Integrating Design Thinking into Interdisciplinary Course with STEM-based Robotic Game < Frontier Guards>

Hsin-Yin Huang¹, Ju-Ling Shih²

¹Department of Information and Learning Technology, National University of Tainan, Taiwan
²Graduate Institute of Network Learning Technology, National Central University, Taiwan
*Corresponding author: franch28@gmail.com

Received September 08, 2022; Revised October 10, 2022; Accepted October 22, 2022

Abstract This study introduces an interdisciplinary course for STEM-based robotic game < Frontier Guards > integrating with the design thinking (DT) model and evaluates the effectiveness of students’ DT and STEM abilities. Students learned to design, assemble, test, and modify their robotics by using the concept of DT, as well as learned to collaborate with team members. A room-size floor map was used to build the game scenario depicting an aboriginal region in Taiwan with terrains and obstacles on the routes for reliving a short piece of Tayal history. Students were assigned to role-play the two parties of frontier guards and learn the history, assess the confrontational situations, design and construct robotics, and iterate during the game sessions. Thirteen 6th-grade students were divided into two parties to design defensive fortifications and fighting vehicles that can be remotely controlled by using block programming for attacking, defending, and snatching the opponent’s objects and winning the game, as were fourteen 5th graders. This study investigated how DT facilitated the achievement of instructional goals by using learning sheets, DT and STEM questionnaires, and interviews. Discussions and reflections during the creation process and the strategic decisions in the game were observed to analyze students’ improvements in problem-solving skills. The result of the study can be proved that using the interdisciplinary robotic game with DT can enhance students’ learning motivation, engagement, DT skills, and STEM performances, as well as problem-solving skills.

Keywords: design thinking, STEM, game-based learning, robotics, interdisciplinary course


1. Introduction

DT is a learning way that encompasses active problem-solving and believing in one’s ability to create impactful change. Embracing DT as an approach to human-centered problem-solving leads to the development of creative confidence. The key components of DT are that it is human-centered, action-oriented, and mindful during the process [1].

Education plays an important role in preparing young people for tackling complex challenges such as globalization, digitalization, and climate change [2]; from the educational perspective, DT has the potential to contribute to the development of students’ creative and adaptive capabilities, which provides an iterative process that leads to successful solutions for complex and open-ended problems. It supports students’ academic performance in core subjects by contributing to critical thinking, social development, and teamwork skills [3]. Vande Zande purported that understanding the design process can help students become critical thinkers [4]. Meanwhile, the integration of science, technology, engineering, and mathematics (STEM) disciplines has the prospective to bring together overlapping concepts and principles in meaningful ways. Using DT and STEM in education to train students to work from small but open-ended problems is important to nurture their problem-solving skills that future interdisciplinary jobs rely on.

In order to enhance students’ learning motivation and to observe their DT skills and STEM performances, this study used an interdisciplinary robotic game < Frontier Guards > designed by the research team to guide the students to apply their existing knowledge and problem-solving skills in the game. Students remotely control the robots they designed on the big floor map to get resources and knock down the facilities of the opponent. The teacher uses competitive psychology to stimulate students’ learning motivation and enhance learning effectiveness, [5] so game mechanisms are implemented to allow learners to strategically cooperate and compete with other players to achieve the gaming goals.

DT can take inspiration and learn from the way designers think and work in any discipline, and apply this to the operations not only in innovation efforts but also in
strategy, innovation or organizational renewal [6]. In addition, the stages of DT, namely empathy, definition, ideation, prototyping, and testing, provide a structured step-process for the implementation of DT [7]. DT can help elementary school students learn problem-solving skills step by step clearly.

The study investigated the effect of the DT instructional approach on students’ robotic creation in the context of the STEM-based game at an elementary school in Taiwan. It was conducted during the interdisciplinary curriculum periods which were integrated with STEM, DT, and robotic creation. Students were examined of their DT skill performances during the learning activities, and semi-structured interviews were conducted to understand their perspectives on the course. This study emphasized an integrated learning environment that enables sufficient interactions between the members of the groups. <Frontier Guards> is an interdisciplinary game which is based on the historical context of Japanese colonization in Taiwan during the 17th to 18th century, and their interactions with Tayal aboriginal tribes. In the game, a big map in the size of 450 x 320 cm showed the geographic area covered in the history depicted in the game. Gaming interactions between two parties were not only economical but also confrontational events. Students were divided into 6 groups of 2–3 students to role-play two confrontational parties. Robots were built by the students with different shapes and structures representing the frontier guards for the two parties. The players controlled their robots by using mobile devices to retrieve resources including rice, camphor, granulated sugar, and woods, or knock down the forts of the enemy. This study maps the landscape of DT in education through a literature review and instructional implementations to answer the following research questions:

RQ1: What are the students’ DT skills and STEM attitudes towards in the interdisciplinary game-based learning with <Frontier Guards>? 
RQ2: How did the students perform in the DT process of the game-based course?

2. Literature Review

2.1. STEM

STEM is a cohesive learning paradigm based on real-world application [8]. It uses an interdisciplinary approach by breaking down the discipline-independent teaching that students often encounter throughout the day, and making connections to the context of the real world [9,10]. Studies have shown that students can learn and develop their DT in and through STEM education which is positioned to provide diverse opportunities to facilitate students learning [11]. In school, design has been increasingly recognized not only as an object for students to learn and experience, but also a general framework for school education and an important approach for conceptualizing and developing integrated STEM education in K-12 schools [12,13,14,15]. It is imperative that school curricula and instructions integrate design in students’ subject content learning, not just in engineering and technology but also in other STEM subjects and beyond, and also help foster their design intuition and thinking early on [16].

Therefore, the STEM cross-disciplinary integration curriculum is developed to provide a guiding framework and hands-on activities that not only provide knowledge, but also allow for the application of STEM knowledge and skills in learning activities, and further develop creative thinking and problem-solving skills. Robotics provides a very rich and attractive learning environment for STEM education [17]. Through robot competition, students are trained to cooperate with spirits of creative collaboration and solve complicated problems.

With building a robot, students can develop logic thinking as they design and implement programs in the process. The purpose of designing robots could enhance students’ learning in STEM subjects and to embed their interests towards STEM which can strengthen the 21st century skills including problem-solving, creative and critical thinking, collaborative teamwork, interpersonal communication [18]. Many studies pointed out that Lego Robots has always been a popular teaching aid for students of all stages, and it is also an effective tool for developing students’ science, technology, information, mathematical cognition and other interdisciplinary or social skills [19,20,21,22].

Therefore, LEGO robots will be used as teaching aids, and DT will be combined with STEM to understand students’ DT ability and STEM learning attitude in this study.

2.2. Game-based Learning

Game-based learning (GBL) refers to an educational system that implements game or game-elements as a motivational driver for students [23]. 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 [24]. It also promote learning in an engaging and entertaining manner to underpin the skills and attitudes of computational thinking [25]. Games provide learning opportunities and learners learn infinitely to take in information from many sources and make decisions quickly, create strategies for understanding and overcoming obstacles through experimentations. While implementing game mechanisms and elements in activities, such as scoring, ranking, getting badges, doing competition and interaction, they can turn the entire teaching activity into a gamified activity [26,27]. 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 [28]. GBL is a developing approach for increasing learners’ motivation, interaction, and engagement by incorporating game design elements in educational environments [29].

Several studies combined robotics and gaming studies by using LEGO-EV3 robotics and game design to develop students’ computational thinking strategies. The application of studies was developed based on STEM technology [30,31]. Efficiently, playing with a robot in a class would be a gimmick that captures and holds interests of little young audiences; likewise, it makes students
intimate with the technology and create better understanding of the subject by explicit demonstration [32]. The key factor that affects to the teaching and learning improvement is “fun”. Enjoyment brought people in class together and increased engagement of the audiences [33].

Robots can be used for learning strategies such as collaborative learning, problem-solving and project-based learning [34]. STEM education is creating a learning situation for students to interact with the others and real-world problems [35], so in recent years, both at home and abroad, the use of robots to carry out STEM educators has seen.

Consequently, students are encouraged and actively participated in learning by game-based learning strategies. Because of this potentiality, the Robotics was widely applied in classes for teaching several types of control flow in computer programming.

2.3. Design Thinking

DT is an approach to address “wicked problems” or problems that seems to have no solutions or whose solutions can only be solved by multidisciplinary means [36,37]. The main purpose of DT is human-centered, starting from the needs of people and seeking innovative and diversified solutions for various issues. DT is a non-linear model, shaping and building insight through the process in order to address unpredictable issues and problems. Several variations of models of DT have been introduced and applied into different fields. Among different versions of the DT process, the most frequently used model is the five-step model created by Hasso Plattner Institute of Design at Stanford University, which is also known as d.school. one of the pioneers in developing this model in education. The curriculum of the d.school is designed for university and K-12 students to develop their problem solving and creativity skills [38]. The DT model consists of five stages (Figure 1); which can be briefly explained as follows [39,40].

Empathize: Empathizing with the study of participants, knowing their intends and needs of the game, is very important in determining the problem situations appropriate for them. Students learn how to build empathy in order to understand clearly and serve people they develop solutions for. In order to reach this aim, tools like interviewing and observation are taught.

Define: It is necessary to define the problems determined in line with the intends and needs of the game participants. The goal of this process is to come up with a narrow problem statement, which seems to be crucial for the ideation phase.

Ideate: This step is the key in the DT process at which focus on idea generation. In this phase, tools like brainstorming are typically performed and taught as one way to come up with new ideas which is innovative solutions that have not been tried before.

Prototype: Students learn how to generate quick and lowcost artifacts to show their resolutions to resolve the problem. To do so, students are taught a variety of methods ranging from simple sketching techniques to computer simulations as well as physical prototypes.

Test: Within this phase user tests are performed in order to evaluate prototypes and to inspire further development. Depending on whether the problem is solved or not, the definition of the problem, design, and prototype stages can be reviewed.

These processes and methodologies are often used by designers to create new ideas, solutions, alternatives and choices that satisfy the desires of the end users or stakeholders. DT has been used more and more widely in different communities and considered as a mindset and approach to learning, collaboration, and problem-solving. Based on the DT process, teachers develop different specialized courses to teach the concept and skills of DT and cultivate innovative capability of students [38].

Figure 1. Design thinking process [41]
For example, Grammenos and Antona [42] designed a course named ‘Future Designer’ to introduce concepts and practices of DT to students. The course encouraged children to generate creative ideas to overcome the problems and challenges. Meshendia Dampier [43] developed a curriculum for her fourth grade students title as ‘Above Us Only Sky?’ It was a science topic about solar system, and specially about the Earth, Sun and Moon. Teacher applied DT methodologies to guide students to identify the problem themselves and generate creative ways to build prototypes of their ideas for interactive space displays. Elisabeth Hales [43] developed a curriculum for her fifth grade students title as ‘Mine, Mine, Mine’ to emphasize the personal conflicts of greed and the changing prosperity of those involved. The children defined their line of enquiry or problem as: ‘How might we design a new flag that can unite all students and teachers, past and present, and acknowledges our school history?

Researchers integrated DT into the maker education starting from kindergarten to grade 2 classrooms (5-8 years old) and has shown DT to be promising educational innovations. It demonstrated that DT approaches are suitable and beneficial for young children and can enhance open-ended, flexible and transferable skills, such as creativity and critical thinking skills [44].

It is clear that the growing collection of cases deploying DT into education globally shows its potential to engage students at all levels in the problem finding process and the eventual proposal of solutions [43]. It has been successfully applied to solve complex problems via creative thinking in the design, business, engineering, and education fields. Conclusively, this study integrated DT and Robotics with STEM to provide a cross-domain learning structure, allowing students to face uncertain or rapidly changing situations and to create solutions. Under the STEM cross-domain curriculum framework, robots are used to explore the impact on students’ problem-solving abilities in using DT in game situations.

3. Research Design

3.1. Participants

There were thirteen 6th grade and fourteen 5th grade elementary students, including 8 boys and 5 girls in 6th grade and 11 boys and 3 girls in 5th grade. Each grade was divided into six mini groups role-playing two parties, namely Taiwan aboriginal tribe Tayal and Japanese. There were 2 to 3 students in each group. This study lasted for one school year with 2 to 3 class hours per week with total of approximately 30 class hours. All students had taken 2 robotics classes per week in fourth grade.

3.2. Research Design

At the beginning, the teacher introduced the concepts, process and skills of DT to students and guided the students to use the DT steps to do problem-solving designs. Students used the empathy of DT to identify the core causes of problems they encountered in the game and found out the key of the problems. Aiming the core of the problems, students narrowed and developed the creative solutions. Then, students had to explain their solutions and how effective it can be. The teacher introduced the related history knowledge of <Frontier Guards> about Tayal aboriginal tribe fighting against Japanese in Taiwan. <Frontier Guards> is a self-designed interdisciplinary game which is about the history of Japanese colonization in Taiwan. With the historical context, a big map in the size of 450 x 320 cm shows the related geographic area in the 17~18th century (Figure 2).

Figure 2. Game map and objects of <Frontier Guards>
Table 1. Design Thinking Instructional Model for STEM-based Robotic Game

<table>
<thead>
<tr>
<th>Design thinking process</th>
<th>Science</th>
<th>Technology</th>
<th>Engineering</th>
<th>Mathematic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empathy</td>
<td>Recognize the functionalities of robots for solving the problems.</td>
<td>Recognize technological tools and applications to be used.</td>
<td>Recognize the structures needed for robot functionalities.</td>
<td>Recognize the geographical limitations of the scenario.</td>
</tr>
<tr>
<td>Define</td>
<td>Identify functionalities that are going to make.</td>
<td>Knowing the programming to control robots.</td>
<td>Define mechanism needed for the robots.</td>
<td>Identify the distance, turns, and heights of the lands.</td>
</tr>
<tr>
<td>Prototype</td>
<td>Make the robot prototypes in terms of physical mechanics.</td>
<td>Test drive the robot to see if it moves as expected.</td>
<td>Make the robot prototypes in terms of structures.</td>
<td>Express outcomes and faults to adjust of programming values.</td>
</tr>
<tr>
<td>Test</td>
<td>Evaluate the physical movements and balance of the robots.</td>
<td>Assess the results of programming and iterate.</td>
<td>Evaluate the functionalities and solutions.</td>
<td>Evaluate the efficiency of robot movements.</td>
</tr>
</tbody>
</table>

Students applied “empathy” to observe the undulating terrain of the scenario, the distribution of resources, the location of facilities, and the possible strategies used by the other party. Then, students “defined” problems with a narrowed problem statement focusing on the analysis of their own corresponding strategies. After defining the problem through discussion with the group members, students “ideated” to identify solutions by designing the robotics in terms of shape, structure, and functions for their purposes. Next, students assemble the robots according to their designs drawn on their learning sheets in the previous stage to create the “prototypes” of the robotics. After completing the assembly of the robots, the students used iPad mini with programming software to “test” the functionalities of their robotics, and control remotely. The detailed plan using the DT instructional model for STEM-based robotic game is as Figure 3 and Table 1.

3.3. Instructional Tools

In this study, learning sheets were associated with respective course activities which were analyzed to understand students’ learning performances in each DT phase.

In the Empathize stage, students were guided to analyze the various elements of the problem situation with AEIOU sheet which stands for Activity (A), Environment (E), Interact (I), Objects (O), User (U). Actions in this stage commonly include dialogues, questions posed by the teacher, occasional statements about things and answers (Figure 4 in Chinese and Table 2 in English). On the learning sheet, students wrote down the resource distributions, terrain features, and functionality needs for <Frontier Guards>. With this sheet, teacher could check students’ performance of Empathy.

---

**Figure 3. Research procedures**

**Table 1. Design Thinking Instructional Model for STEM-based Robotic Game**

<table>
<thead>
<tr>
<th>Design thinking process</th>
<th>Science</th>
<th>Technology</th>
<th>Engineering</th>
<th>Mathematic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empathy</td>
<td>Recognize the functionalities of robots for solving the problems.</td>
<td>Recognize technological tools and applications to be used.</td>
<td>Recognize the structures needed for robot functionalities.</td>
<td>Recognize the geographical limitations of the scenario.</td>
</tr>
<tr>
<td>Define</td>
<td>Identify functionalities that are going to make.</td>
<td>Knowing the programming to control robots.</td>
<td>Define mechanism needed for the robots.</td>
<td>Identify the distance, turns, and heights of the lands.</td>
</tr>
<tr>
<td>Prototype</td>
<td>Make the robot prototypes in terms of physical mechanics.</td>
<td>Test drive the robot to see if it moves as expected.</td>
<td>Make the robot prototypes in terms of structures.</td>
<td>Express outcomes and faults to adjust of programming values.</td>
</tr>
<tr>
<td>Test</td>
<td>Evaluate the physical movements and balance of the robots.</td>
<td>Assess the results of programming and iterate.</td>
<td>Evaluate the functionalities and solutions.</td>
<td>Evaluate the efficiency of robot movements.</td>
</tr>
</tbody>
</table>

---

**Figure 4. Empathize: AEIOU learning sheet**
Table 2. Empathize: AEIOU learning sheet in English

<table>
<thead>
<tr>
<th>Activity</th>
<th>Environment</th>
<th>Interaction</th>
<th>Object</th>
<th>User</th>
</tr>
</thead>
<tbody>
<tr>
<td>what people want to achieve</td>
<td>The current environment in which you want to operate</td>
<td>The interactive content desired by the current behavior</td>
<td>What objects does each person have in his environment? How are these objects related to them?</td>
<td>Who are the people in the environment? What is the relationship between their roles?</td>
</tr>
<tr>
<td>look at the bus stop</td>
<td>Next to the waiting seat at the bus booth</td>
<td>Pointing to the route map on the stop sign, as if looking for the destination station</td>
<td>Vegetable basket, hair tie, thick coat</td>
<td>woman</td>
</tr>
</tbody>
</table>

In the Define stage, children reflected their reasoning process as they worked through actions such as identifying and solving problems encountered, making hypothesis and solutions, and applying the sentence of “Point of View” (POV) to formulate problem solutions. For example, students wrote: “When the enemy comes, I want to build a watchtower so that I can know what the enemy is doing and calmly prepare for defense.” The students discussed about the problems they encountered and wrote down their solutions (Figure 5 in Chinese and Table 3 in English). With this sheet, teacher could check students’ performance of Define.

The Ideate stage reflected children’s creations. Through the method of DT, students gained insights and observed the problems to identify the key factors in define step. Students began to design the robots, including the shapes, structures, and functionalities. Key pieces of dialogues reflecting their ideation included: “I think the suggestion about making a claw to grasp the object and knock down the facilities is great, and the claw should be put on the top of the robot.” Students explained their designs to the classmates with drawing (Figure 6). With this sheet, teacher could check students’ performance of Ideate.

The Prototype stage reflected children’s mechanical assembly abilities to demonstrate their ideations. This stage involved manipulating embodied ideas through prototyping. Students used the LEGO EV3 bricks to assemble the prototype. In DT, prototyping interplay between learning and creating that involves conceptualizing, building, testing, and evaluating. Initial prototypes roughly represent ideas, using papers, tapes, clays, LEGOs, cardboards, woods, and various other materials recycled [45]. Robotics provide opportunities for students to explore how technology works in real life, while giving them the chance to work together to foster collaboration skills, express themselves using the technological tool, problem-solve, and think critically and innovatively. Robotics provide a fun and exciting learning experience for its hands-on and integrative nature [46]. Key pieces of dialogue typically included children’s descriptions of their prototype (Figure 7). With this sheet, teacher could observe and check students’ performance of Prototype.

In Test stage, students completed robot assembly. They tested the movement and grasping function of robots, and the stability of its structure. Dialogues at this stage were often reflective that guided students for iterations. Finally, students went on to the game for formal playing (Figure 8). Teacher observed students’ teamwork, enthusiasm, and participation in this stage.
3.4. Game Mechanism and Objects

In the game, in order to distinguish the resources and robots of respective parties, color tapes were used as identifiers (Figure 9). The teacher guided the students to use LEGO Mindstorms Commander App with iPad mini to set the parameters and write programming for remote controlling robotic functions to move forward, backward, grasp objects, and other actions (Figure 10). Students discussed strategic plans, offensive or defensive, to get around the crooked routes for retrieving scattered distributions of resources, and demolish adversary facilities and armies. Students also had to evaluate the shape, size, and weight of resource props, and calculate the distance, turns, and heights of the land to define the power for the robots. During the game, students solved interdisciplinary complex problems, and had the ability to comprehensively summarize the whole situation.

![Game Map and Objects](Image)

Figure 9. Game map and objects of < Frontier Guards >

![LEGO MINDSTORMS Commander](Image)

Figure 10. LEGO MINDSTORMS Commander

All students’ sheets were evaluated by teacher, teacher interviewed with students to understand their creativity and their behaviors were observed. After they completed the assembly and testing of the robot, they explained the structure, function and action of the robot, and then had a battle of 5 minutes each round. There were 2 rounds in one class. First round, one group roleplayed as Aboriginal people and another group roleplayed as Japanese Army. In the second round, the students switched the roles with each other. After the first round, there would be a 5 minutes gap. Students could decide whether to modify the robot according to the performance that they just played against and during the battle, but no one do so. The students controlled robots to go to the enemy’s territory to obtain resources, knock down the facilities and even attack the enemy. Students get 2 points for a resource object and get 1 point for knocking down a facility or an opponent’s robot. If the robot goes out of bounds or the part falls or the two robots get stuck and then the student can take it or repair it, but must pause for 5 seconds before entering the game again. At the end of each round, the score is settled and the one with the highest score wins.

3.5. Design thinking and STEM Questionnaire

Students used LEGO EV3 Mindstorms robots for their creations. The students’ designing process were recorded to observe their performances in the DT process. Questionnaires of DT and STEM were used to assess learners’ DT and STEM attitudes. Before the start of the course, STEM questionnaire was distributed to the students as the pre-test. Then, at the end of the course, the students played the game <Frontier Guards> for about 5 minutes every round. After the game was finished, DT and STEM questionnaires were distributed again as post-test. The results of the questionnaires were cross-analyzed with the students’ gaming outcomes. Independent sample t-test was used for analyzing DT questionnaire and paired sample t-test was used for analyzing STEM questionnaire.

The DT questionnaire was made based on the relevant literature and research [47]. It includes five dimensions: empathize, define, ideate, prototype, and test. There are 5 questions in Empathize, 4 questions in Define, 5 questions in Ideate, 5 questions in Prototype, and 4 questions in Test with total of 23 questions. For example, “I will understand the real needs of users,” is to test out the students’ perception to the Empathize; “I will look for the cause of the problem from the user’s point of view,” is to test out the students’ perception to the Define. “I will discuss the problem with the team members and find a solution to the problem,” is to test out the students’ perception to the Ideate. “I will make a prototype to solve the problem first, even if it is not perfect,” is to test out the students’ perception to the Prototype and “I will conduct a simulation test of the completed prototype with the team members,” is to test out the students’ perception to the Test. The reliability Cronbach’ $\alpha$ value of this scale is 0.974; the reliabilities for the five dimensions were ranged from 0.845 to 0.950.

The STEM questionnaire in this study was made based on the relevant literature [48,49]. It includes three dimensions: Mathematics, 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 value of this questionnaire in three dimensions scale were ranged from 0.568 to 0.897. It showed good reliability in internal consistency.

4. Result and Discussion

These research tools examined children’s DT skills and STEM competences during the course and game. Students designed the robots by following the procedure of DT and applying the course tools such as AEIOU and POV at the game. With the steps of enquiry, students worked collaboratively to explore interesting ideas to interact with each other and present creative thinking. They were able to draw upon the concepts and new understandings they had learned from the immersion period. It was around this time that students shared the details of their problems and their progress in generating new ideas.

4.1. Design Thinking Skills

In order to evaluate students’ DT skills, independent sampled t-test for DT questionnaire analysis used the “Engineering and Technology” dimension of STEM as the predictor. There was significant difference on the Empathize dimension of DT between the HET (High Engineering and Technology) group and LET (Low Engineering and Technology) group (Table 4).

<table>
<thead>
<tr>
<th>Comparison</th>
<th>mean (HET)</th>
<th>mean (LET)</th>
<th>Total</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empathize</td>
<td>23.50</td>
<td>20.43</td>
<td>21.85</td>
<td>1.928</td>
<td>0.044*</td>
</tr>
<tr>
<td>Define</td>
<td>17.67</td>
<td>16.00</td>
<td>16.77</td>
<td>1.088</td>
<td>0.150</td>
</tr>
<tr>
<td>Ideate</td>
<td>21.83</td>
<td>20.71</td>
<td>21.23</td>
<td>.673</td>
<td>0.257</td>
</tr>
<tr>
<td>Prototype</td>
<td>22.50</td>
<td>21.29</td>
<td>21.85</td>
<td>.872</td>
<td>0.201</td>
</tr>
<tr>
<td>Test</td>
<td>17.67</td>
<td>17.86</td>
<td>17.77</td>
<td>-.154</td>
<td>0.440</td>
</tr>
</tbody>
</table>

*p < .05.

The results showed that this course was helpful to explore students’ DT skills dimensions. For the HET group, students’ skill of Empathize was related to the design and game outcomes. These students walked on the map to design robots from a first-person perspective, observing and immersing themselves in various scenes, positions and angles, showing empathetic thinking and actions. During the testing and adjusting phase, the HET group students also tested the robot’s functionality at various terrain locations on the map iteratively. Studies have shown that students can learn and develop their DT in and through STEM education which is positioned to provide diverse opportunities to facilitate students learning [11]. This study confirmed that the STEM robotics course can indeed promote students’ learning and cultivating of DT. Although HET students performed significantly better than LET students, grouping allows HET and LET students to work in small groups to learn DT.

4.2. STEM Attitude

In order to assess how the game influenced students’ STEM attitude, analysis was conducted using the three dimensions of the questionnaire. The results of STEM t-test between pre-post test indicated that all students’ STEM attitudes were significantly different on mathematics and science dimensions after the game-based course (Table 5). The findings show that integrating DT concepts with a robotics design and assembly curriculum has positive benefits for students’ performance in mathematics and science. Students seriously studied the knowledge of mathematics and science related to the game. In the process of assembling and operating robotics, students can integrate knowledge and skills in various fields of STEM and apply them to the problem-solving process encountered in the competition [12,13,14,15]. Robot provides a fun and exciting learning environment because of its hands-on nature and the integration of technology [8].

<table>
<thead>
<tr>
<th>Comparison</th>
<th>mean (HET)</th>
<th>mean (LET)</th>
<th>t</th>
<th>p2 tailed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics</td>
<td>-5.30769</td>
<td>8.27027</td>
<td>-2.314</td>
<td>.039*</td>
</tr>
<tr>
<td>Science</td>
<td>-2.92308</td>
<td>4.62712</td>
<td>-2.278</td>
<td>.042*</td>
</tr>
<tr>
<td>Engineering and Technology</td>
<td>-.84615</td>
<td>4.45058</td>
<td>-2.278</td>
<td>.506</td>
</tr>
</tbody>
</table>

*p < .05.

4.3. Changes in Gaming Behavior

The score of the student is the result of the game behavior. It can be seen whether the students grasp the key to win. The performance of the students’ scores can be seen from Table 6 and Figure 11. The scores of the two groups at the first three rounds were not high because two teams of robots were chasing and attacking each other. The students were too excited to control the self-designed and assembled robots from the interview. As a result, the original design function of the robot was forgotten. From the 4th round, the scores of the two sides began to show a trend of gradually increasing, and teammates would also have strategies such as covering each other to seize resources and defending their own facilities and resources.

<table>
<thead>
<tr>
<th>Round</th>
<th>A Group</th>
<th>B Group</th>
<th>Getting Points</th>
<th>Chasing and Attacking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>1</td>
<td>30.23%</td>
<td>55.81%</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>7</td>
<td>35.09%</td>
<td>43.86%</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>3</td>
<td>21.21%</td>
<td>54.55%</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>6</td>
<td>50%</td>
<td>27.78%</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>7</td>
<td>50%</td>
<td>5.88%</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>13</td>
<td>42.86%</td>
<td>26.19%</td>
</tr>
<tr>
<td>7</td>
<td>12</td>
<td>10</td>
<td>54.55%</td>
<td>9.09%</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>12</td>
<td>44.68%</td>
<td>23.40%</td>
</tr>
</tbody>
</table>

Table 5. Paired sample T-test

Table 6. Student Group Score
From Figure 12, it can be seen that the students' game behavior has gradually changed from chasing the opponent's robot that does not help to score at the beginning to the behavior that can help score and win the game.

In addition, in the short gap after each round, the students will discuss and remodel the structure and function of the robot, so that the structure and function could be stronger and more helpful.

4.4. Design Drawings Learning Sheets

The formation of the robot configuration was closely related to the first three steps of the DT learning sheet. Students used the AEIOU sheet of empathy to analyze each other's relevant factors and list them on the study sheet. The student’s worksheet were shown at Table 7.

In the Define stage, the POV sheet was used to confirm the way to solve the problem with the intends and needs of the game participants and present it in a concrete way.

The goal of this process is to come up with a narrow problem statement, which seems to be crucial for the ideation phase. The student’s POV worksheet were shown at Table 8.

The next step was the Ideate which was POV-based creative idea. At this stage, each group constructs a robot designed by discussion and explains it to the classmates. The students' practical design drawings were shown at Table 9. Finally, the students started to assemble the robot and test it according to the design drawings. The students' practical activities were shown at Table 10.
Table 7. Design thinking practices and tools. - AEIOU

| AEIOU (1st. Empathize) A student’s AEIOU sheet in Chinese

<table>
<thead>
<tr>
<th>Activity</th>
<th>Environment</th>
<th>Interaction</th>
<th>Object</th>
<th>User</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attack aboriginal people</td>
<td>Rices, Salt, Sugar, Weapon, Medicine</td>
<td>Refined camphor, Build a shrine</td>
<td>High voltage grid, Gun, Canon</td>
<td>Japanese Army</td>
</tr>
<tr>
<td>Attack Japanese Army</td>
<td>Camphor tree, Cypress, Mineral, Sambar skin</td>
<td>Hunting, Farming</td>
<td>Bow and arrow, Pike, Aboriginal knife, watchtower</td>
<td>Aboriginal people</td>
</tr>
</tbody>
</table>

Table 8. Design thinking practices and tools. - POV

| POV-Point of View (2nd. Define) A student’s POV sheet in Chinese

<table>
<thead>
<tr>
<th>Group</th>
<th>User</th>
<th>Needs</th>
<th>Surprising Insights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aboriginal people</td>
<td>When the Japanese Army comes</td>
<td>I want to build a watchtower.</td>
<td>We can know the enemy is coming.</td>
</tr>
<tr>
<td>Japanese Army</td>
<td>When the aboriginal people comes</td>
<td>I want to make an alert.</td>
<td>We can know what the aboriginal people is doing and calmly prepare for defense.</td>
</tr>
</tbody>
</table>
The conclusion of AEIOU is presented in the POV stage, and the specific presentation of the POV is presented in the Ideate stage. Finally, the prototype robots of each group were the concrete presentation of the first three steps of DT.

The main impact of this research on students is that after learning the methods of DT, they have got the key of the problem, not only in designing and assembling robots, but especially in the strategic decision-making in game battles. In the last 4 rounds of the game, it was observed...
that the partners would cover one of their robots that was
good at grabbing resources to grab resources for higher
scores, and other robots defend the territory and the enemy.
This finding is in line with research by Hatzigianni [44].

Students followed the DT process to design, assemble,
and test robots. The learning experience was real and had
tangible impacts on them. Children not only identified the
problems by themselves but generated unique ways to
solve the problems. In relation to children’s use of DT skills
across all stages of the d.school model, their learning
sheets provided substantial evidences on how children’s
designs could be sustained, iterated, and improved over
the course in each stage of work especially in the testing
and gaming phases. Students constantly make changes
based on the problems found during the game. Using
innovative and creative learning approaches in elementary
schools provides opportunities to broaden children’s future
aspirations and confidence as designers and makers.
According to the results of DT and STEM questionnaires,
the game-based course might make science, technology
and engineering more appealing to children, promoting
scientific and digital literacy skills [50], and encourage
students to become designers in the future. In this study,
the robots designed and assembled by the students have been
tested in the gaming phase that students have the chance to
compare their imagination with the real-world situations.

5. Conclusion

This study has shown that the students can obtain the
DT skills and STEM hands-on work in the interdisciplinary
game<Frontier Guards>. The students were excited and
immersed in the game scenario. They learned how to solve
problems presented in the game collaboration. The
students had received many positive feedbacks from the
game. This course and game helped students to integrate
and apply interdisciplinary knowledge and skills they have
learned as proved by Plass et al. [51]. The DT 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 [17].

DT was originated from the corporation of the world
and has expanded to education as an innovative, future
focused, cutting edge approach which has rich potential in
enhancing students’ problem solving, critical and creative
skills, aligned with the ideologies of transforming school
curricula for the needs of the 21st century [52,53,54]. In
this game, the robots were controlled remotely and there
was no fixed scoring and winning model, so DT can
provide students with a method to cultivate problem-
solving ability. It demonstrated that DT approaches are
suitable and beneficial for young children and can enhance
open-ended, flexible and transferable skills, such as
creativity and critical thinking skills [44].

Through observation, in order to win the game,
Students solved the unexpected problems, such as the
robot parts fell off and was immediately withdrawn from
the game and then was fixed right away. They remodeled
robots right away at changeover time. Games have a
positive impact on students’ problem-solving abilities
through observation.

So game-based learning with robotics is a developing
approach for increasing learners’ motivation, interaction
and engagement by incorporating game design elements in
educational environments [29]. Besides, students’ interviews have shown that this course was very
interesting. Robotics also provides a rich and attractive
learning environment for STEM education [17].

Research on effective ways to integrate DT into
mainstream education starting from a young age is needed
since we need to fully explore the potential of this creative,
multidisciplinary, and innovative approach for children’s
authentic future-oriented learning [55]. In this study,
course framework was examined and discussed, which
demonstrated that DT approaches are suitable and
beneficial for elementary students and can enhance
flexible and transferable skills, such as creative and
critical thinking for problem-solving skills. DT is a
multipurpose approach for managing conflicting ideas,
identifying the key needs and common goals, making
productive use of diverse backgrounds, enhancing
empathy, and developing a sharing vision [45]. Consistent
expectations of learning for the future and improving
elementary students’ development of DT capabilities
could potentially contribute to equipping them with the
sufficient capacities to manage challenges themselves in
the future.

References

[1] Ulbarri, N., et al., Research as design: Developing creative
confidence in doctoral students through design thinking.

[2] Siftung, S., Design Thinking in STEM<sup>†</sup>: Education project
combining STEM education, design-based education and the
challenges addressed by the SDGs. Sustainable Development
Goals Partnership Platform. Available at:

[3] Carroll, M., et al., Destination, imagination and the fires within:
Design thinking in a middle school classroom. International

p. 12-18.

[5] Lin, C.-H., et al. Game-Based Learning Effectiveness and
Motivation Study between Competitive and Cooperative Modes.
In 2017 IEEE 17th International Conference on Advanced

transforms organizations and inspires innovation. Vol. 20091,

design thinking methods and tools in innovation process. in ISPIM
Conference Proceedings. 2016. The International Society for
Professional Innovation Management (ISPIM).

[8] Afari, E. and M. Khine, Robotics as an educational tool: Impact of
lego mindstorms. International Journal of Information and

Conceptions of STEM in Education and Partnerships. School

in K-12 education: Status, prospects, and an agenda for research.

2019. Springer.

integrated STEM education. International Journal of STEM

[13] Wright, N. and C. Wrigley, Broadening design-led education
horizons: Conceptual insights and future research directions.
Future designers: Introducing game design


Balogh, R. Basic activities with the Boe-Boe mobile robot. in Proceedings of conference Digidino. 2008.

Chetty, J. Lego® mindstorms: merely a toy or a powerful pedagogical tool for learning computer programming? in ACSCE. 2015.


