Effects of the Interdisciplinary Robotic Game to Elementary School Students' Abilities of Computational Thinking and STEM

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Abstract: In 21st century, problem solving, computational thinking (CT) and collaborative skills are essential skills to achieve. In this study, problem-solving aptitude including five CT dimensions and STEM attitudes were examined through questionnaires. Total of ninety-nine 5th-graders were involved in the interdisciplinary robotic game <STEM Port>, which is designed to enhance the effectiveness of the new learning structure in the context of Great Voyage. It is found that CT dimensions has intersected correlations to the STEM aspects. Interdisciplinary education has positive effects to the students, and the curriculum would lead them to have better performance in the complex problem-solving situations.

Keywords: Interdisciplinary robotic game, game-based learning, computational thinking, stem education.

1. Introduction

The application of robotics game in learning is one of the various learning technological advancements that have been highlighted in recent years. The robotic is a unique learning tool which could offer hands-making and fun activities. Therefore, the interdisciplinary education of CT and STEM has become the world trend. CT is regarded as one of the basic key skills of fundamental problem solving skills beyond the computing. Many countries aim to develop students' CT skills for improving problem-solving skills through interdisciplinary curriculum (Bocconi, Chioccariello, Dettori, Ferrari, & Engelhardt, 2016; Shih, Huang, Lin, & Tseng, 2017). We designed interdisciplinary Robotic Game to stimulate students' skills of CT and STEM due to most robotic game that was designed for just one disciplinary or single activities. This isn't the same as the complex surroundings in real life. CT includes five basic dimensions, such as algorithm, evaluation, decomposition, abstraction and generalization; and STEM refers to science, technology, engineering, and mathematics. Both usually integrate problem-based learning concept (PBL) to cultivate learners' problem-solving skill in real life.

In order to enhance students' learning motivation and to observe their CT skills and STEM performances, we used an interdisciplinary robotic game <STEM Port> to allow the students to apply their existing knowledge, CT and problem-solving skills to win the game. The game is designed for the students to use block coding to control the robots to navigate on the big map to the predicted locations. Students discuss how to control the robot to the right location and whether to trade or fight. Teachers often use competitive psychology to stimulate students' learning motivation and enhance learning effectiveness (Lin, Huang, Shih, Covaci, & Ghinea, 2017). Therefore, the strategic mechanism, which allows the learners to cooperate and compete with other players in order to achieve the goals. The use of interdisciplinary robotics game improve the students' problem solving and CT skills in this study. Results of this research suggested that the pedagogical value of robots lies in making learners to get interdisciplinary knowledge to identify and solve problems. But it's could not apply to all fields.

2. Related Work

2.1 Game-based Learning

Game-based learning (GBL) refers to an educational system that implements game or game-elements as a motivational driver for students (Park, Kim, Kim, & Mun, 2019). It is perceived as a potentially engaging form of supplementary learning that could enhance the educational process and has been used at all levels of education including primary education (Hainey, Connolly, Boyle, Wilson, & Razak, 2016). Passive learning becomes more active (Liu & Chen, 2013; Papastergiou, 2009), and children learn to construct knowledge in the process. Students explore the issues assigned by teachers from various perspectives, work with peers to find answers, and then develop the skill to communicate, coordinate, and do creative thinking and problem solving. Game activities involve problem solving spaces and challenges that provide learners with a sense of achievement (Qian & Clark, 2016).

Traditional games like Scrabble and chess are examples of appropriate vehicles for evoking the higher-order skills that are necessary for effective problem-solving. It also promote learning in an engaging and entertaining manner and to underpin the skills and attitudes of CT (Apostolellis, Stewart, Frisina, & Kafura, 2014). Games provide learning opportunities and learners learn infinitely more such as to take in information from many sources and make decisions quickly; to create strategies for overcoming obstacles; to understand complex systems through experimentation.

While implement game mechanisms and elements in activities, such as scoring, ranking, getting badges, doing competition and interaction, can turn the entire teaching activity into a gamified activity (Curzon, Dorling, Ng, Selby, & Woollard, 2014; Perrotta, Featherstone, Aston, & Houghton, 2013). Motivation is the most important factor that drives learning. The definition of motivation is a learners' willingness to make an extended commitment to engage in a new area of learning (Gee, 2003).

2.2 Computational Thinking

CT represents a cognitive ability to apply fundamental concepts and reasoning that derive from computer science in general and computer programming/coding in particular, including real life activities and to solve daily life problems. As a cognitive ability, CT was argued to be one of the most important skills in the 21st Century (Mohaghegh & McCauley, 2016), and should be fostered in childhood (Tsarava, Moeller, & Ninaus, 2018; Wing, 2006).

The skill of abstraction is a way to accelerate the efficacy of thinking, analyzing, and taking actions. Problem solutions can be produced through analyzing problems, making judgments and decisions, and integrating tools and resources to carry out. The purpose is to help students to solve problems by assessing the appropriate tools and strategies to be used in specific situations. CT has been studied by many scholars since Wing put forward it, and Selby, Dorling, and Woollard (2014) defined the five core concepts: *A) Algorithm* is to develop rules that can solve similar problems step by step and be implemented repeatedly. *B) Evaluation* is the process of ensuring an algorithmic solution is a good one. *C) Decomposition* is a way of thinking about problems, algorithms, artefacts, processes, and systems in terms of their parts. The separate parts can then be understood, solved, developed, and evaluated separately. This makes complex problems easier to solve and large systems easier to design. *D) Abstraction* is another way to make problems or systems easier to think about. It simply involves hiding details and removing unnecessary complexities. *E) Generalization* is a way of quickly solving new problems based on previous problems solved. It is to take an algorithm that solves specific problems and adapts the algorithm to solve a whole class of similar problems. Generally speaking, CT is a type of analytical thinking that employs mathematical and engineering thinking to understand and solve complex problems within the constraints of the real world (Voskoglou & Buckley, 2012). To help produce future generations with these competencies, we should teach these concepts at a young age, and continue using a spiral curriculum to reintroduce elements of CT in interdisciplinary and different years (Apostolellis et al., 2014).

2.3 STEM and Robotic Game

Existing research mentioned the importance of foundational coding skills for STEM learning by suggesting young children to learn various skills and concepts through playing apps and computer games (Pila, Aladé, Sheehan, Lauricella, & Wartella, 2019). STEM is a cohesive learning paradigm based on real-world application (Afari & Khine, 2017). It is not limited to those subjects which often includes other domains such as social studies, English language arts, art, and more (Breiner, Harkness, Johnson, & Koehler, 2012). It uses an interdisciplinary approach (Barak & Assal, 2018) by breaking down the "silos" of discipline-independent teaching that students often encounter throughout the day, and making connections to the context of the real world (Breiner et al., 2012; Honey, Pearson, & Schweingruber, 2014).

Robotics provides a very rich and attractive learning environment for STEM education (Barak & Assal, 2018). Robot is a learning tool that enhances student experiences through hands-on, mind-on learning. It also provides a fun and exciting learning environment because of its hands-on nature and the integration of technology (Afari & Khine, 2017). The hands-on, project-based and goal-oriented learning experience that an educational robotics competition provides has long-lasting impacts on students' learning and motivation for further exploring in STEM or STEM related fields (Eguchi, 2016). Educational Robotics creates an environment where children can interact with the context and work with real-world problems.

3. Research Design

3.1 Game design of <STEM Port>

<STEM Port> is an interdisciplinary game designed by the research team which is based on the historical context of Great Voyage. In the game, a big map in the size of 600 x 400 cm showed the geographic area covered in the Age of Discovery in the 17th century (Figure 1). Students were divided into five groups and role-play one of the five countries such as England, Netherland, Portugal, Spain, and France. Robots represent the ships of respectively countries by colored lights. The players took turns to move their ships by block coding to go to designated colonies to trade for spices. Whichever country completed its spice tasks first won.

Learners should apply their interdisciplinary knowledge and CT skills to complete the tasks of the game. They "decompose" the task requirements and rules of the game; try to obtain the goals in limited rounds. Then, apply "algorithm" skills to calculate the distance, angle, of the robots, and do "abstraction" to turn the measurement into coding blocks. They "evaluate" the differences between the predict and the actual paths, and make decisions to their actions in the next round. As the students solicit the main strategies for the game, they can "generalize" the patterns to different rounds and quickly use the resources around them to solve the problems.

This robotic game mechanism required the students to use block coding (Figure 2), in this case was mBlock, to control robot ships to move forward or turn. They had to estimate the distance to go to their destinations, and used the limited game points to move the robots. In the navigation process, they had to decide whether they would do trading or going into battles. By using simple and basic commands, the students would focus on using the coding skills to solve the game problems and to complete their tasks. Thus, a coding-based and problem-solving-oriented CT were functioned at the same time in the game. This programming environment can cultivate students' CT abilities during programming activities by enabling them to concentrate on the problem solving process as they learn (Kong, Chiu, & Lai, 2018). Robotics offer a broad range of challenges and opportunities for learners to develop disruptive thinking, innovative ideas, and other learning skills needed in the classroom and outside the school (Constantinou & Ioannou, 2018).

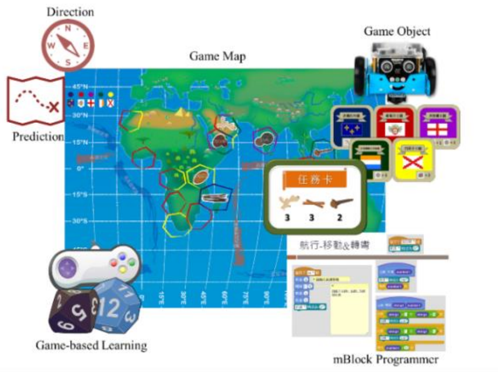

Figure 1. Game design of <STEM Port>.

Figure 2. mBlock coding program.

3.2 Computational Thinking & STEM Questionnaire

In this study, four classes of 5th graders in an elementary school in southern Taiwan participated the activity. There were 65 boys and 34 girls with a total of 99 students. Each class played an individual game in four different days. This study used mBot robots and navigation route prediction records as well as computational thinking and stem questionnaires as research tools to assess learners' CT performances and STEM attitudes in the robotic game.

Before the start of the game, the CT questionnaire was distributed to the students as the pre-test. Then, the students played the game <STEM Port> for about 60 minutes. After the game was finished, post-test CT and STEM questionnaires was conducted. The results of the questionnaires were cross-analyzed with the students' gaming outcomes with regressions in CT and Pearson Correlation Coefficient in STEM.

The CT questionnaire used in this study was newly designed based on the relevant literature (Atmatzidou, Demetriadis, & Systems, 2016; Curzon et al., 2014; Dagienė, Sentance, & Stupurienė, 2017; Selby, Dorling, & Woollard, 2014) and taking the principles of International Challenge on Informatics and Computational Thinking as the main reference. To construct a valid and reliable questionnaire for computational thinking, two faculty members specializing in education validated the items twice (Chu, Liang, & Tsai, 2019).

The questionnaire includes five dimensions, each with 5 questions. For example, "I will try to dissect the big problems into small parts" is to test out the students' perception to the Decomposition skills; "I will try to think of the most efficient way to solve the problems" is to test out their Evaluation skills; "I will figure out the detailed steps for problem-solving" is for the Algorithm skills; "I will try to find out the key factor of the problem" and "I will try to use previous experience to solve new problems" is to test their Abstraction and Generalization skills respectively. The analysis showed that the correlation coefficients of the overall divergence ranged from 0.42 to 0.61, and both reached significant ($p<.01$), which was a medium-high correlation, indicating that each dimension has a certain degree of correlation. The reliability Cronbach' α of this scale is 0.91. The reliabilities for the five dimensions ranged from 0.74 to 0.83. The pattern coefficient of all dimensions is above 0.4. It shows that the reliability and validity of questionnaire is good.

The STEM questionnaire used in this study is designed based on the relevant literature (Lou, Diez, Hsiao, Wu, & Chang, 2009; Unfried, Faber, Stanhope, & Wiebe, 2015).The questionnaire includes three dimensions: Mathematic, Science, and ET (Engineering and Technology). There are 9 questions in Mathematics, 9 questions in Science and 12 questions in ET with total of 30 questions. For example, "In the future, I could do harder math problems." is to test out the students' perception to the Mathematics attitude; "Science will be important to me in my life's work." is to test out the students' perception to the Science attitude. "I am good at building and fixing things" and "I would like to use creativity and innovation in my future work" is to test out the students' perception to the ET attitude. The reliability Cronbach's α of these three dimensions scale is ranged from .568 to .897. The values is above .5。

Two invalid copies of the questionnaire were excluded which ended up with 97 copies for analysis. The analysis is to answer the research questions: "Could this game improve the elementary school students’ computational thinking skills?” and “What is the relationship between <STEM Port> game and students’ computational thinking skills and STEM attitude?”

4. Result and Discussion

4.1 Computational Thinking Skills

In order to explore how the students’ CT skills influence their gaming outcomes, regression analysis was conducted using the five dimensions of the CT skills as predictors (Huang, Huang, Shih, Tsai, & Liang, 2019). Overall speaking, the CT skills of LA (low algorithm) group were not related to the outcome, therefore, only the CT skills of HA (high algorithm) group were briefly discussed in the following explanations.

In the beginning Round, the analysis result showed that HA group's Decomposition skill was positive (t=2.96, p=.004), indicating that if the students know how to dissect the problem into small parts, they can have better performance in this interdisciplinary robotic game. As such good performance, the HA group also could dissect the next path into some parts well and get the right location. Thus the decomposition is typically discussed in terms of breaking apart problems into manageable parts, so the complex problems can be broken into smaller parts by HA group in the <STEM Port>(Rich, Binkowski, Strickland, & Franklin, 2018).The analysis result of the Generalization skill was negative (t=-1.94, p=.057<.1), indicating that making reference of their current strategies to the new round was not what the students should do at this stage. In Round 2, the analysis result of the HA group's Generalization skill was negative (t=-1.64, p=0.106), indicating that the students were still familiarizing with the game and programming skills.

In the end Round, the analysis result of the HA group's Decomposition skill was negative (t=-3.46, p<0.001), which is different from Round 1, indicating that the Decomposition skill was not as important at the end stage since they were supposed to be very familiar with the game mechanism and programming. However, the result of Evaluation skill was positive (t=2.25, p=0.029), indicating that being able to know what strategies were good or bad for their victory, and to apply correct strategies became the most important at the end of the game.

The results showed that this activity was helpful to explore the functions of the CT skill dimensions of the students. For the HA group, and the students’ skill of Decomposition and Evaluation were closely correlated to their gaming outcomes. Generally speaking, students with high algorithm skill performed better than those with lower algorithm skill. Algorithmic thinking is the core element of CT, and is difficult for the LA group. It is our aim to plan curriculum that would increase students’ algorithmic thinking thus better fill up the gap between the LA and HA students. Based on this result, we aim to further investigate what might influence students’ CT skills in terms of their STEM attitude.

4.2 STEM Attitude

In order to assess how the interdisciplinary robotic game influence students’ STEM attitude with their gaming outcomes, analysis was conducted using the three dimensions of the questionnaire (Table 1). The results of STEM t-test between HA/LA groups (Table 2) indicated that the STEM attitude of HA group was better than LA group.

Table 1. *STEM attitude Cronbach's Alpha value*

STEM	N	Item	Mean	Std.	Cronbach's α
Math	94	9	3.212	.527	.568
Science	94	9	3.063	.784	.865
Engineering/Technology	94	12	3.791	.698	.897

Table 2. *The STEM attitude t-test of HA group and LA group*

STEM	Std. Error	t
Math	.199	2.252*
Science	.191	2.378*
Engineering/Technology	.178	2.339*

*p<.05, **p<.01

4.3 Relationship between CT skills and STEM Attitude

After the game, as shown in table 3, all STEM aspects of the students are correlated with Decomposition and Generalization skills. Engineering and technology are correlated with Algorithm skill. In <STEM Port> students decomposed the entire path into some sections of codes which compose the ship routes, they need to apply all CT skills to solve problems.

Table 3. Correlations between CT and STEM

Fact	N	STEM	Pearson Correlation	Sig. (2-tailed)
Abstraction	94	Math	.147	.157
		Science	.165	.111
		ET	.142	.171
Algorithm	94	Math	.148	.154
		Science	.189	.067
		ET	.261*	.011
Evaluation	94	Math	.113	.279
		Science	.082	.431
		ET	.081	.436
Decomposition	94	Math	.356**	.000
		Science	.213*	.039
		ET	.356**	.000
Generalization	94	Math	.319**	.000
		Science	.223*	.031
		ET	.272**	.008

*p<.05, **p<.01

As shown in table 4, the HA students' math are correlated with Decomposition and Generalization. Engineering and Technology are associated with Abstraction and Decomposition. It indicates that the interdisciplinary robotic game is significant for high algorithm skill students' CT skills in Decomposition, Abstraction, and Generalization. Although the LA students' STEM attitudes are not related to CT, the gaming results show that the robotic game could raise their learning motivation. In particular, the LA students were highly motivated in their problem-solving tasks even without extrinsic rewards and scores.

Table 4. *The Correlations between CT and STEM among High & Low Algorithm skills students*

Group		High Algorithm skill		Low Algorithm skill	
N		64		30	
Fact	STEM	Pearson Correlation	Sig. (2-tailed)	Pearson Correlation	Sig. (2-tailed)
Abstraction	Math	.142	.264	-.152	.421

	Science	.101	.425	-.010	.960
	ET	.264*	.035	-.329	.076
Algorithm	Math	.071	.580	-.107	575
	Science	.012	.928	.188	.320
	ET	.205	.104	.083	.662
Evaluation	Math	.104	.415	-.236	.210
	Science	.057	.654	-.253	.177
	ET	.125	.326	-.330	.075
Decompositio n	Math	.265*	.034	.268	.152
	Science	.123	.334	.038	.844
	ET	.318*	.011	.201	.286
Generalization	Math	.271*	.030	.188	.319
	Science	.118	.353	.214	.256
	ET	.152	.230	.313	.093

*p<.05, **p<.01, ET: Engineering/Technology

5. Conclusion

In this study, the students can obtain the CT skills in the <STEM Port> game. From other research (DomíNguez et al., 2013), students completed the gamified experience and got better scores in practical assignments and in overall performances. Students were excited and immersed in the game. The students learn how to win the game with discussion. The game had received many positive feedbacks from the students. It is likely to reduce distractions, thereby improving the quality of learning beyond what is provided in this activity.

The students need to establish spatial concept, and use their CT skills to complete the tasks. HA group used the Decomposition skill the most in the first round, since they had to try out to dissect the tasks and transformed the route into codes. In Round 2 and 3, they were familiarizing the game mechanism and the coding skills, so their performances tend to be more stable. Until the last round, Evaluation skill started to take effects since they started to use their experiences, resources, and strategies to apply their successful experience to the end. That also indicated that the game was appropriately designed to require the students to apply different CT skills in the game. Reversely, from students' CT skills, it could even predict how the students might perform in the game since the predictors were elicited from the statistics.

In this study, games helped students to integrate and apply the interdisciplinary knowledge and skills (Plass, Homer, & Kinzer, 2015). The robotic learning environment and the pedagogical approach of involving the students in rich assignments of growing complexity were among the major factors that contributed to students' motivation and success in learning the course (Barak & Assal, 2018).

The students with low Algorithm skills cannot achieve as much as those with high Algorithm skills. It is necessary for us to help the students to have better Algorithm skills so that they can accomplish more in the strategic game and problem-solving tasks, and can have better performance in general. More dimensions of CT skills should be reinforced in our pre-activity training. CT courses should be diagnosed with the five dimensions, and make sure students were educated in a more well-rounded CT skills and STEM attitude so that they can have better performance in the complex problem-solving situations(Chen et al., 2017). Concerning the attitude of STEM, we need to foster the LA students' CT skills with informal teaching and learning approaches. The critical purpose of applying CT and sharing its elements with other disciplines is to teach students how to better solve problems and discover new questions in future. While most CT and STEM studies have focused on assessing students' learning achievement in some kinds of activities, one of the major contributions in this study is the proposal of interdisciplinary robotic game learning approach that guides students to complete problem-solving tasks in an effective and enjoyable manner.

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