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Assessing the Effectiveness of Board Game-based Learning for Enhancing Problem-Solving Competency of Lower Secondary Students

Surawit Assapun
Asst. Prof. Dr., Thammasat University, Thailand, *hulse@lsed.tu.ac.th*

Phonraphee Thummaphan
Asst. Prof. Dr., corresponding author, Thammasat University, Thailand, *phonraphee@lsed.tu.ac.th*

The use of game-based learning in education is prevalent. However, the effectiveness of it as a tool for promoting real world problem-solving competency in STEM education is yet unclear. The main research question was how well the board game-based learning improves students' problem-solving competency in lower secondary schools. Mixed-method research was used with embedded design comprising of one group pretest-posttest quasi-experiment, and case study. The research developed a GBL model based on three specifically designed board games and experimented with three classes of 30 students each by two participating teachers in two schools using one of the games for one lesson. Students' problem-solving competency was assessed quantitatively before and after each class and analyzed by descriptive statistics. Qualitative data were collected through observation, focus group discussions, and in-depth interviews and analyzed by content analysis. The results found that GBL model consists of problem-solving concept. learning process, learning content, and game mechanics. Teachers used the model following learning process for different learning objectives. Students' problem-solving behavior and skill scores increased after participating GBL, while changes in self-efficacy were mixed. Students' learning experiences were positive with high engagement. This study shows how GBL can be practically used with various serious games and applied in different classes, and it suggests teachers to apply this model to promote student problem-solving proficiency.

Keywords: problem solving, competency development, game-based instruction, board game, STEM education

INTRODUCTION

Learners' competencies are very important for developing their imagination, learning, and living. The importance of competencies has been increasing over time. This is particularly true for real world problem-solving competency, which has been recognized

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as one of the 21st century skills (Sarathy, 2018; World Economic Forum, 2016). However, while problem-solving competency is important for learners' work and life success (Kailani et al., 2019; Programme for International Student Assessment, 2004; Thummaphan et al., 2020), the evidence show that real world problem-solving competency of Thai learners is unsatisfactory (OECD, 2017; Panichsuay et al., 2021). Potentially it is due to students have not enough opportunity to practice what they have learned and apply it to real-life situations (Panichsuay et al., 2021). Hence, appropriate learning material and methods are needed for improving students' problem-solving competency.

Game-based learning (GBL(is an increasingly popular method of instruction. GBL is based on the use of educational games to reach specified learning goals (Connolly et al., 2012; Ramsi, 2015; Türkoğlu, 2019). Games can engage students' interest and give them learning opportunities by simulating real-world scenarios while also making the class fun. Playing games for learning helps learners gain knowledge identified in the syllabus and understand, practice, and use diverse learning and problem-solving strategies (Budasi et al., 2020; Chin et al., 2009; Moursund, 2016; Pramono et al., 2021). GBL can utilize board games, which have parts or cards that can be moved around on a game board according to the game's rules)Vij, 2011(. Board games have multiple advantages: they can be used to simulate various situations to make learners interact face-to-face with the learning content of the game (Pho & Dinscore, 2015), also playing board games does not require electronic equipment or an internet connection. For these reasons, learning through board games has garnered much interest recently in STEM education.

While the advantages of GBL are intriguing, there has not been much empirical study on the effectiveness of board game-based learning for supporting competency to solve problems in the real world. Researchers mentioned that empirical research on the influence of GBL on problem-solving skill remains limited (Eseryel et al., 2014; Hussein et al., 2019; Kailani et al,, 2019). Based on the experiential learning theory (Kolb & Kolb, 2009; Kolb, 2015), GBL should be designed and implemented to provide learner with experience of problem solving and naturally develop competency through learning activities (Ho et al., 2022; Plass et al., 2015), rather than just an activity of playing game. Moreover, past research has focused on the results of using games in education, rather than on how teachers use games in this context)e.g., Chung, et al., 2017; Marklund & Taylor, 2015; Yodsanga & Srisawasdi, 2021). In addition, most research on learning through games has tended to be mostly experimental and quantitative, whereas learners' experiences have received less attention (Chung et al., 2017). Therefore, empirical evidence covering GBL model, teachers' use of the model, and the competencies that learners acquire as a result of such instruction is required.

Thus, the present study aimed to develop GBL model for enhancing learners' problem-solving competency using, study teachers' use of board GBL model for enhancing learners' problem-solving competency, and evaluate the effectiveness of board GBL model for enhancing learners' problem-solving competency. This research used three board games: 1) Control Wave, 2) PW Mastery, and 3) Yes/No Organ, developed as a part of a research project to examine the practicality of GBL. This research also offers additional insights on the effectiveness of GBL by examining problem-solving competency in sub-domains of behavior, skill, and self-efficacy as well as learning experiences.

Review of Literature

Game-Based Learning Model for Enhancing Problem-Solving Competency

GBL model for this study aims to encourage problem-solving competency which is one of the essential competencies people today need. In order to solve problems in the real world, one must constantly engage with the environment (Sarathy, 2018). Problem-solving competency refers to "an individual's capacity to use cognitive processes to confront and resolve real, cross-disciplinary situations where the solution path is not immediately obvious and where the content areas or curricular areas that might be applicable are not within a single subject area of mathematics, science or reading" (Programme for International Student Assessment, 2004, p. 26). It requires a set of factors, e.g., knowledge, skills, abilities, for effectively solving problems (Fischer & Neubert, 2015; Fischer et al., 2015; Funke et al., 2018), and involves multiple steps from problem recognition to problem solving (Hardin, 2002; Hoi et al., 2018). Numerous concepts on problem-solving have been developed, including One of the essential competencies people today need out the plan, and look back, and Bransford and Stein's (1993) IDEAL problem-solving model: identify the problem, define goals, explore solution, act on the strategy, and look and learn. Based on these concepts, this study views problem-solving competency as student's capacity to effectively solve real-life related problems by application of knowledge, skill, and attributes, involving six stages: 1) specifying the information needed to understand the problem, 2) choosing the problem to be solved, 3) identifying options in solving the problem, 4) selecting the problem-solving method after considering pros and cons, 5) implementing the problem-solving plan, and 6) monitoring and evaluating the results.

GBL is an educational trend that has been actualized in STEM instruction. GBL is a learning model that integrates game and learning for educational purposes and contexts. GBL requires games and activities specifically designed for learning purposes (Connolly et al., 2012; Pho & Dinscore, 2015) and allowed for the applications of STEM concepts to real world problems (Contente & Galvão, 2022; Dare et al., 2021; Jurdak, 2016). Based on experiential learning theory (ELT) that considers learning as a knowledge creation cycle consisting of four bases---concrete experience, reflective observation, abstract conceptualization, active experimentation (Kolb & Kolb, 2009; Kolb, 2015), learning experiences should be design and provided throughout the learning environment. Fundamental issues in integration of game and learning are learning process, learning content, game characteristics, and learning environment (Marklund & Taylor, 2016; Ramsi, 2015). A GBL model consists of concepts or learning outcomes to be achieved, learning process or pathway for players to pursue knowledge, and game mechanics which are the rules governing the game play (Ramsi, 2015). Another model, known as the general model, consists of a challenge, a player's response, and feedback (Plass et al., 2015). It emphasizes a cycle of learning in which the player's response to feedback can either create new challenges or inspire them to find new ways to solve existing ones. Based on ELT and these models, GBL model employs 4 major components: (1) problem-solving concept with six stages as mentioned above, (2) learning process in which teachers and students follow during the whole instructional session to provide students with rich opportunities to transform experience to problem-solving competency., (3) learning content or objectives in the subject matter as this GBL focuses on educational context, and (4) game mechanics as the rules for game play.

Although there is growing interest in enhancing students' competency of real world problem-solving using GBL, there are still few empirical studies demonstrating its effectiveness. While there is much evidence that GBL increases students' interest and engagement, problem-solving competency are still needed (Hussein et al., 2019; Kailani et al., 2019). A few studies found positive results of GBL on some aspects related to problem-solving competency, e.g., behavior (Eseryel et al., 2014; Hou et al., 2022), skill (Gürbüz et al., 2017; Kailani et al., 2019; Perrotta et al., 2013), and self-efficacy (Harden, 2022; Threekunprapa & Yasri, 2020; Yu & Tsuei, 2022). These research, however, are not truly concentrated on the game that is created especially for real world problem-solving abilities, and GBL is not utilized for different classes, which limits our understanding of its effectiveness and applicability. Therefore, there is a need for empirical evidence that shows the GBL model using various board games enhancing students' problem-solving competency.

Teachers' Use of Game-Based Learning Model

Examining teachers' use of GBL is one of interesting issues. It is interesting Teacher roles in using GBL are crucial for successful implementation (Marklund & Taylor, 2015; Molin, 2017). More significant than the games' designs are the roles that teachers play in incorporating them into instructional activities (Lindgren, 2018). Teacher's use of GBL can be considered as the way of delivering GBL lesson from starting to ending the lesson. Teachers must do many tasks such as creating a lesson plan based on games, setting up the infrastructure to support game play sessions, and managing activities during and after game play sessions (Marklund & Taylor, 2015). To do that, teachers need sufficient understanding of the game that will be using in the classroom activities (Marklund & Taylor, 2015). Moreover, they need ability to effectively apply GBL in their classrooms (Lindgren, 2018; Liu et al., 2020; Molin, 2017). Besides importance of teachers' roles in using GBL, it is lacking empirical research that discuss the function of the teacher and the logistics of placing games in a learning setting (Molin, 2017). To address this issue, the study considers teacher's use of GBL on both teacher actions and views on their instructional practices.

Effectiveness of Game-Based Learning Model

Considering effectiveness of GBL on enhancing problem-solving competency requires various aspects. Effectiveness of GBL refers to the evaluation of the students' competency and learning from using game in the instruction. To assess whether the GBL is effective or not, the Game-based Evaluation Model (GEM; Oprins et al., 2015) provides a framework for examining the effectiveness of a game used in practical instruction. Importantly, GEM considers effectiveness of GBL by considering learning indicators in terms of emotional–motivational and cognitive domains, and learning outcomes based on knowledge, skills, attitudes, competencies, performances, by which indicators can be selected based on a certain study premise. This study selected problem-solving competency as an indicator of learning outcome based on the goal of the three selected games and considered it in the view of sub-domains of skill, behavior, and self-efficacy, to yield subtle information given a short period of experimentation. Problem-solving skill refers to the ability to solve problems based on the six stages. Problem-solving behavior is defined as students' perceived practice or actions in response to the problem situation based on the six stages. Self-efficacy is defined as individuals' beliefs in their capabilities to control their functioning in a particular domain (Bandura, 1977; 1997). In this study, it refers to learners' beliefs about their performance to solve the problems.

In addition, according to the ELT that views learning as an iterative process for transforming experience to knowledge (Kolb & Kolb, 2009), students' behaviors (engagement and actions), and learning experiences are crucial and thus are selected as additional indicators of effectiveness of GBL model. Past research on the use of learning through games has tended to be mostly quantitative and experimental, whereas learners' experiences have received less attention (Chung et al., 2017; Eseryel et al., 2014). As a result, there are gaps in our knowledge of how learners learn when they play games for educational reasons. The quantitative and qualitative nature of these indicators are considered to reflect the effectiveness of GBL.

METHOD

The Study Design

The study employed mixed-method research with the embedded design (Creswell & Plano Clark, 2011; Tashakkori & Creswell, 2007). Creswell (2012, p. 572) described the purpose of the embedded design as "to collect quantitative and qualitative data simultaneously or sequentially, but to have one form of data play a supportive role to the other form of data." In this investigation, both quantitative and qualitative techniques were employed to demonstrate the effectiveness of GBL. The one-group pre-test post-test quasi-experiment was the quantitative method, and a case study was the qualitative one. The one-group pretest-posttest design was adapted to investigate the difference in the levels of lower secondary students' problem-solving competency between before and after the GBL. The dependent variable of the design is problem-solving competency (problem-solving skill, behavior, and self-efficacy) of students in lower secondary schools. The independent variable was GBL The case study viewed each class as a case and used to explore teachers' instructional practices and students' behaviors and learning experiences which support the data from experimental design. The data were gathered via observation, focus group discussions, and in-depth interviews of teachers and students by researchers. The GBL is an instructional model using three specifically designed board games titled 1) Yes/No Organ, 2) Control Wave, and 3) P.W. Mastery, which aims to enhance problem-solving competency of students. The GBL, designed by researchers and teachers, was applied to three classes of students in two lower secondary schools in Pathumthani and Bangkok: one game for one class of 100 minutes. The teachers implemented the GBL in their own classes in the daily activity environments. Prior to the deployment, the researcher taught the grade teachers who would be delivering the GBL.

Participants

Participants were purposively selected based on pre-set criteria, as the purpose of the study was to experiment with games in a real-life educational setting. Emphasis was on contextual validity to ensure that practitioners can effectively apply the findings in their work settings. All types of students, including inclusive students, were included to assess the scientificity of the GBL. Two lower secondary STEM education teachers participated in the study. Both were currently working in the Greater Bangkok area of Thailand, had at least one year's classroom teaching experience, and involved in the game development process. Also, ninety lower secondary students participated in the study. One class of 30 students participated in experimenting with each game, 30 of them in School 1 in Pathumthani and 60 in School 2 in Bangkok. Given inclusive school context, some had special needs.

Procedures

The initial GBL model was developed from literatures. Then, it was applied and adjusted by participating teachers during developing lesson plans with researchers' assistance to ensure its applicability in practical setting (Marklund & Taylor, 2015). The research team had meetings with the individual teachers to practice playing games to enhance teachers' understanding of the game and how they would be played. After that, teachers developed lesson plans to use the games as a part of their instruction, based on the suggested GBL model. The teachers and researchers discussed the lessons that are suitable for using GBL by considering the matches between the game content and lesson's learning objectives, the game content and sequence of the course content, as well as the game play duration and teaching schedule. Finally, the lesson plans were discussed and revised to make it better fit with instructional practices. The actual GBL model, as lesson plans, were then used in participating teachers' classrooms.

After the lesson plans ready to be used, teachers implemented them in their classrooms using three board games that developed by researchers in the previous research stage. During the actual lessons in the late of the first semester of academic year 2020, each group of 30 students received a 100-minute (double-length, 2 x 50 min) lesson, one of which was provided by the first teacher and two of which were provided by the other teacher. Data were collected before, during, and after each lesson.

The study received approval from the Human Research Ethics Subcommittee Thammasat University, 2nd batch, Social Sciences, Certificate No. 039/2563. Throughout this investigation, ethical issues about participant rights and safety—both physically and psychologically—have been taken into account.

Instruments and Data Collection

Board games for enhancing problem-solving competency were specifically designed by the researchers, as a part of a research project, for use in lower secondary STEM classroom context, to promote learners' competency to solve problems in real-world scenarios. There are three board games 1) The Control Wave game teaches 9th graders about mechanical and electromagnetic waves; 2) The Yes/No Organ game teaches 8th graders about food digestion and excretion; and 3) The P.W. Mastery game develops learners' scientific process skills for grades 7-9.

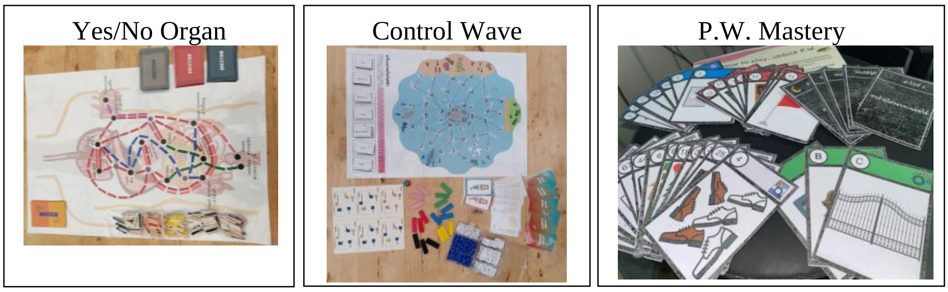

Figure 1
Sample images of each game used in the study

GBL model for enhancing problem-solving competency was co-designed by researchers and teachers. The four components of GBL model were specifically applied for three games as shown in Table 1. There are most common characteristics of GBL model used in all three games and some different features in each game. Specifically, Control Wave game focuses on various types of waves. Problem solving happens from managing limited resources while completing the mission. Yes/No Organ game emphasizes functions of various organs in the human body. Problem solving occurs when players answer the questions and complete given missions. P.W. Mastery game focuses on scientific processes. Problem solving occurs as solving the puzzles to figure out the murderer and get out of the risky areas. The three game mechanics request players to find the solutions for given missions or challenges by using problem solving process. Learning process for three games generally involves six steps and have some different activities in different games.

Table 1
Game-based learning model components for three games

GBL model components	Control Wave	Yes/No Organ	P.W. Mastery
Problem-solving concept	Solve problems by managing limited resources to complete mission	Solve problems through answering knowledge-related questions and complete the mission	Solve problems through resolving puzzles to find out the way to escape from the situation
Learning process	Teacher introduces content, pre-test, teacher asks volunteer students to demonstrate game playing, students play games in group, reflect after played, post-test	Teacher reviews content students already learned, pre-test, teacher explains the game, students play games in group, reflect after played, post-test	Teacher introduces the GBL activity, pre-test, students play games in group, reflect after played, post-test
Learning content	Mechanical and electromagnetic waves	Food digestion and excretion	Scientific process skills
Game mechanic	Team players get the missions to go different places of the underground city that call for gathering various parts and wave types as well as trading limited existing resources. Completing mission will get points. The team with the highest points wins the game.	Partners get the mission to go from one organ to another. Each mission requires different points based on difficulty levels. Players get points from answering questions correctly. The team with the highest points wins the game.	Team players get mission to identify murderer and escape form the risky place. They must solve each puzzle correctly to continue to the next step. The first team that can complete the mission wins the game.

Problem-solving competency evaluation forms comprised the students' problem-solving evaluation form, students' views on problem-solving form, and students' problem-solving practices form. Students were handed these forms in a paper and pencil format before and after the lessons. The students' problem-solving evaluation form assesses students' problem-solving skill. This form employed two real-world problems, one for before the game and one for after it: scheduling difficulties in group meetings and poor student participation in school events. Both problems consisted of five open-ended questions to which students responded in writing including 1) what information are given and what are needed to identify the problem, 2) what is the problem to be solved, 3) what are options in solving the problem, 4) after considering pros and cons of each option, what is the selected option and what are plan or steps to solve the problem, 5) how to monitor and evaluate the results. Each sub-item was given a score ranging from zero ("no ability") to two points ("clear ability"), so a higher total score indicates higher problem-solving skill. The students' views on problem-solving form assessed students' problem-solving self-efficacy (Bandura, 1977; 1997) consisting of six items, some positively and some negatively worded. Each item was assessed on a five-point scale, ranging from "most untrue" to "most true;" a higher score indicates higher problem-solving self-efficacy. The students' problem-solving practices form assessed their problem-solving behaviors and consisted of six items, each assessed on a five-point scale ranging from “never” to “regularly,” with a higher score indicating more frequent problem-solving behaviors.

These instruments were approved their content validity by three experts in measurement, problem-solving, and STEM education with purposively selected by the criteria of currently working as a teacher or university lecturer or educator and having at least three-year relevant working experience. Then, the instruments were tried out on 30 students on grades 7 to 9. The Cronbach’s Alpha reliability of the students’ views on problem-solving form was 0.737, and inter-item correlations ranged from 0.214 to 0.670. The Alpha coefficient of the students’ problem-solving practices form was 0.866 and inter-item correlations ranged from 0.577 to 0.678. Calculating a reliability coefficient for the students’ problem-solving evaluation form was not done since its questions were open-ended. Anyway, these instruments were fit for purpose.

Four qualitative data collection forms: 1) Focus group questions for participating students’ learning experiences inquired the students’ feelings towards the game they played and what they learned from it, following the GBL lessons, 2) Guidelines for observing the behavior of students playing the games focused on students’ engagement in playing each game and in solving problems while playing the game, 3) Guidelines for observing teachers’ instruction focused on how teachers introduced the lesson, the way they explained how to play the game, any help they provided to students while they were playing, and how they concluded the lesson, 4) Interview questions for participating teachers inquired the teachers about how they felt about their experience of trying out GBL, what they thought the students had learned, and etc., soon after the GBL lesson. These forms passed a face validity evaluation by three experts in educational measurement, problem solving, and STEM education.

Data analysis

The quantitative data analysis was performed using SPSS 18.0 for Windows program to describe changes in students’ problem-solving competency before and after their game-based lesson. Means and standard deviations of pretest and posttest as well as of the differences between the two tests were presented for the students’ problem-solving skills, behavior, and self-efficacy in each class. The qualitative data analysis was employed with a descriptive approach using steps of Miles et al. (2014) to gain a more nuanced perspective on the effects of GBL in each case. The recordings of the interviews and focus groups were transcribed. Coding was done on both the field notes and the transcribed data. Subsequently, themes and subthemes were developed. Checking the connections between the themes and sub-themes as well as the connections between each theme helped to ensure coherence and, consequently, internal consistency. The researchers used self-reflection during and after the data analysis to detect any bias this study may have to ensure the validity and accuracy of the results.

FINDINGS

Game-Based Learning Model for Enhancing Problem-Solving Competency

The GBL model, shown in Figure 2, consists of four components: problem-solving concept, learning process, learning content, and game mechanics. Problem-solving concept is finding the solutions of puzzles and challenges under conditions or constraints. Learning process includes six steps: the teacher explaining the learning objectives to the class, using a pre-test to gauge each student's level of problem-solving competency, having the class play a game with teacher support, having the class review and reflect on the lesson after the game, and using a post-test to determine whether the learning objectives were met and to see if problem-solving competency changed. The learning content focuses on STEM disciplinary content and scientific process. Game mechanics require players to solve problems in order to complete missions and win.

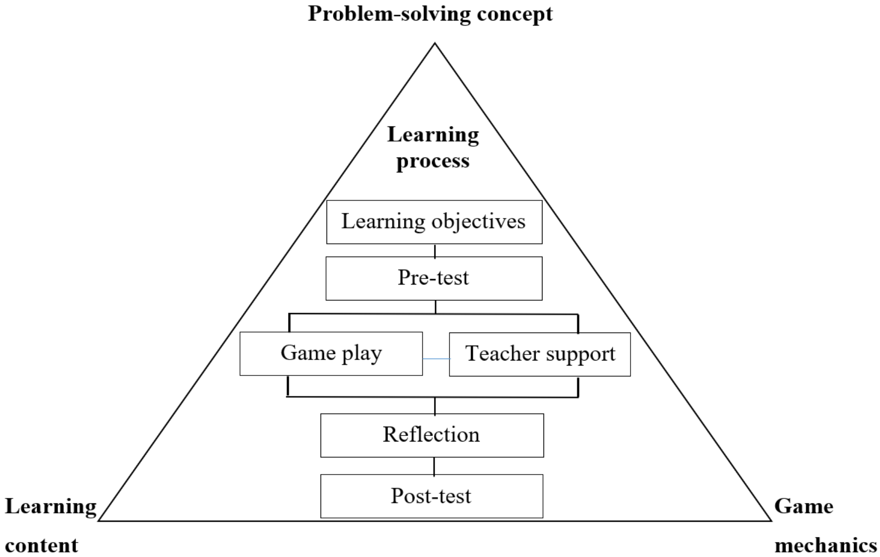

Figure 2
Board game-based learning model

Teachers' Use of Game-Based Learning Model

Control Wave. The teacher provided the lesson on mechanical and electromagnetic waves, focusing on everyday phenomena involving waves, to Grade 9 students in science class. The students had been divided into groups beforehand, and the teacher had asked for a volunteer from each group to try out the game before the class. During the class, these volunteering students facilitated the game-playing in their groups, explaining the game's rules, roles, and goals. Students took about 40 minutes to finish the play. After that, the teacher invited them to review their knowledge about these topics. Then, the teacher led the debrief about what the students had learned about problem-solving processes, by inviting the students to reflect on the problems they had encountered while playing the game and how they had solved them, before concluding the class by explaining about the six stages of problem-solving. When interviewed about the GBL, the teacher noted that Control Wave is suitable for teaching about waves, but many parts of the required content were not included. The teacher recommended using the GBL utilizing Control Wave at the beginning of the first class on waves, followed by other learning activities to cover the remaining content. She also mentioned that doing so, covering the topic would take as long as with other instruction methods, but the students would be very engaged with the class.

"It made every kid in the class engaged with the learning activity." (Teacher #1)

Yes/No Organ. The teacher provided the lesson on food digestion and excretion to 8th grade students as a part of their science class. The teacher started the class by asking questions about the various organs in the human body. The students were divided into groups of eight students each, given an explanation about the game and how to play it, and provided with an opportunity to ask any questions about the game. Then, the students were invited to play the game to review their knowledge on these contents for approximately 30 minutes. After playing the game, the teacher invited the students to discuss what topics they had already understood correctly and which ones they had misunderstood prior to playing the game. The students reflected on their problem-solving processes while playing the game, in particular their strategic planning and getting various tasks solved in the game. When asked about the GBL, the teacher viewed her GBL that the Yes/No Organ game was a very useful tool for revising and checking content comprehension related to digestion and excretion systems, but more time was needed for the post-game discussion.

"The game is suitable for revising one's knowledge because the learners need to have the knowledge about organs in the body to be able to play it. It would be good to increase the time for extracting lessons learned about problem solving while playing the game." (Teacher #2)

P.W. Mastery. The lesson was provided to 8th grade students' Independent Inquiry subject. The teacher begun the lesson by explaining that the activity in the class would involve playing a game as a group. The students were then asked to form groups of their own choosing, told how to play the game, and given an opportunity to ask any questions about how the game would be played. While the students were playing the game, the teacher provided further advice on how to play. The game took approximately 45 minutes to play, and after that, the teacher reiterated that scientific process is a kind of inquiry process that was reflected in the mechanisms of the game. The students then examined their learning experiences while playing the game, with questions about which problems each student got to solve in the game, and after this the teacher concluded the class. When interviewed about the GBL, the teacher revealed that the game could develop scientific process skills, and it could equally well be used with students on any grade. Considering the level of interest the students showed toward the game, the teacher planned to use the game in teaching the Independent Project subject in the following year.

"[Even] those students who aren't interested in studying had a lot of fun with the game, and were engaged in learning." (Teacher #2)

Effectiveness of Game-Based Learning Model

Quantitative findings on students' problem-solving competency before and after playing.

The effects of GBL on students' problem-solving competency are summarized in Tables 2-4. The results indicated similar patterns in the effects of GBL on students' problem-solving competency with each of the three games. Students' problem-solving behavior and skill scores were higher after each lesson. Students' self-efficacy scores were found mixed results. In sum, all three lessons enhance learners' problem-solving behavior and skills, but not self-efficacy.

Table 2
Means, standard deviations, and results of the t-test for the Control Wave game

Variable		Mean	S.D.	Mean of the difference	S.D. of the difference
Problem-solving skill	Pre	5.69	2.73	0.03	1.70
	Post	5.72	2.55		
Problem-solving behavior	Pre	3.80	0.67	0.33	0.34
	Post	4.12	0.64		
Problem-solving self-efficacy	Pre	3.64	0.48	0.02	0.39
	Post	3.66	0.52		

Table 3
Means, standard deviations, and results of the t-test for the Yes/No Organ game

Variable		Mean	S.D.	Mean of the difference	S.D. of the difference
Problem-solving skill	Pre	4.06	3.68	0.03	1.05
	Post	4.09	3.40		
Problem-solving behavior	Pre	3.54	0.57	0.21	0.80
	Post	3.74	0.65		
Problem-solving self-efficacy	Pre	3.55	0.53	-0.13	0.53
	Post	3.43	0.60		

Table 4
Means, standard deviations, and results of the t-test for the P.W. Mastery game

Variable		Mean	S.D.	Mean of the difference	S.D. of the difference
Problem-solving skill	Pre	4.16	3.25	0.02	1.64
	Post	4.19	3.10		
Problem-solving behavior	Pre	3.50	0.97	0.60	0.86
	Post	4.12	0.73		
Problem-solving self-efficacy	Pre	3.54	0.30	-0.11	0.35
	Post	3.42	0.31		

Qualitative findings on students' behaviors and learning experiences

Students' problem-solving behaviors while playing.

In the Control Wave game class, it was noted that the majority of pupils initially sought further explanation from teacher regarding the game's rules before beginning to play. Most students collected the kinds of waves they still needed and chose a path that would lead them to get those parts of waves that they needed to complete missions. When the game was nearly finished, they exchanged electromagnetic waves to collect points instead. All students in each group involved in playing the game including. Throughout the activities, children with special needs or slow learners played the game with other students, however some took longer to pick up the rules.

In the Yes/No Organ game class, with teacher explanation, the majority of pupils immediately understood how to play it. It was found that most students followed the missions that they got and did not ask for changing the mission. They used the same methods to solve the problems. For example, if some player changed their task once, they tended to do this again later, or if a player chose to erase a path that was crossed, they would stick to this method throughout the game. Those with special needs or slower learning participated in playing the game throughout its duration, but other students who were paired up with them were the main persons who answer the questions.

In the P.W. Mastery game lesson, most students asked for additional explanation when playing it for the first time. It was observed that while the majority of students worked in groups to solve the puzzles by going step by step, some students chose random solutions to the challenges. Most students did not collect the clues to find the villain of the game in the beginning, but rather tried to do this after they had passed each room and the only task that remained was naming the villain. The students collaborated well within their groups. Students who had attention deficits introduced the game rules to their peers, divided the roles for the players, and kept track of the information gathered by their group. Students who were slow learners participated in the activities according to the role division within their group.

Students' learning experiences while playing.

In the Control Wave class, students revealed that they got to learn about parts of waves that were repeated while collecting these parts. They also learned about the types and benefits of electromagnetic waves. However, they specified that they did not necessarily remember everything about these types of waves, or sometimes only hastily checked out a card. As for problem solving, students mentioned that they learned various kinds of problems and tasks that make them carefully plan paths to undertake to complete the missions. Students also reported that they understand more clearly about waves and problem-solving process from the reflection step:

"This game made me remember the different types of waves and their parts. When we were playing, I had to plan my path and solve problems to reach the goals of the tasks as quickly as possible.")Student #1, Control Wave)

In the Yes/No Organ game class, students mentioned that in the beginning, they were more interested in answering the questions than building a path for themselves, but once they had collected items for a while, they got more engaged with path building. Students recognized that some questions seem too difficult, but overall, they considered the game fun to play and wanted to play it again. They gained additional knowledge of human organs from the difficult questions and were motivated to learn the related content. Students revealed that playing in pairs was liked because the pairs got to think collaboratively about the questions, and if one student in a pair did not know the answer, the other one might. Students noticed from the post-game debrief that they tended to stick to a single problem-solving method, but in hindsight they could see that there were other options that could be used in each case, and different methods could be used in different situations.

"At first I thought I'd follow the same path to get lots of points, but after playing for a while, I had to change my path to get points more quickly.")Student #1, Yes/No Organ)

In the P.W. Mastery game class, students explained that they learned to work collaboratively to solve the various problems they encountered from the cards to get to the next steps to get out of the dangerous place as fast as possible. They mentioned that they had to observe and think carefully how the cards connected to each other. Sometimes they had to do trial and error as well as go back and forth to test the hypothesis. Students also mentioned that they see problem-solving and scientific processes that took place during the game more clearly from the reflection step.

"This game can develop problem-solving skills, because you have to observe, analyze, sort the cards and clues, make a hypothesis and then look for the answer.")Student #1, P.W. Mastery)

DISCUSSION

Game-Based Learning Model for Enhancing Problem-Solving Competency

Overall, GBL model to enhance students' problem-solving competency consisting of four components covers important characteristics of concept, process, content, and mechanics. The model seems like the previous GBL models (Ramsi, 2015; Marklund & Taylor, 2016). However, while all process, content, and mechanics are common components of general GBL, problem-solving concept gains critical importance as the main objective of the games used in this GBL and guides learning throughout the gameplay (Pho & Dinscore, 2015). The distinctive intention to problem-solving concept helps the GBL model directly focus on what it is created for.

The GBL model employs a learning process starting with an introduction by the teacher, followed by the main learning activity (playing the game), and finished with students reflecting on their learning experiences. These activities facilitate provide learners with direct learning experiences and encourage them to construct their own knowledge from the processes of playing the game and then reflecting on their game-playing experience afterwards as stated in experiential learning theory (Kolb & Kolb, 2009; Kolb, 2015).

Moreover, since learning through game sounds fast and students are overwhelming with mission completion, they probably do not have sufficient time to reflect on what they have learned through game. This GBL model then provides students with more reflection opportunity is crucial for transforming experience to knowledge and even gaining feedback from teachers and peers (Kolb & Kolb, 2009; Pho & Dinscore, 2015; Plass et al., 2015). Hence, reflection after gameplay is a suggested step for this GBL.

Teachers' Use of Game-Based Learning Model

Basically, teachers used GBL by following the learning process. These teachers could deliver lessons in accordance with their objectives. Teachers were satisfied with the resulting instruction and the students' high levels of engagement. The way GBL used in STEM classroom contexts may vary due to the content and complexity of the games. Based on the fact that teachers in various classrooms were able to employ the GBL model in their education, the results were consistent with earlier studies (Lindgren, 2018; Marklund & Taylor, 2015). One important reason is that teachers were familiar with the model since they involved throughout the process of design and application of the game, as well as they collaboratively designed lesson plans based on the model with researchers. Moreover, they also understood the context of the game since it used their contexts as game scenario and researchers helped accommodate GBL model to fit with teachers' instructional setting (Marklund & Taylor, 2015). Following the learning process outlined in the GBL model is essentially the main practice that teachers employed with the model. This provided evidence that teachers manage multiples tasks during and after gameplay (Lindgren, 2018; Marklund & Taylor, 2015). Following systematic learning process is a good strategy that teachers use to utilize GBL in the classroom.

However, an important consideration in game-based instruction is that the teacher must be familiar enough with the rules and mechanisms of the chosen game. This study confirmed results of previous studies that teachers must have ability to incorporate GBL into classroom activities (Lindgren, 2018; Liu et al., 2020; Molin, 2017). Specifically, clear understanding of the games is required for teachers to operate GBL effectively (Marklund & Taylor, 2015; Molin, 2017). The researchers observed that quite a bit of effort was required to make the participating teachers fully understand each game, its mechanisms, and the teacher's own roles at each stage of the class, to design an efficient class for their students. Otherwise, the GBL will be just gameplay during the lessons and not reach the intended purpose of building learners' problem-solving competency.

Effectiveness of Game-Based Learning Model

The results indicated GBL improved learners' problem-solving competency, particularly in the behavior domain and to a lesser extent in the skill domain, but not self-efficacy. Almost all students were engaged in playing each game throughout, and they participated in various activities of GBL beginning with studying the rules of their game and ending with examining their lessons learned. Moreover, they have learned problem solving through responding to challenges as well as planning and changing strategies with their peers mostly through the game mechanics and reflection. The rise in problem-solving behavior is in line with earlier research finding (Eseryel et al., 2014; Hou et al., 2022). Given that these learners were teenagers, these findings correspond to Piaget's intellectual development theory (1943) which notes that teenagers have the courage needed to learn through trial and error, and games involve activities prompting players to try out and learn new things while playing (Adeyemo, 2010; Budasi et al., 2020; Pramono et al., 2021(. GBL basically requires students to practice problem solving through the challenges of the games which directly influences the changes in their problem-solving behavior (Eseryel et al., 2014). This is confirmed by qualitative data that the players themselves reported that the games stimulated their problem solving, especially in terms of problem-solving planning and implementation. Moreover, the development of problem-solving behavior is influenced by high engagement of learners (both those with special needs and those without). This is consistent with the previous studies that discovered problem-solving competency is built by engagement in problem-solving procedures and experiences of successful problem solving (Eseryel et al., 2014; Hoi et al., 2018). This is not only in keeping with the goal of developing board games in which players need to engage in problem solving while playing, but also the design of the GBL that facilitate students in active learning process.

The results of some improvement in problem-solving skill in all classes is another interesting point. This is consistent with previous studies that GBL has positive impact on problem-solving skill (Gürbüz et al., 2017; Kailani et al., 2019; Perrotta et al., 2013). The results noticed a little increase of problem-solving skill scores which may have been due to the fact that skill development generally take time to practice, especially when it comes to tackling real-world problems. Due to the time constraints of the current study, participating in the GBL only once for around 100 minutes might not be enough to produce a significant change in skill development. Therefore, it is recommended that future research examine the impact of GBL on problem-solving skill over a longer experiment duration.

The mixed effects of GBL on self-efficacy domains—either increases or reductions depending on the game—sound interesting. While previous research only found mentioned that GBL has positive impact on self-efficacy (Harden, 2022; Yu & Tsuei, 2022), this discovery found some conflict findings. The results may be impacted by the game difficulty and how student response to it (Eseryel et al., 2014). For the Control Wave game which found some improvement of self-efficacy, it might be because the game helps students learn challenging content of wave and then encourage them to be more confidence in their ability (Bandura, 1977; 1997; Eseryel et al., 2014). For other two games which found the decrease of self-efficacy after attending the GBL, it is possible that some participants were still thinking about the outcome of the game, namely who won and who lost (Eseryel et al., 2014). Losing the game may have caused some players to doubt their problem-solving abilities and thus experience decreased problem-solving self-efficacy in the immediate aftermath of the game. Given these contradictory findings, additional research that takes into account GBL's subtler facets, such as the interaction between game difficulty level, student motivation, and problem-solving self-efficacy, is valuable to pinpoint the precise impact of GBL.

CONCLUSION

With the GBL model, the study offers a framework for incorporating serious board games into STEM instructional practices with problem-solving competency as a learning goal. In order to make the problem-solving competency stand out, the model distinguishes between problem-solving concept and learning content components. The GBL model is used in various STEM classes, demonstrating its applicability as an instructional framework by providing stimulating learning opportunities through the simulation of real-world challenges for applications of STEM concepts and scientific process skills. This study provides insights in the effectiveness of GBL by considering various measures of learning indicators and outcomes with both quantitative and qualitative data. These measures provide more thorough results on the application of GBL to improve real world problem-solving competency, and they are advised for use in examining the effectiveness of GBL.

For recommendations, designing and implementing effective GBL is important for facilitating learner problem-solving competency. Teachers who use GBL are required to fully understand game instruction manual and carefully plan lesson with sufficient time for using each game. Moreover, because competences to problem-solve in the real world naturally require time to develop, future research should assess the GBL model over a longer experimentation period to track how students' problem-solving competencies change over time. Furthermore, additional factors need be added to explain the effectiveness of GBL on problem-solving competencies more thoroughly.

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