course. In order to succeed in the game, students need to know about the global geography, the production places of spices, countries involved in the Great Voyage, and their ship forces respectively. Then, the students need to think about group strategies to sail, trade, and attack in the game so that they are required to apply what they have learned about math to calculate their distance and directions for sailing, and opportunities for trading.

The research results have shown that they students can effectively learn the related subject content even when they had no coding experience. Both the learning achievements and learning motivation improvements had reached significance differences.

It is seen from the observations that students enjoyed the learning process, and the atmosphere was joyful and pleasant. The course is challenging to all levels of students, and they were all highly immersed in the game. The mBot game was conducted with one computer per group, and older students were normally the leader of the group; therefore, younger students had less chance to control the computer in the game.

From this experiment, it is learned that student groups in the game need to be limited to three members so that every member can be well immersed in the game. Student background difference has to be as similar as possible. Also, the course can be most effectively used for nurturing outstanding students.

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References

Bybee, R. W. (2010). Advancing STEM education: A 2020 vision. *Technology and Engineering Teacher*, *70*(1), 30-35.

Bruner, J. S. (1960). *The process of education:[a searching discussion of school education opening new paths to learning and teaching]*. Vintage Books.

De Lisi, R., & Wolford, J. L. (2002). Improving children's mental rotation accuracy with computer game playing. *The Journal of genetic psychology*, *163*(3), 272-282.

Druckman, D. (1995). Situational levers of position change: Further explorations. *The Annals of the American Academy of Political and Social Science*, *542*(1), 61-80.

Eskelinen, M. (2001). The gaming situation. *Game studies*, *1*(1), 68.
Huang, Y. M., Huang, S. H., & Wu, T. T. (2014). Embedding diagnostic mechanisms in a digital game for learning mathematics. *Educational Technology Research and Development*, *62*(2), 187-207.
Jacob, E. (1999). *Cooperative learning in context: An educational innovation in everyday classrooms*. Suny Press.
Johnson, D. W., & Johnson, R. T. (1990). Social skills for successful group work. *Educational leadership*, *47*(4), 29-33.
Keller, J. M. (1987). Development and use of the ARCS model of instructional design. J*ournal of instructional development*, *10*(3), 2-10.
Kirriemuir, J., & McFarlane, A. (2004). Literature review in games and learning.
Lin, C.H.*, & Shih, J.-L. (2017). Analysing Group Dynamics of a Digital Game-based Adventure Education Course. *Educational Technology & Society*.(In press).
Mayer, R. E. (2003). The promise of multimedia learning: using the same instructional design methods across different media. *Learning and instruction*, *13*(2), 125-139.
Mayer, R. E., Mautone, P., & Prothero, W. (2002). Pictorial aids for learning by doing in a multimedia geology simulation game. *Journal of Educational Psychology*, *94*(1), 171.
Prensky, M. (2003). Digital game-based learning. *Computers in Entertainment (CIE)*, *1*(1), 21-21.
Pepler, D. J., & Ross, H. S. (1981). The effects of play on convergent and divergent problem solving. *Child Development*, 1202-1210.
Shih, J-L., & Hsu, Y.-J. (2016). Advancing Adventure Education Using Digital Motion-Sensing Games. Journal of Educational Technology & Society, 19(4). 178-189.
Vos, N., Van Der Meijden, H., & Denessen, E. (2011). Effects of constructing versus playing an educational game on student motivation and deep learning strategy use. *Computers & Education*, *56*(1), 127-137.
Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, *49*(3), 33-35.
Wing, J. M. (2008). Computational thinking and thinking about computing. *Philosophical transactions of the royal society of London A: mathematical, physical and engineering sciences*, *366*(1881), 3717-3725.
Wing, J. (2014). Computational thinking benefits society. *40th Anniversary Blog of Social Issues in Computing, 2014*.
Yang, Y. T. C. (2012). Building virtual cities, inspiring intelligent citizens: Digital games for developing students’ problem solving and learning motivation. *Computers & Education*, *59*(2), 365-377.