MODESTUM

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Let's play! Transforming STEM education with board games

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Abstract

This study examines the development and effectiveness of four board games designed to promote cognitive learning activities and STEM education, focusing on kinematics and energy. We used the Engagement - Purpose - Deign - Prototype - Evaluation process to develop four board games. The study involved 53 senior high school students in Vietnam. We used a mixed methods approach to evaluate the impact of these board games on students' cognitive understanding and motivation in STEM education. Data collection included multiple-choice tests before and post-tests from the previous literature study to measure cognitive gains. We also surveyed students using 5-point Likert scales and open-ended questions to explore their motivation and engagement. Quantitative and qualitative analyses assessed whether board games significantly improved students' motivation and learning outcomes. These results suggest that integrating board games into STEM education can improve student engagement and understanding of STEM learning. In light of the results, we discussed the implications of the Engagement - Purpose - Deign - Prototype - Evaluation process and the effectiveness of four board games.

Keywords: board games, STEM education, motivations, game-based learning, game development

INTRODUCTION

STEM education is effective for students in many ways, such as fostering problem-solving skills, creativity, collaboration, computational thinking, and engineering design. However, the effective implementation of STEM education still faces many challenges. Teachers face many challenges in terms of STEM content knowledge, changing teaching methods, and changing opinions (Asghar et al., 2012; Chang et al., 2021; Guzey et al., 2016; Thibaut et al., 2018; Wang et al., 2011). In addition, effective teacher professional development must also be emphasized (e.g., Aldahmash et al., 2019; DeCoito & Myszkal, 2018; DeJarnette, 2018; Powell-Moman & Brown-Schild, 2011). From the students' perspective, effective STEM learning requires engineering and technological skills and mathematical thinking (Wahono et al., 2021). Students face technological and content knowledge difficulties (Chang et al., 2024). Such difficulties may cause them to lose interest and leave STEM education tasks. Therefore, there is an urgent need to transform STEM education to better engage students and teachers in STEM tasks.

There is an urgent need to improve learner interest and learning outcomes in STEM education, and it is essential to recognize the potential values that STEM education can bring. Researchers are constantly updating approaches to implementing STEM education. Students are placed in engaging learning contexts, such as socio-scientific issues (Wahono et al., 2021). Project-based learning, the engineering design process (EDP), and problem-based learning are often organized to provide students with opportunities to engage in STEM learning tasks (e.g., Du et al., 2018; Fernández-Limón et al., 2018; Goodnough, 2018; Han et al., 2015). The effectiveness of these implementations has also been highlighted in terms of increasing student motivation and learning outcomes. Game-based learning in STEM education has recently been advocated as innovative instruction for effective STEM implementation.

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Contribution to the literature

- This study developed four board games based on the EPDPE process and focused on practice and challenge-based STEM educational activities to meet the objectives required by the science education curriculum, particularly in Vietnam.
- While most current board games have rules and design ideas that just can be used as support for some academic content, the board games in this study integrated the inquiry and design characteristics into their mechanisms as a transformation of STEM education.
- The study's results suggest the effectiveness of using games in the learning environment, including promoting students' learning outcomes (cognitive perspective), motivation, and studying interest.

Educational games have been presented to increase student motivation and learning outcomes. Game-based learning is a student-centered approach to motivate and engage students with other players (Bressler et al., 2022; Bressler & Tutwiler, 2020; Cardinot & Fairfield, 2019; Cardinot et al., 2022; Küçükşen Öner et al., 2024; Wilson et al., 2013). Game-based learning was emphasized as a tool combining game rules and defined learning outcomes (Plass et al., 2015; Shaffer et al., 2005). Wang et al. (2022) conducted a meta-analysis on the use of games in STEM education from 33 studies published between 2010 and 2020. This study showed that educational games contribute to a moderate overall effect size compared to other teaching methods. Game-based learning, including board games, has recently been demonstrated in studies on STEM education.

Several studies have shown that the use of board games in the delivery of STEM education increases effectiveness. Board games are based on the theory of using games in teaching. In many studies, board games have been mentioned as an effective tool for implementing science education, or STEM education, to help students achieve a wide range of outcomes, such as motivation, cognitive outcomes, and problem-solving skills (Cardinot & Fairfield, 2019; Cardinot et al., 2022; Chen et al., 2021; Hashim et al., 2024; Küçükşen Öner et al., 2024; Tsai et al., 2020; Vita-Barrull et al., 2023). Najiah Hanim Hashim et al. (2024) conducted a systematic review of a board game in science education of 11 empirical studies between 2018 and 2022 to demonstrate the effectiveness of using board games in science teaching. However, educators and teachers still face many challenges when developing board games. Studies proposed design processes to facilitate educators to create board games, such as the process of Cardinot et al. (2022) or the process of Küçükşen Öner et al. (2024), specifically for the solar system unit. Board games are considered an effective teaching method to improve the quality of teaching and are an efficient way for students to review the material. Wang et al. (2022) reviewed studies on STEM subfields instead of following the characteristics of STEM education. STEM education includes problem-based learning, project-based learning, and the EDP (Bybee, 2010; Chung et al., 2018; Guzey et al., 2016; Wahono et al., 2020). Therefore, board games in STEM education could closely align with the EDP to emphasize the value of STEM. The current study integrated the EDP into the development to transform STEM education with board games.

Game-based learning, including educational board games, has positively and broadly impacted outcomes. Plass et al. (2015) proposed four aspects to build and evaluate the effectiveness of game-based learning: a cognitive perspective, a motivational perspective, an affective perspective, and a sociocultural perspective. The cognitive perspective includes variables related to learning outcomes, knowledge retention, and conceptual knowledge (Arztmann et al., 2023). The motivational perspective of game-based learning is based on the theories of self-determination and self-efficacy. Educational games were evaluated as a tool to engage and motivate learners. Accordingly, educational board games were designed and evaluated according to the four aspects mentioned above (a cognitive perspective, a motivational perspective, an affective perspective, and a sociocultural perspective).

In the present study, we describe the methodology of designing, developing, and evaluating an educational board game for high school students in STEM education. The designed board game is suitable for teaching and learning the topic of kinematics and energy. The research questions:

- How are board games for STEM education designed and developed with the emergence of the EDP?
- How is the effectiveness of board games designed for students' motivations and learning outcomes?

METHODOLOGY

Designing of Educational Board Games for Practice Activities and STEM Activities

Some studies have proposed different processes for designing board games in physics education, such as the study by Cardinot et al. (2022). Building on the foundational work of categorizing educational games, the authors identified six essential design principles for developing effective educational games that support formal science education and thus proposed five key steps for creating basic framework of a game, including

(1) empathize,

(2) define,

(3) ideate,

(4) prototype, and

(5) playest (Cardinot et al., 2022).

Küçükşen Öner et al. (2024) developed board games following the process specific to the solar system unit:

(1) subject of the game,

(2) initial ideas,

(3) sketch,

(4) prototype and test, and

(5) final version.

However, these processes focused only on knowledge, without emphasizing the design of board games that require players to apply skills, knowledge, and competencies to solve real-world problems, which aligns with STEM education and the general education curriculum that Vietnam aims to achieve.

Considering the different approaches to using educational games, the perspectives of gamification and game-based learning, and the previously proposed process of game development, we created a process for developing board games that facilitate practice activities and the organization of STEM activities. This process (**Figure 1**) includes 5 steps called **EPDPE** (**E**ngagement, **P**urpose, **D**esign, **P**rototype, and **E**valuation). In a crucial initial phase, educators need to consider the educational milieu where these games will be used to ensure their practicality and relevance. This basic understanding includes consideration of school curricula, estimated game length, the intended student demographic, methods for evaluating the game's effectiveness after play, and an inventory of existing game options suitable for the intended audience. The specific educational objectives of the game must then be formulated in line with the educational objectives regarding knowledge acquisition, skills development, and personal attributes. The design of the game mechanics, which includes elements such as cards and competitive dynamics, challenges learners while reinforcing educational content. In addition, the game's design intricacies, from thematic coherence to clarity of instructions, are critical to player comprehension and informed decision-making during gameplay. Using a gamification perspective that integrates game design principles for educational benefit emphasizes the need to effectively engage and motivate learners, translating into measurable educational outcomes. The iterative prototyping phases are followed by a rigorous evaluation where a preliminary game version is tested with the target audience to refine the logic, aesthetic appeal, and operational rules. This evaluation scrutinizes whether the game achieves its educational objectives. The understanding of the content and the enjoyment of the participants are measured, and, if necessary, an iterative refinement or redesign is made. This comprehensive approach aligns with the ethos of STEM education and ensures that educational interventions are relevant, engaging, and effective in achieving the desired learning outcomes in Vietnam's education system. The process is illustrated in **Figure 1**.

We developed four board games using the EPDPE process. The topic of the board games is kinematics and energy, based on the Vietnamese physics curriculum. Two of the four board games are designed for practicing skills and knowledge related to competency-based learning outcomes. At the same time, the other two are based on the EDP for STEM activities.

Board game for practice activities

Two innovative board games, "Mystery of Motion" and "Bingo!", have been developed to enhance skills and

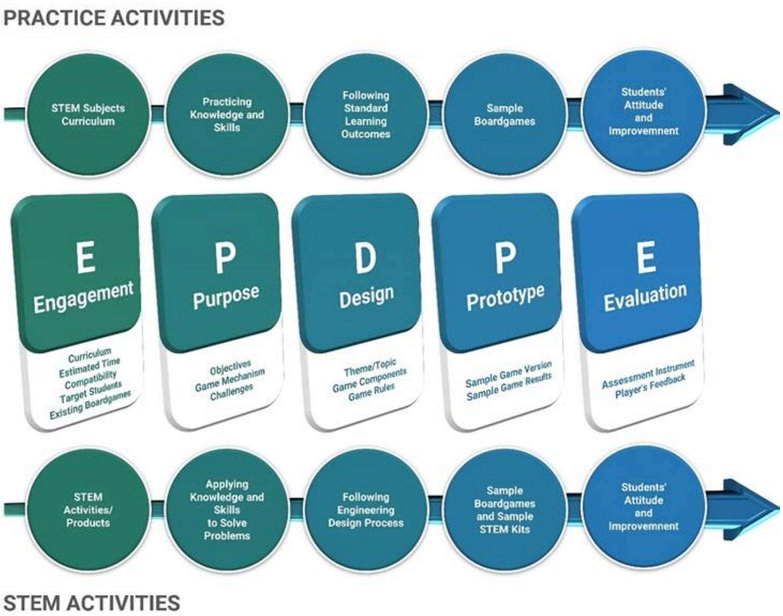

Figure 1. The EPDPE board game design process (Source: Authors' own elaboration)

Figure 2. The game "Mystery of Motion" (Source: Personal Documentation)

Figure 3. The game "BINGO!" (Source: Personal Documentation)

knowledge when practicing experiences in physics education. "Mystery of Motion" (**Figure 2**) encourages players to explore the concepts of kinematics through interactive gameplay, integrating educational tasks and strategic card mechanisms. "Bingo!" (**Figure 3**), on the other hand, transforms the traditional game format into a tool for reviewing work, energy, and power topics, encouraging active learning and application of knowledge through engaging, question-based interactions. These games reinforce learning content and promote student interest and understanding in the context of science education.

Table 1 provides basic information, including the game board overview, learning objectives, game components, and game rules for two board games with practice activities.

Table 1. Board game for practice activities

Board game	Mystery of Motion	BINGO!
Overview	"Mystery of Motion" is an interactive board game designed for three or more players to explore fundamental concepts of kinematics.	"BINGO!" is an interactive board game designed for three or more players to explore fundamental concepts of motion physics.
Learning objectives	1. Apply the formula for calculating speed and velocity. 2. Apply the formulas for uniformly accelerated linear motion.	1. Apply the formula for calculating potential energy, kinetic energy in some simple cases. 2. Analyze and explain the conversion of kinetic energy and potential energy of an object in some simple cases. 3. Apply the law of conservation of mechanical energy in some real-life situations. 4. Apply efficiency in some practical cases.
Game components	In "Mystery of Motion," the game incorporates two main types of cards (**Figure 4**) to facilitate gameplay and learning. *Normal cards:* These cards feature values closely related to kinematics, specifically acceleration, velocity, and time. Each quantity (acceleration, velocity, time) has cards with values ranging from 1 to 4. Players use these cards to apply motion formulas during gameplay. The combination of these cards determines the distance their chess pieces move on the game board. *Functional cards:* These cards introduce strategic elements to the gameplay, enhancing competitiveness and tactical thinking. Types of functional cards include: STOP cards: Halts any player's turn. MINUS cards: Inverts the value of a quantity or reverses the direction of any player. APPROXIMATE cards: Rounds off calculation results when they are decimal numbers. CHANGE cards: Allows players to alter any number of cards in their hand. Functional cards add an additional layer of complexity and decision-making to the game, encouraging players to strategize and adapt their gameplay tactics based on the cards they hold and the current game situation. Alongside normal and functional cards, there are "LEARN" cards designed to enrich players' understanding of kinematics. These cards are typically encountered at specific locations on the game board, such as the Temple of Literature.	The question cards (**Figure 5**) included in the game vary in difficulty, covering all levels of cognitive processes: recognition, understanding, and application. The content of the questions is diverse, including theoretical aspects, formulas, and problem-solving in real-life situations. This ensures that the game caters to different learning needs and helps students to apply their knowledge in various contexts.

Table 1 (Continued). Board game for practice activities

Board game	Mystery of Motion	BINGO!
Game rules	The objective of the game is to move a piece from number 1 to number 50 on the map. The person whose piece reaches number 50 first is the winner. On the map, there are special places that are activities or famous places associated with the lives of the Hanoi people. At each of these points, players must complete the corresponding task. At the Temple of Literature location in the game (number 24), players are required to read the information in "LEARN" cards (**Figure 3**). This game has four learn cards, each with distinct content, which can be a question or information. These cards will be kept separate from the other types of cards. There are two main types of cards in the game: normal cards and functional cards. Rules for combining cards will be clearly described in the game rulebook (**Figure 6**).	A player designated as the caller randomly selects a question card from the deck and reads aloud the question or problem. Players check their Bingo cards to see if they have the correct answer to the question on their card. If a player has the correct answer on their card, they mark or cover that square. The first player to complete a predetermined pattern on their Bingo card (such as a straight line horizontally, vertically, or diagonally) and calls out "Bingo!" wins the round.

Figure 4. Game cards of "Mystery of Motion" (Source: Authors' own elaboration, using Canva at www.canva.com)

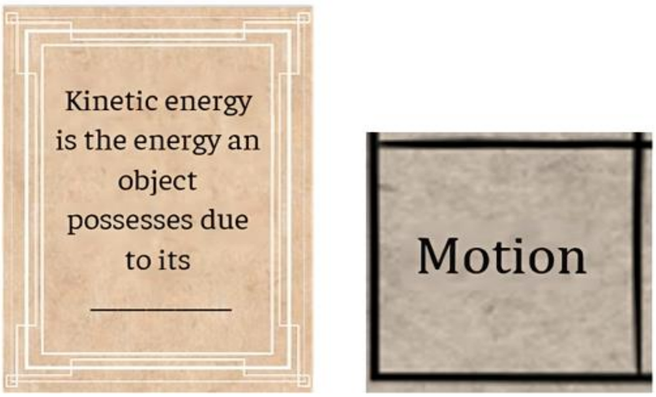

Figure 5. Question card and answer card (Source: Authors' own elaboration)

Board games for STEM activities

"Catapult" and "The Adventures of Little Engineers" are engaging STEM board games designed to integrate learning with hands-on activities and associated STEM kits.

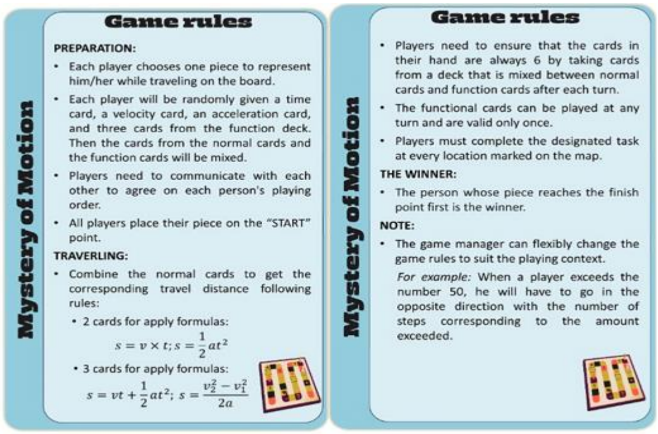

Figure 6. The game rule book of "Mystery of Motion" (Source: Authors' own elaboration, using Canva at www.canva.com)

Figure 7. Board game "Catapult" (Source: Authors' own elaboration)

In "Catapult" (**Figure 7**), players become ancient weapon makers tasked with constructing catapults, navigating a dynamic game board to collect materials, and applying principles of projectile motion.

In "The Adventures of Little Engineers" (**Figure 8**), players embark on a quest to build gravity-powered cars, applying the concepts of work, power, and energy while overcoming challenges on an interactive game board. Both games immerse players in practical STEM applications, fostering critical thinking, problem-solving

Figure 8. Board game "The Adventures of Little Engineers" (Source: Personal documentation)

skills, and collaborative learning in an exciting and educational setting.

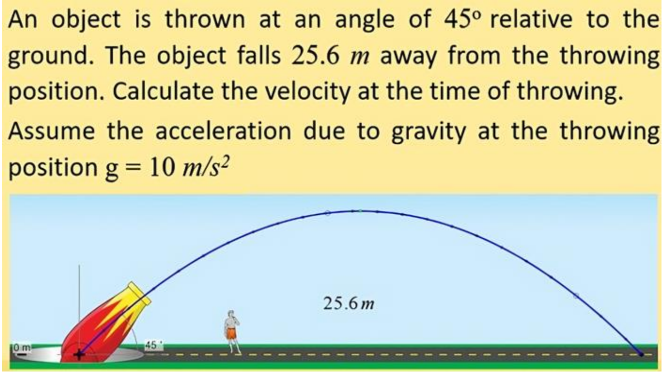

Figure 9. A question card of "Catapult" (Source: Authors' own elaboration, using Canva at www.canva.com and phet.colorado.edu)

Table 2 presents essential details, including the game board overview, learning objectives, game components, game rules, and the pivotal addition of STEM kits for two STEM board games. This highlights the critical

Table 2. Board game for STEM activities

Board game	Catapult	The Adventures of Little Engineers
Overview	"Catapult" immerses players in the role of ancient weapon makers tasked with constructing functional catapults. Through strategic navigation of a dynamic game board, players collect materials and tackle challenges rooted in projectile motion physics.	"The Adventures of Little Engineers" invites players to build gravity-powered cars using materials gathered across a vibrant game board. As young engineers, players apply principles of work, power, and energy while solving challenges that require strategic planning and problem-solving skills.
Learning objectives	1. Discuss how to design a plan or choose a plan and implement it, measuring the speed using practical instruments. 2. Carry out a project or research topic to find the conditions for throwing an object in the air at a certain height to achieve the greatest height or distance.	1. Apply the formula for calculating potential energy, and kinetic energy in some simple cases. 2. Analyze and explain the conversion of kinetic energy and potential energy of an object in some simple cases and in the construction and assembly of a gravity-powered car. 3. Apply the law of conservation of mechanical energy in some real-life situations. 4. Apply efficiency in some practical cases.
Game components	The board game consisted of five elements namely: (1) game board, (2) game pieces, (3) question cards, (4) mechanism of the game, and (5) KIT STEM. *Game board:* The game board is designed with various positions linked to different tasks, creating an experience as if the players are embarking on a sea journey filled with numerous challenges. Each point offers diverse missions such as collecting materials by using the provided money to purchase necessary items; trading goods by allowing players to buy additional goods if they lack or sell excess items for the appropriate ones; taking challenges, which involve answering questions related to projectile motion content; and returning to previous positions to gather tools they have missed. *Game pieces:* The game pieces are represented by ships, symbolizing the teams, making the game more dynamic and realistic, as if they are truly setting sail. *Physical challenge question card:* To overcome the challenge position, players need to answer questions about projectile motion, helping them recall how to calculate physical quantities such as initial angle, initial velocity, range, and maximum height. These physics questions assist players in having a clearer plan when designing and adjusting their catapults, ensuring they can hit their desired targets. Figure 9 shows one example question.	The board game consisted of five elements namely: (1) game board, (2) game pieces, (3) question cards, (4) mechanics of the game (rules of the game), and (5) KIT STEM. *Game board:* The game board features four iconic locations in Vietnam, interconnected by a central subway system for instant travel. Each area is linked by a network of pathways. Players collect secret gift boxes and essential materials scattered across the map to build their gravity-powered car. Traffic lights at intersections add realism and strategy by requiring players to follow traffic rules. *Game pieces:* The adorable animal game pieces add charm and fun, elevating the game's visual appeal and boosting player enjoyment and engagement. *Set of cards:* The challenge cards (Figure 10) are meticulously designed to align with 2018 General Education Program for Physics grade 10, focusing primarily on developing problem-solving skills in real-world contexts. The questions are categorized according to Bloom's Taxonomy, ensuring that they target various learning objectives, from basic knowledge and comprehension to higher-order thinking skills such as analysis, synthesis, and evaluation. For example, there are some questions that students asked to state, explain, give example about some physic laws, or do calculation to find physical quantity. Besides, there are action cards that prompt short activities aimed at creating moments of joy or helping players regain focus. These cards add an element of fun and engagement, preventing monotony and maintaining high energy levels throughout the game. In addition, there are secret cards such as gaining an extra turn, losing a turn, swapping materials, etc., to make the game more surprising and exciting. Finally, the material cards essential for making a gravity-powered car.

Table 2 (Continued). Board game for STEM activities

Board game	Catapult	The Adventures of Little Engineers
Game rules	The game rules (Figure 11) are designed with clear instructions to help players quickly grasp the gameplay. Notably, the process of engineering design in STEM education is directly embedded into the rules, rather than merely combining the game with physics in a mechanical way. Players will have the opportunity to create their own design for a catapult, assemble it, test, and adjust it multiple times to produce a finished product that meets the specified criteria. Besides, through trading function, players will also learn money management skills, buying and selling materials appropriately to build an effective game strategy. For the game facilitator, each task at every position is clearly guided to allow them to effectively manage the game, from controlling player's turns to facilitating trading. Additionally, we have included a QR code that provides the game facilitator with the answers to the challenges.	The game rules (Figure 12) are designed with clear instructions to help players quickly grasp the gameplay. Students take on the role of engineers tasked with designing a car that does not operate by fossil fuels or electricity. Thus, they came up with the idea based on the law of conservation of energy, where kinetic energy can be converted to potential energy and vice versa. Our little engineers have sketched a car that can run by converting the potential energy of a falling object under the influence of gravity into kinetic energy to operate. Their current task now is to collect enough materials to build this gravity-powered car. To achieve this, they must move to different locations on the map and collect materials by overcoming challenges in the game cards. The game includes three main types of cards: challenge cards (40 question cards and 10 action cards), material cards (wooden sticks, wheels, wires, weights), and secret cards (item exchange, question exchange, bomb, protective shield, etc.). The engineers must discuss and strategize to collect the most materials quickly to win the race of making a gravity-powered car.
STEM kids	The STEM KIT in the game is a collection of materials including wooden sticks, rubber bands, and rulers. These materials are easily obtainable, cost-effective, and can be reused multiple times, emphasizing sustainability and practicality. The KIT not only supports hands-on learning but also encourages creativity and innovation as players engage in testing and adjusting their products at various times. By using affordable materials, the KIT ensures accessibility for all participants, fostering an inclusive and engaging gaming experience.	The STEM KIT is a thoughtfully assembled collection of materials that allows students to build their gravity-powered car based on provided design plans. These materials are easily obtainable, cost-effective, and can be reused multiple times, emphasizing sustainability and practicality. The KIT not only supports hands-on learning but also encourages creativity and innovation as students engage in the process of constructing their vehicles. By using affordable materials, the KIT ensures accessibility for all students, fostering an inclusive learning environment. This practical approach not only reinforces theoretical knowledge but also develops essential skills such as problem-solving, critical thinking, and technical proficiency, making the STEM KIT an invaluable component of the educational experience.

Figure 10. Game cards of "The Adventures of Little Engineers" (Source: Authors' own elaboration, using Canva at www.canva.com)

Figure 11. Game rule book of "Catapult" (Source: Authors' own elaboration, using Canva at www.canva.com)

inclusion of hands-on STEM materials in enhancing the educational experience and the practical application of STEM concepts in the games.

It is noticeable that the mechanisms of the designed board games for STEM activities are purposely designed to embed the required competencies in physics and EDPs directly into the gameplay. This means that students are not just doing a simple mechanical integration of board game elements and physics knowledge but are actively developing these skills as

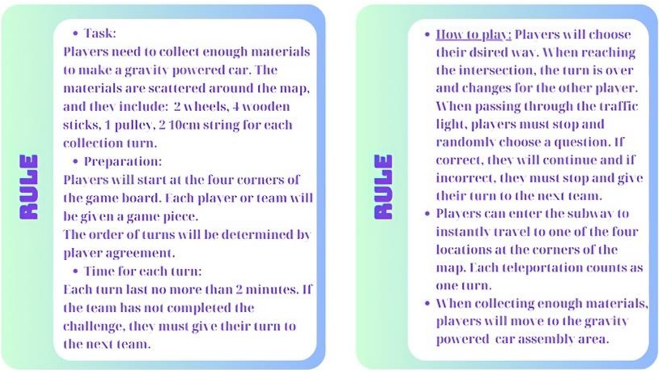

Figure 12. The game rulebook of "The Adventures of Little Engineers" (Source: Authors' own elaboration, using Canva at www.canva.com)

they learn to follow the rules and participate in the game. Through this immersive approach, players gain a deeper understanding and mastery of physics concepts and technical design skills while enjoying the dynamic and interactive environment of the board game.

Procedure and Sample

We surveyed students' motivation and engagement after playing board games in STEM education. The cross-sectional survey included 10 five-point items and open-ended questions. The paper version of the survey was given to students in class. Data were also collected from a pretest and a posttest, adapted from research by Irmak et al. (2023) and translated into Vietnamese. The data was collected in April 2024.

We implemented board games for 53 grade 10 students in Vietnam. All the students are in gifted high schools, but most are not in science. They learn science as an elective subject. Most of the participants are female students (81.13%). 53 students participated in the pedagogical experiment, with 20 participating in games for STEM activities and others for practice activities.

Instruments

The instrument consisted of 10 items. The students answered the questions on a five-point scale from "strongly disagree" to "strongly agree." The Kaiser-Mayer-Olkin test value for sampling adequacy was 0.754, meaning the variables were highly factorizable (Cohen et al., 2018). The Barlett's test for sphericity is statistically significant at the $p < .001$ level. The results show that the variables are correlated. Overall, 69.13% of the total variance was explained by the two identified factors. We found two components using the principal component and varimax with the Kaiser normalization rotation method. For component 1, the indices range from approximately 0.626 to 0.907; for component 2, the indices range from approximately 0.785 to 0.913. We used Cronbach's alpha (alpha) to evaluate the reliability as internal consistency. The calculated alpha was 0.874, indicating a reliable scale. In addition, students' competencies are measured using pre-and post-tests. This test is based on a previous publication by Irmak et al. (2023). It has been translated into Vietnamese and adapted to the teaching context in Vietnam.

Data Analysis

Qualitative data from open-ended questions and quantitative data from 10 items of the surveys were analyzed to assess students' motivation and engagement in board game effectiveness. A paired samples t-test assessed the changes in students' cognitive perspectives. The quantitative and qualitative data were analyzed using SPSS 26 and NVIVO 14.

Implementation Testing

We implemented four board games for students, including games for STEM and practical activities (**Figure 13** and **Figure 14**).

RESULTS

The Results of Students' Engagements in STEM Board Games

The Likert scale questionnaire analysis results show that board games positively enhance interest in learning and help students effectively engage in practice and

Figure 13. The study with games for STEM activities (Source: Personal documentation)

Figure 14. The study with the game for practice activities (Source: Personal documentation)

Table 3. Means and the standard deviations of each item

No	Items	M	SD
1	I feel excited when participating in learning through board games.	4.23	0.847
2	I find that board games help me review knowledge more easily.	4.08	0.756
3	The learning activities in board games help me achieve the learning objectives of the course.	3.91	0.861
4	Board games help me connect content knowledge in new ways.	4.26	0.836
5	Board games enable me to participate in activities in different ways enhancing my learning competencies.	4.15	0.784
6	Board games provide me with opportunities to practice and improve my skills.	3.92	0.937
7	I feel excited to learn the next topics related to physics.	3.53	0.912
8	I feel that these STEM games help me actively learn and apply the knowledge I have learned to practical problems.	3.75	0.786
9	I find playing STEM games exciting because knowledge is no longer boring and becomes more authentic.	4.05	0.826
10	Through the games, I get to experience the work of engineers, applying knowledge to design, create, and test my own products.	3.95	0.759

application lessons. **Table 3** displays the results obtained.

The opinion that board games help students connect knowledge content in new ways was rated highly (mean [M] = 4.26, standard deviation [SD] = 0.836). The opinion that board games help students easily review knowledge was rated highly and smallest SD (M = 4.08, SD = 0.756). These two results indicate that most players share the same opinion and agree highly with the questionnaire. The players, therefore, think that board games are a tool that allows them to learn actively without getting bored.

Two questions on the level of interest yielded results at medium and high levels. Firstly, when asked about interest in further learning content related to physics (M = 3.53, SD = 0.912), the results show that players had a moderate level of interest, though not exceptionally high, level of interest. This suggests that motivation to learn comes from a variety of sources, and the result is rated as medium on a five-point Likert scale. Interestingly, when students were asked about their interest in STEM games, they showed high interest (M = 4.05, SD = 0.826). This suggests that STEM is an area that students find intriguing, and when incorporated into games, it significantly increases their interest and motivation to learn.

In addition to the quantitative analyses, the qualitative analysis of the responses to the open-ended questions also yielded positive feedback, indicating increased students' interest in learning. In particular, 50.93% of players found the games an effective way to deepen and practice their knowledge. In addition, 56.61% of players felt that the lessons organized with gamification and game-based learning methods were lively and engaging. Remarkably, 100% of players expressed a desire to participate in the games 2 to 3 times within a class, showing their enthusiasm and desire to continue experiencing these learning methods.

The Results of Students' Cognitive Learning Outcomes

We conducted a paired samples t-test to evaluate the impact of the board games on students' test scores. There was a statistically significant increase from before playing games (M = 4.76, SD = 1.79) to after playing games (M = 8.19, SD = 1.97), t(20) = -6.492, p < .001 (two-tailed). The mean increase in WPECT scores was 3.43, with a 95% confidence interval from 2.33. to 4.53. The eta squared statistics (.678) indicated a moderate effect size. These findings underscore the effectiveness of board games from a cognitive perspective. The results proved that board games could transform STEM education to enhance students' learning outcomes.

CONCLUSIONS

Educational games have demonstrated their crucial role in improving student learning outcomes and stimulating learner interest and motivation. This study developed four board games based on the EPDPE process and focused on practice and challenge-based STEM educational activities. The four board games were designed to meet the objectives required by the science education curriculum, particularly in Vietnam. The study's results confirmed that the game development process and the quality of the board games met the program's objectives. The questions in the games increased competition among the students by asking them to compete against each other, creating excitement among the learners. This competition helped students improve their discussions and collaboration in solving problems that arose during the lessons.

While most current board games have rules and design ideas that can be used as substitutes for various academic content, the board games in this study highlighted the characteristics of STEM education as a transformation of STEM education. They appeared to be specific to STEM education. Practicality and the EDP were emphasized and integrated into the game design. When playing the games, students had to solve tasks related to real-world contexts, such as in the Mystery of Motion game, which included many local events on the board game map. The EDP was reflected in the practical context in which the game began, prompting them to solve tasks that went through the steps of the EDP. Although the design phase in solving STEM educational tasks has not been thoroughly developed, these board games were designed to emphasize this phase. For example, in the catapult game, students had stopping points to reference or discuss the design of the catapult. The board games emphasized practical connections and allowed students to acquire the basic knowledge to perform STEM tasks and go through the necessary processes to improve their design thinking.

These board games can help teachers make STEM education more interesting and engaging. Teachers can use the board games for practice activities to help students review related STEM concepts. Questions are asked about the concepts, and teachers can act as referees, or students can take turns being referees to facilitate the game. In addition, teachers can organize activities where students experience STEM practically, from identifying real-world problems that need to be solved to solving those problems with a STEM product through STEM competencies. However, in practice, implementing these games in STEM education is time-consuming, but the challenge of lack of time is not necessarily a barrier to implementing STEM education (Wahono et al., 2021).

The study's results confirm the effectiveness of using games in the learning environment. The effectiveness of board games can be seen in promoting students' learning outcomes (cognitive perspective) and their motivation and interest in learning (emotional perspective). Researchers (e.g., Bressler & Tutwiler, 2020; Chen et al., 2021; Küçükşen Öner et al., 2024; Tsai et al., 2020) also came to similar conclusions about the effectiveness of board games in improving students' academic knowledge and motivation. The way players interact can also promote collaboration between students. Some games we develop can also be used outside the classroom, e.g., in extracurricular activities or at home. This also helps to improve students' communication skills. The EPDPE process and the games developed can be widely used in classrooms to transform STEM education and create an engaging and exciting learning environment.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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