Examining the Efficacy of a Physical Board Game for Geometric Transformations

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Abstract: A group of Hong Kong secondary school mathematics teachers collaborated on the creation of a physical board game, "War of Transformation", specifically designed to aid Hong Kong Secondary 1 students in applying transformation (i.e. translation, reflection, and rotation) of 2D figures, a topic in the local mathematics curriculum. The objective of the study was to delve into the game design and player experience from the viewpoint of the students as indicators of the effectiveness of the board game, comparing these elements across different abilities. A mixed-method design was adopted, from which data was gathered utilizing questionnaires and a focus group. The study involved a total of 102 junior form students secondary school students from three districts in Hong Kong, with a selected group of five students and three school teachers participating in interviews. The questions for the questionnaire and interviews were derived from the Model for the Evaluation of Educational Games. Quantitative data were used to provide an overview of student experiences, while qualitative data from the interviews provided further insights of the results. The findings revealed that students valued the game's design and had a positive gaming experience, comparing these elements across different abilities The design of the board and the use of online teaching aids were found to significantly enhance gameplay and learning. This study highlights the potential of thoughtfully designed game-based learning in fostering effective and engaging learning experiences.

Keywords: Game-based Learning, Board Game, Geometry, Student Motivation, MEEGA+

1. Introduction

Mathematics is an essential subject, providing the foundation for many professional fields such as artificial intelligence and business. It is also vital in solving everyday life problems. However, there is a concerning decrease in the proportion of students who are willing to pursue more advanced study in mathematics. According to the Hong Kong Examinations and Assessment Authority (2023) report, the proportion of candidates who took the optional extension part of mathematics examinations [1]decreased from 22% in 2012 to 15% in 2023. There is also an alarming mismatch between competence and interest in mathematics. Despite Hong Kong students demonstrating mathematical competence above the international average, their interest in mathematics is relatively low in the context of a high-stake examination-oriented culture in Hong Kong (李鎮揚 & 霍秉坤, 2022). These two observations highlight the need to look for ways to arouse students' interest in learning mathematics.

2. Literature Review

Geometric transformations are fundamental to the field of mathematics and involve mapping points on a plane in a one-to-one and onto manner (Junius, 2002). Each point on a plane undergoes a specific transformation (i.e. translation, reflection or rotation) mapping it to a new position from its original location. These transformations are not just mathematical operations, but they also connect various areas of mathematics. They are intertwined with other geometric concepts like similarity and congruence and extend to other areas of mathematics such as algebra, patterns, and functions. Moreover, they play a crucial role in mathematical reasoning (Uygun & Akyüz, 2019).

In secondary education, geometric transformations are also significant. They provide a practical way for students to begin grappling with abstract mathematical concepts. Geometric transformations can be represented

[1] The Hong Kong Diploma of Secondary Education Examination includes Mathematics as a compulsory subject for all candidates. The Extended Parts, which are separate subjects from the compulsory one, are optional for students who want to further study or work in related areas. The Extended Part offers two modules, namely Module 1 (M1): Calculus and Statistics, and Module 2 (M2): Algebra and Calculus.

algebraically, helping students make connections between geometry and algebra. They also deepen students' understanding of the concept of a function, considering transformations as functions that take points in the plane as inputs and generate other points as outputs. Geometric transformations can be represented algebraically. For example, a reflection over the y-axis can be represented as the transformation (x, y) -> (-x, y).

Traditional mathematics education often involves assigning exercises to help students review and apply mathematical concepts. However, such learning activities may unintentionally decrease students' motivation (Schukajlow et al., 2017), presenting a significant challenge in mathematics education. A positive correlation has been observed between learning motivation and academic achievement in Hong Kong (Cheung, 1988). Therefore, alternative pedagogical approaches that maintain student motivation while support student learning are desired.

Game-based learning (GBL) is a pedagogical approach that uses games to support student learning. Game-based learning can take many different forms, including board games, online games and Virtual Reality. Board games were widely used in mathematics education, such as in South Africa, Greek, and Indonesia. GBL has also widely contributed to mathematics in different aspects such as geometry, arithmetic, mathematical reasoning, and statistics. Trajkovik et al. (2018) stated that their outdoor game, a form of game-based learning, enhanced Macedonian primary students' motivation and academic results compared to traditional teaching methods. Besides knowledge and motivation, Garris et al. (2002) found that GBL enhances students' motor skills, strategic knowledge and attitude. As such, GBL remains a promising pedagogical approach in mathematics education to promote students' affect and academic success.

Solihatun et al. (2019)'s study highlights the challenges that students face in narrative tests in geometry, such as explaining and determining the circumference and area of squares, rectangles, and triangles. The use of board games in teaching geometry could provide an interactive and engaging method for students to develop their problem-solving skills and overcome these challenges through e.g. visualizing abstract concepts using real objects. Meanwhile, Achor et al. (2010) highlights the importance of the teaching method employed in academic achievement in geometry learning. Their finding supports the use of board games in teaching geometry as a promising alternative to traditional teaching methods. Moreover, Ketamo (2003)'s study demonstrates the effectiveness of developing a geometry learning game that adapts to the user's behavior, which produced good academic results among Finnish preschool students. This finding suggests that handheld devices and simple adaptation systems have the potential to enhance the learning experience for students. The existing body of research underscores the effectiveness of Game-Based Learning (GBL) as a powerful method for teaching geometry. However, a notable gap exists: most studies have predominantly focused on online games, leaving physical board games relatively unexplored. At the same time, GBL in either online or physical form should have similar outcomes (Debrenti, 2024). This study seeks to address this gap by providing valuable research data for educators and game developers alike. Specifically, it sheds light on the effectiveness of GBL from a user's perspective with both quantitative and qualitative data.

This study makes three key contributions. Firstly, it introduces a physical, hands-on board game that helps students apply geometric transformations. Secondly, the study examines the effectiveness of the board game across diverse student groups representing different mathematical abilities in three Hong Kong secondary schools. Finally, investigate students with different abilities respond to the use of GBL and the associated factors. The primary objective of the study is to investigate the effectiveness of the board game in terms of board game design and students' experience. This can verify the potential of board games as an educational tool.

3. Methods

The board game developed aimed at helping secondary junior form students and their families strengthen essential transformation concepts. This innovative board game underwent rigorous pilot within a Hong Kong secondary school. Building upon this pilot work, our study aimed to evaluate the effectiveness and quality of the game using the Model for the Evaluation of Educational Games (MEEGA+; Petri, 2018).

MEEGA+ is an adaptation of the original MEEGA model, specifically designed to evaluate computer-based educational games. Although its primary focus is digital education, two crucial quality factors, usability and player experience, remain highly relevant across different gaming contexts.

Player experience encompasses several dimensions, including attention, engaging challenges, social interaction, confidence-building, relevance, satisfaction, and perceived learning. These factors contribute to a holistic gaming experience. Usability evaluates the effectiveness and efficiency of the board game. Perceived learning

embodies the notion of transformation, which includes aspects like translation, reflection, and rotation in this study.

Our study extends the model's application beyond its original scope in mathematics education. We aim not only to gauge the perceived effectiveness of game-based learning but also to measure cognitive learning outcomes. Specifically, we assess students' perceived performance on transformations of 2D figures within a coordinate system involving translation, reflection, and rotation. Our investigation aligns with MEEGA+'s quality factors and is guided by two research questions:

RQ1: Is the board game designed to ensure usability learning experiences?

RQ2: Does the board game foster a positive player experience?

3.1 Game Design

The board game was co-developed by a group of local secondary school mathematics teachers in Hong Kong. The main purpose of "War of Transformations" is to promote geometric exploration. Designed for four players, this game unfolds on a 100 cm x 100 cm board (refer to Figure 1). Four hint cards about the movement of the piece are provided (Figure 2) for each player. Each player wields a set of numbered pieces, ranging from 1 to 9 (see Figure 1). Before the game commences, players strategically select six pieces, ensuring that the sum of their chosen numbers totals 23.

Figure 1: The Game Board

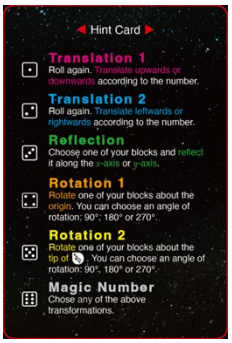

Figure 2: The Hint Card

Game Setup: Piece Placement: The dice roll determines the order in which players place their pieces. Sequentially, they take turns positioning their pieces on the board until all available spaces are filled. If no room remains, players can rearrange their already-placed pieces.

Movement Options: Once the game begins, players roll the dice to dictate their piece movements. The following options come into play:

- Translation (Up/Down): Roll the dice again to determine the number of squares to move.
- Reflection (Across the Reflection Axis): Reflect the piece along the specified axis on the board.

- Rotation (Around the Center of Rotation): Rotate the piece using the indicated centre point.
- Translation (Left/Right): Roll the dice again to determine the lateral movement.
- Reflection (Along Another Axis): Reflect the piece anew.
- Rotation (Centered at the Board's Center): Execute a rotation around the board's midpoint.

Figure 3 illustrates two examples of translation.

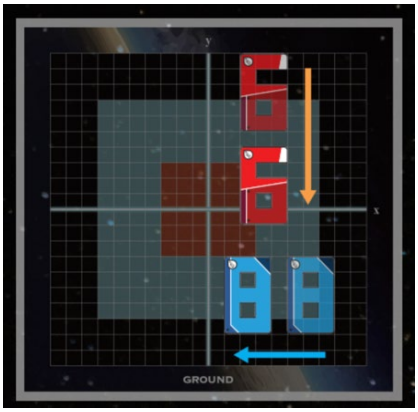

Figure 3: Examples of Valid Translations

Overlapping Pieces: When a player's piece overlaps with their opponent's, they can remove the opponent's overlapped piece.

Endgame Conditions: The game ends in one of two ways, whichever comes first: (1) Last Piece Standing: If only one piece remains on the board; and (2) Time Limit: The game has lasted for 10 minutes.

Scoring and Winning condition: When the game ends, players calculate their scores based on the pieces they removed. Each piece's score corresponds to the number it represents. The player with the highest score claims victory. Should multiple players tie for the highest score, they all win the game.

3.2 Other Game Resource

Some students may experience difficulty executing the movement of the pieces. To resolve this, the research team has developed a GeoGebra lesson activity (Figure 4) to assist students in verifying the correctness of their movements. This tool makes a significant contribution to the game, serving as a valuable aid for students to check their validity of the moves.

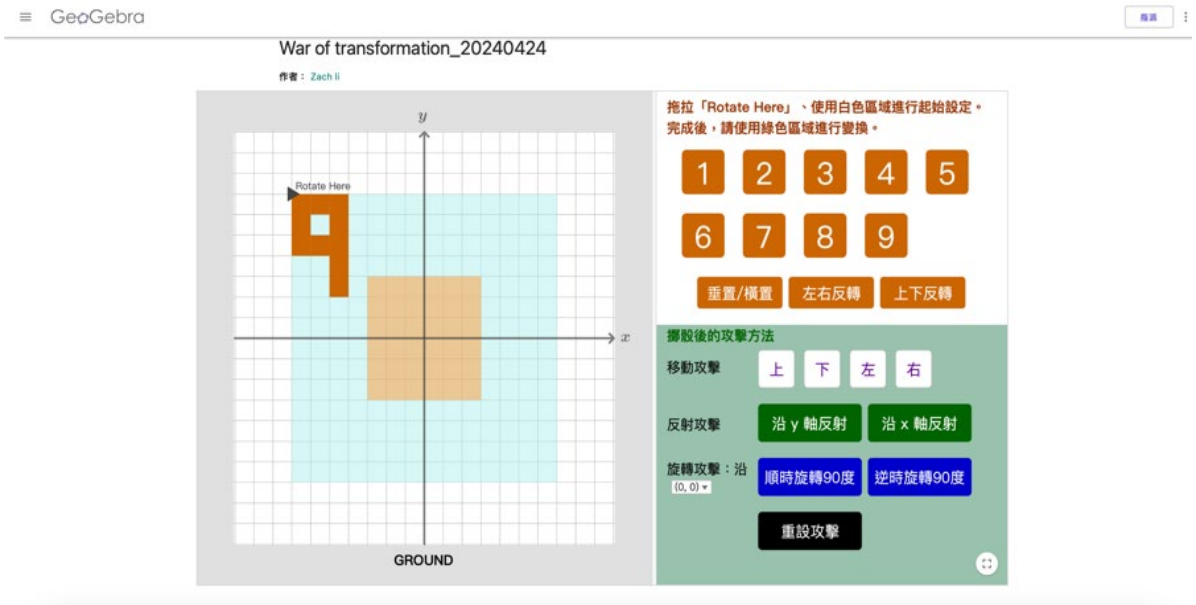

Figure 4: GeoGebra Lesson Activity

3.3 Research Design

The study was carried out in three Hong Kong public secondary schools, with 112 S1 and S3 student who are voluntary participants aged between 12 to 15. As part of the research procedures, these students engaged in the "War of Transformation" game at least thrice after school hours. After gameplay, they were asked to complete a questionnaire, and five students were randomly selected for an interview which prompted their perceptions of the board game. Schools A, B, and C are all mixed gender schools. According to public examination and intake results, School A excels in mathematics, School B shows average performance, and School C has lower mathematical abilities.

The study aimed to explore the effectiveness of the board game in terms of board game design and students' experience. The research methodology adopted is a mixed-method approach, encompassing questionnaires and interviews. The study aims to shed light on the students' perceived mathematical learning, motivation, and skills upon engaging with the board game.

The questionnaire is divided into three sections. The first section gathers demographic data, including school, age and gender. The second and third sections address RQ1 and RQ2 respectively (add RQ3 correspondingly), and utilizes the MEEGA+KIDs self-assessment questionnaire (Petri, 2018) to gauge student perceptions of the educational board game. Despite its development based on MEEGA+, targeting computer education, the questionnaire serves as a general framework for evaluating educational board games. The second section comprises a series of five-point Likert scale questions, ranging from strongly disagree to strongly agree, and includes 9 items and 23 items related to usability and player experience domains, respectively.

The focus group discussion questions were also developed from MEEGA+KIDs self-assessment questionnaire (Petri, 2018). It included 5 and 10 items related to usability and player experience domains, respectively. Five students were randomly selected.

3.4 Data Analysis

Inductive approach was adapted in this study. After the interview questions were designed, a codebook was created to facilitate the analysis of the interview transcripts. The coding process established a hierarchical structure of factors, including overarching themes and their corresponding subthemes. The initial set of subthemes was based on a review of relevant existing literature. For each code in the codebook, illustrative examples were provided from the interview transcripts to support the analysis.

The quantitative data derived from questionnaire served as supplementary information in support of the interview data. The mean scores of all items by each student within the same domain were computed. This mean score represented the students' attitudes towards that domain, with a range from 5 (Strongly Agree) to 1 (Strongly Disagree). As for the qualitative data obtained from the focus group, all data were transcribed. This transcribed data served as in-depth information for each domain.

4. Results and Discussion

Table 1 summarizes the demographic information drawn from the questionnaire.

Table 1: Demographic Information of Participants from the questionnaire

Demographics	School A (n = 32)		School B (n = 68)		School C (n = 12)	
	n	%	*n*	%	*n*	%
Age						
12 years old	12	37.5%	30	44.1%	0	0%
13 years old	20	62.5%	35	51.5%	1	8.3%
14 years old	0	0%	3	4.4%	9	75%
15 years old	0	0%	0	0%	2	16.7%
Gender						
Male	13	40.6%	41	60.2%	5	41.7%
Female	19	59.4%	27	39.8%	7	58.3%

4.1 RQ1: Is the Board Game Well-designed, Ensuring Usability Learning Experiences?

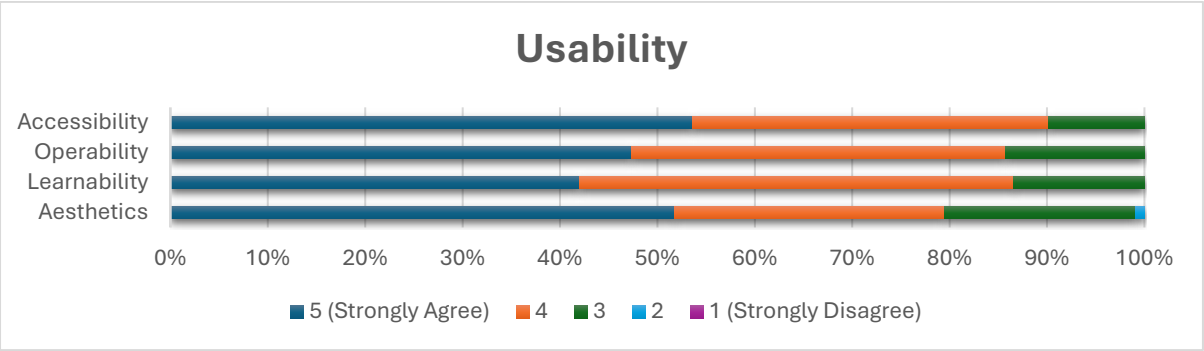

Figure 5: Perception towards the boardgame in the domain of Usability

The data generally indicates a positive perception among students towards the board game design. A large proportion of students strongly agree in the area of accessibility (90%), operability (86%), and learnability (87%). While the game is well-designed in these areas, there are also opportunities for improvement. For instance, in the area of aesthetics, one student disagreed with the aesthetic design, and several others remained neutral on this aspect when comparing it to other themes. All three schools are similar in their distribution of learning experiences across all domains.

4.1.1 Aesthetics

A majority of the students agreed that the game's design is appealing. This includes various elements such as the interface, graphics, cards, and boards. Furthermore, the students found the text font and colors to be harmoniously blended and consistent throughout the game.

4.1.2 Learnability

Most of the students concurred that they needed to acquire certain prior knowledge, specifically in the transformation of figures, to effectively engage with the game. The rotation aspect was particularly emphasized. The students agreed that the preparatory activities provided by the GeoGebra lesson activity were beneficial in this regard. Furthermore, the game's accessibility and learnability, which were positively noted by approximately 80% of the students, facilitated a quick understanding of the gameplay for most individuals. According to the School C teacher, the IT software initially assisted students with assessment, and used iPads to help them with their thinking. However, by the later stage, students no longer needed to use the iPad to assist with their thinking.

4.1.3 Operability

A significant proportion of students concurred that the game was easy to play, attributing this ease to the clarity and simplicity of the game rules. An accessory of the game, the "Hint Card", was noted to be particularly helpful. It served as a reminder to students about the correlation between the faces of the dice and the type of transformation that would occur.

4.1.4 Accessibility

A considerable percentage of students concurred that the game's typography, both in terms of size and style, was easy to read. Additionally, they found the color scheme used in the game to be meaningful. In particular, the color of the game board was noted to facilitate movement, especially in rotation. These findings suggest that the game's design not only meets accessibility expectations but also significantly contributes to the gameplay experience.

4.2 RQ2: Does the Board Game Foster a Positive Player Experience?

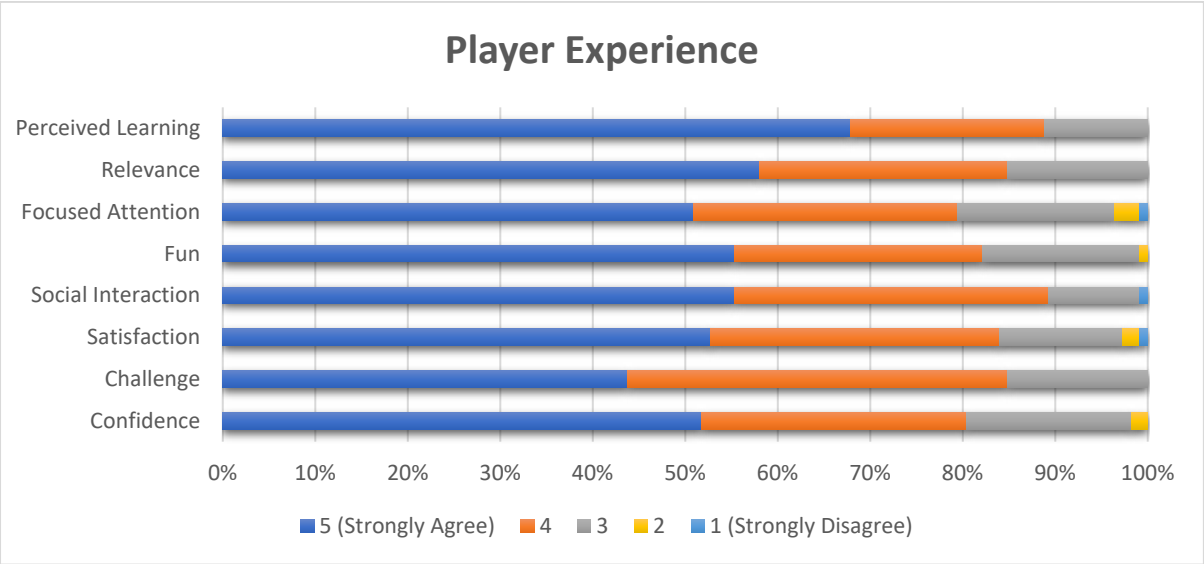

Figure 6: Perception towards the boardgame in the domain of Player Experience

The data generally indicates a positive perception among students towards the player experience of the board game. The game particularly excels in areas such as challenge, social interaction and relevance with a majority of students expressing strong agreement on these aspects. While the game is well-designed in these areas, there are also opportunities for improvement. For instance, in the areas of confidence, satisfaction, fun, and focused attention and Perceived Learning. Similar results are observed among all three schools in their distribution of learning experiences across all domains.

4.2.1 Confidence

Most students concurred that the game's content and structure enhanced their confidence in their learning capabilities. However, it was noted that a few students encountered difficulties in discerning the results, which subsequently impacted their confidence in playing the board game. Only 2 students from School A expressed low confidence in playing the board game. Triangulating from the teacher' interview, we speculate one possible reason is that School A provided less guidance for students compared to School B and School C.

4.2.2 Challenge

The majority of students concurred that the game posed an appropriate level of challenge for them. They appreciated that the game introduced new challenges and variations at a pace that was manageable and engaging. One educational institution implemented a scaffolding approach to gameplay, introducing students first to translations, followed by rotations, and finally reflections. Importantly, students also noted that the game did not become monotonous as it progressed, avoiding repetitive or boring tasks, which contributed to sustained interest and engagement.

4.2.3 Satisfaction

A significant majority expressed a high level of satisfaction derived from the completion of game tasks. This satisfaction was attributed to the sense of accomplishment experienced upon task completion. Furthermore, the students believed that their personal efforts were instrumental in their progression within the game. An additional aspect of the game that was highly valued by the students was its educational component. They expressed satisfaction with the knowledge and skills they acquired through gameplay. Based on these positive experiences, the students indicated a strong inclination to recommend this game to their peers. These findings suggest that the game effectively fosters a sense of achievement, encourages personal effort, and provides a satisfying learning experience, making it a valuable educational tool.

4.2.4 Social Interaction

A high percentage of students concurred on the positive impact of player interaction. They reported being able to engage with other players during the game, which significantly enhanced their gaming experience. The design of the game was found to foster both cooperation and competition among players, contributing to a dynamic and engaging social environment. Furthermore, students reported positive emotions associated with player interaction, indicating that the social aspect of the game was not only functional but also enjoyable. During the interview, the teachers communicated that the students were not actively moving their own game pieces; they were happy to provide suggestions and strategic recommendations to the players who were taking their turns. They were constantly thinking and discussing ways to persuade their opponents, in order to avoid having their own pieces captured. Regardless of whether they were actively participating or observing, the students maintained an engaged focus on strategizing and deliberating throughout the gameplay. One student commented how other players corrected the movement of the pieces; he learned from them. This aligns with Hwang et al. (2014)s' perception of peer assessment-based game development as an effective learning strategy. Moreover, when other players rectified the movement, they did not experience frustration; instead, they perceived it as part of the gaming process. This perception contributed to what is known as 'graceful failure.' Graceful failure refers to the ability of students to manage failures or errors in a manner that minimizes their impact on academic performance. This observation supports the notion that engaging in games that encourage risk-taking and exploration can mitigate the repercussions of failure (Hoffman & Nadelson, 2010). Such an attitude is crucial for students to achieve success in learning transformation.

4.2.5 Fun

A majority of students agreed that they had a positive and enjoyable experience with the game. The students expressed that they had fun while playing the game, indicating that the game was successful in creating an engaging and entertaining environment. According to the teacher interview, this student also made a lot of noise while playing and stood up to try and teach the other participants. Only one student from School B did not agree that the game was fun. Furthermore, the students noted specific instances during gameplay, such as certain game elements or competitive aspects, that elicited positive emotions, particularly happiness. However, a few students may still feel disengaged. One possible reason could be that the game requires prerequisite knowledge for transformation. If students lack this knowledge, they may not be able to fully enjoy the game.

4.2.6 Focused Attention

A significant proportion of students reported that the game successfully captured their attention right from the outset. They found elements of the game particularly interesting, which served as a strong hook for their engagement. Moreover, students reported a high degree of immersion in their gaming tasks, often to the point of losing track of time. This intense involvement suggests a profound engagement with the game. Many students also reported a sense of detachment from their immediate surroundings while engaged in the game. Only 3 students from School A and 1 student from School C agreed that they did not maintain focused attention during the game. According to Flow Theory, motivation peaks when individuals encounter challenges that are above average and perform at a skill level that is also above average. This phenomenon appears to resemble a state of flow. The state of flow has been positively correlated with academic performance (Chang et al., 2018). However, some students may easily lose their attention when playing the game. This could be attributed to the game's requirement for prerequisite knowledge in transformation. If students are deficient in this knowledge, their enjoyment of the game may be compromised.

4.2.7 Relevance

Most students concurred that the game's content was relevant to their interests. This relevance significantly contributed to their engagement and satisfaction with the game. Furthermore, students found a clear connection between the game's content and the transformation process, indicating that the game effectively communicated its intended learning outcomes. Moreover, students perceived the game as an adequate practice tool for the transformation process. This suggests that the game not only aligns with students' interests but also serves as an effective educational tool for facilitating understanding and practice of the transformation process.

4.2.8 Perceived Knowledge

In terms of knowledge acquisition, most students agreed that the board game contributes to their learning about various mathematical transformations, including translation, reflection and rotation. This finding aligns with the study by Moral-Sánchez et al. (2022), which suggests that game-based learning has a positive impact on learning geometry in secondary school. The content of the game was found to be well-aligned with the course objectives, thereby enhancing the relevance and applicability of the game in an educational context. Moreover, the teaching strategies employed within the game were reported to facilitate the understanding of the acquired knowledge. The practical opportunities provided by the game were also acknowledged for their role in enhancing learning outcomes.

Concerning skill development, the game was not only beneficial in terms of knowledge acquisition but also in the development of various skills. Students reported that the game helped them enhance their problem-solving abilities, a critical skill in many areas of life and study. The game's design and structure were found to promote communication skills, strategic thinking, and problem-solving abilities. These skills are not only valuable in the context of the game but also transferable to other areas of the students' academic and personal lives. Furthermore, the presage variable of academic motivation and the process variable of learning engagement positively affect the product variable of transferable skill development, respectively. This dual focus on knowledge and skill development underscores the game's potential as a comprehensive educational tool.

Overall, students with different prior knowledge level needed different preparation for the game and personalized feedback to successfully perform transformation of the pieces during the game. It is suggested that future research may further examine the types of preparation and personalized feedback to accommodate students' gaming and learning experience with varying backgrounds.

In short, this study emphasizes the value of physical board games in transformation and bridges the gap between theory and practice. Educators can leverage these findings to create engaging learning experiences that resonate with students from diverse backgrounds. Specifically, it sheds light on selecting diverse games for educational purposes and encourages the creation of new physical board games tailored to geometry learning.

The scope of this research was confined to a limited number of schools due to the resources available to the researchers. Consequently, the applicability of the findings to other school environments may be limited. Therefore, future studies should involve a larger number of schools to enhance the generalizability of the findings. As only perceived learning was investigated through a questionnaire, additional more objective quantitative methods should be incorporated to further explore the effectiveness of student learning, such as using an experimental pre-post test design.

5. Conclusion

In conclusion, this research has effectively verified a physical board game, "War of Transformation", as a novel method for learning, applying, and engaging in geometric transformation. The results align with the majority of GBL studies, which focus on online games. However, the physical game places importance on student face-to-face and immediate interaction, playing a pivotal role in facilitating peer feedback and enabling graceful failure. A significant number of students concurred that the game was well-structured and offered a positive player experience, particularly in learning transformation. The study further supported that the use of teaching aids and thoughtful board design can augment students' learning experiences. It is suggested that more educational institutions can adopt this strategy to contribute to the widespread adoption of this innovative learning approach. This study highlights the potential of meticulously designed educational games in fostering effective and engaging learning experiences.

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