How Effective is Game Based Learning for Teaching Graph Theory Concepts? :

A Case Study of the Treasure Hunt Game

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***Abstract*— This study aims to assess the efficacy of game-based learning strategies versus conventional learning techniques in teaching complex subjects such as graph theory. The Treasure Hunt game is showcased as a practical example of a game-based learning strategy designed to impart graph theory concepts in a fun and captivating manner. The paper explores the benefits and drawbacks of each method and analyzes how they can be combined to create a more effective learning experience. A detailed description of the Treasure Hunt game and its design is provided, as well as the graph theory concepts incorporated into the game. The results of a user study conducted to evaluate the game's effectiveness in teaching graph theory concepts to students are also presented. Overall, the paper suggests that game-based learning approaches have the potential to revolutionize education and make learning more engaging and effective for students.**

Keywords—Game-based learning; Graph theory; Educational game; Effective learning; Student engagement

I. INTRODUCTION

As technology continues to advance, new and innovative methods of teaching and learning are emerging, with gaming being one of the prominent approaches. While traditional learning methods have been used for centuries, they often suffer from being tedious and unengaging, leading to a lack of interest and motivation among students [1]. In contrast, games offer a fun and interactive way to learn complex concepts, which can be particularly beneficial for younger generations who are more familiar with technology.

Teaching and learning graph theory present unique challenges due to its focus on the study of graphs and their properties, making it a distinct branch of mathematics. Its abstract concepts and complex algorithms can make it difficult for students to grasp and apply effectively [2]. However, the emergence of game-based learning approaches has opened up new possibilities for teaching graph theory concepts in a fun and interactive manner.

This paper focuses on exploring the effectiveness of game-based learning approaches compared to traditional learning methods, specifically within the context of teaching graph theory concepts. By examining the benefits and drawbacks of each approach, we aim to analyze how they can be combined to create a more effective learning experience.

One such game-based learning approach is the Treasure Hunt game, which is specifically designed to teach graph theory concepts in an engaging and interactive way. Through the use of game mechanics, players are immersed in a virtual environment where they can explore graph theory concepts, solve problems, and navigate through challenges. By incorporating elements of gameplay, the Treasure Hunt game aims to make the learning process more enjoyable and effective.

In addition to discussing the design and implementation of the Treasure Hunt game, this paper also incorporates a detailed description of the graph theory concepts integrated into the game. By aligning the game mechanics with the educational content, the game aims to provide a holistic learning experience that enhances understanding and retention of graph theory concepts.

A user study was carried out to assess the efficacy of the Treasure Hunt game in educating graph theory. The results of this study, which measured the game's impact on students' comprehension and engagement, will be presented and discussed in this paper. By analyzing the findings, we can gain insights into the potential of game-based learning approaches for revolutionizing education and making learning more engaging and effective for students [3].

Major objectives that the paper covers are:

1. Assess the effectiveness of game-based learning compared to traditional methods, specifically in teaching graph theory concepts. 2. Analyze the advantages and disadvantages of game-based learning in education. 3. Present and discuss the implementation of the Treasure Hunt game, a specific game-based learning approach for graph theory. 4. Evaluate the impact of the Treasure Hunt game on students' comprehension and engagement in learning graph theory. 5. Contribute insights into the potential of game-based learning approaches

for enhancing education and making learning more engaging and effective for students.

II. Literature Review

The literature on game-based learning suggests that it is an effective way to teach complex concepts in a fun and engaging way. This is particularly beneficial for younger generations who are more familiar with technology. Games provide a safe and interactive environment in which students can explore and experiment with different concepts and ideas. This is important because it encourages a hands-on approach to learning, which has been shown to be more effective than traditional learning methods [4].

It has been demonstrated in numerous research that game-based learning can help pupils comprehend and remember mathematical topics [5]. For instance, Tokac, Umit, Novak, Elena, and Thompson, Christopher (2019) conducted a study which demonstrated that the utilization of game-based learning resulted in a noteworthy enhancement in students' mathematics achievement when compared to traditional teaching methods [6]. Similarly, Barreto, Daisyane & Vasconcelos, Lucas & Orey, Michael. (2017) found that students who played math games showed a higher level of motivation and engagement in learning compared to those who received traditional instruction [7]. The effectiveness of using games for teaching graph theory concepts has been evaluated in several studies. By utilizing virtual reality (VR) technology, a game was developed to visually and practically illustrate the concepts of graph theory. The majority of students' survey replies made it clear that the game had a considerable impact on their comprehension of the fundamental ideas of graph theory. The students acknowledged the game's efficiency as a learning strategy for understanding graph theory and indicated a rise in interest in playing related games [8].

Not only graph theory, Games have shown to enhance the learning process in various areas of computer science education, including computer memory [9] , in the VET sector [10]. In the field of science a study was conducted whose aim was to investigate the effectiveness of instructional games in facilitating the comprehension of scientific concepts among first-grade students. The findings revealed that the teaching strategy employed by the experimental group resulted in significant and measurable improvements in the students' grasp of scientific concepts.[11]

Nevertheless, game-based learning approaches face certain limitations. One significant challenge lies in striking the right balance between creating games that are both entertaining and educational. Designing games that effectively integrate game mechanics with educational content requires careful consideration [12]. Moreover, the development of games can be time-consuming and expensive, which may hinder their widespread adoption in educational settings.

Despite these challenges, game-based learning approaches hold immense potential to revolutionize education and enhance the effectiveness and engagement of student learning. Particularly in the context of teaching complex concepts like graph theory, which can be challenging to grasp using traditional methods, game-based learning provides a promising avenue.

The Treasure Hunt game is a prime example of a game-based learning strategy intended to engage students and make learning graph theory principles fun. The subsequent section of this paper will provide a detailed description of the Treasure Hunt game and its design, shedding light on its potential in facilitating effective learning experiences.

III. Methodology

The methodology of the Treasure Hunt game, an educational and engaging game designed to teach graph theory concepts, is detailed below. The game generates a random subgraph that is always a tree, and uses the BFS shortest path algorithm to determine the shortest path between a random starting point and a random endpoint. Checkpoints in the game act as nodes, while roads or paths between the checkpoints act as edges. To progress through the game, the player must answer questions correctly at each checkpoint to receive the key to the next checkpoint. The game's scoring system awards points for correctly answered questions and deducts points for incorrect answers. If the player answers incorrectly to five questions, the game ends.

The game is developed using the Python programming language and the Pygame library. The Tiled Map Editor is used to create the city map, while vector graphics and sprites enhance the game's visual appeal. The Pygame library creates the game's graphical user interface (GUI), including the map and checkpoint pillars. Python is used to implement the game's logic.

The game incorporates various graph theory concepts, including unweighted graphs, directed graphs, trees, and graph types such as the wheel graph, complete graph, bipartite graph, bridge (cut edge), and cut vertex. The game's incorporation of these concepts provides players with an opportunity to learn and apply them, particularly the BFS shortest path algorithm. Questions generated from various domains, including general knowledge, science, math, politics, and graph theory itself, also encourage players to learn and apply concepts to progress through the game.

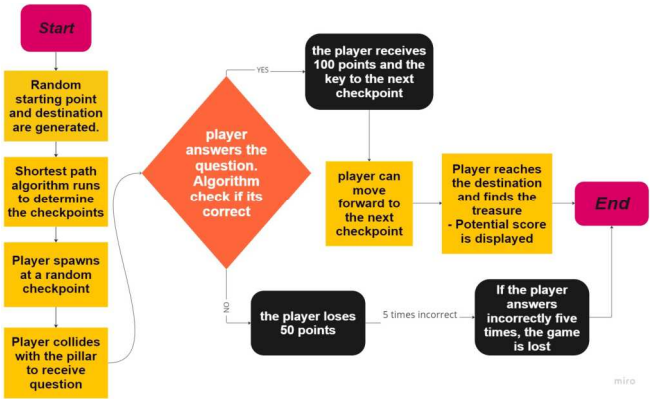

Fig. 1. Flowchart of the game

Overall, the Treasure Hunt game is designed to be an educational and engaging game that teaches players graph

theory concepts while they play. Its unique and challenging gameplay, along with its incorporation of various graph theory concepts, makes it both fun and educational. Here are some of the screenshots from the game, showcasing the game-play of the game.

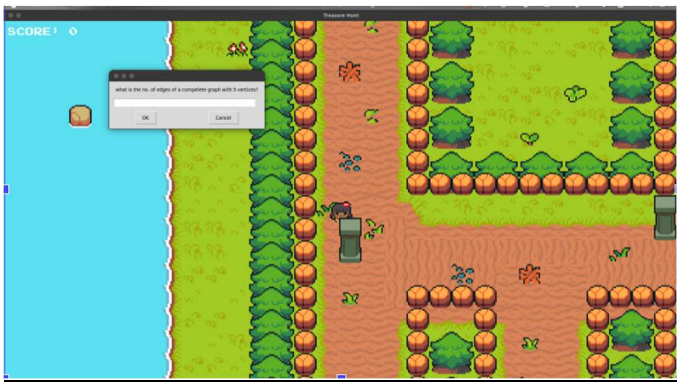

Fig. 2. Question is asked, if player doesn't know the answer he can attempt new different question

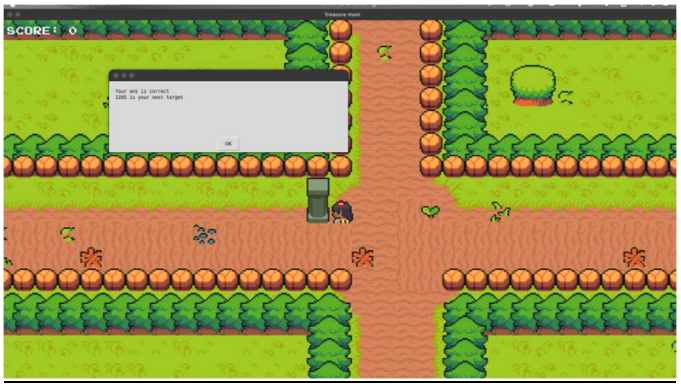

Fig. 3. Correct answer is given, the key to next checkpoint is provided upon answering the question correctly

Fig. 4. 100 points are awarded and the game continues

Figures 2 to 4 showcase the gameplay of the Treasure Hunt Game. In Fig. 2, players face a question at a checkpoint. Fig. 3 depicts the correct answer, while Fig. 4 shows the player receiving the key to the next checkpoint and earning 100 points.

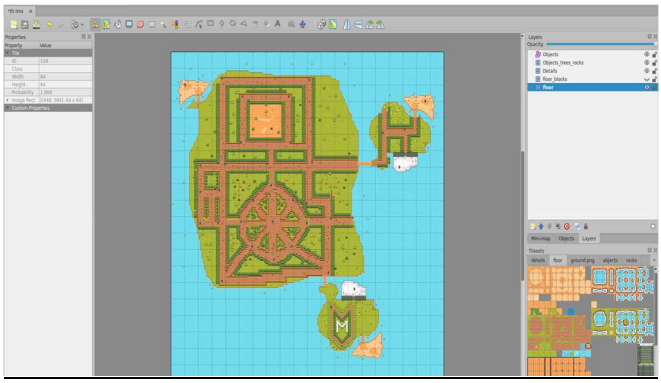

Fig. 5. Making of map using tiled map editor

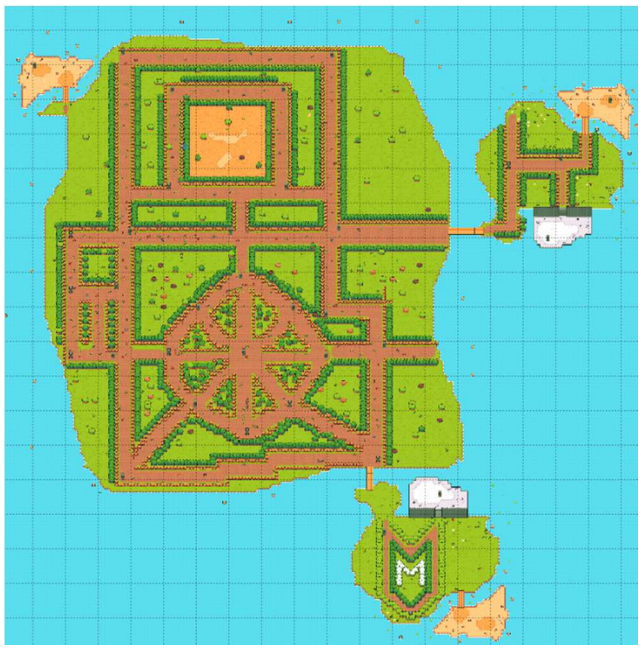

Fig. 6. Overall map of the city

IV. RESULTS

The survey aimed to investigate the effectiveness of learning through gaming versus traditional learning methods. Participants were asked if they had played the game Treasure Hunt Road, and if they had played similar games that helped them learn. The survey also included questions about motivation to learn, likelihood to recommend the game, effectiveness in understanding complex concepts, and attention span and focus while learning.

An analysis using a z-score test with a significance threshold of 0.01 was conducted on the 106 survey respondents. The findings showed a statistically significant difference between learning through conventional techniques and learning through gaming, which led to the rejection of the null hypothesis. This validates the alternative theory and points to a significant difference between the two methods.

A. Hypothesis Testing

Null hypothesis (H0): There is statistically no notable distinction between the outcomes of learning through traditional methods and learning through gaming approaches.

$$\mu = \mu_0$$

Alternative hypothesis (H1): There shows the notable difference in learning through traditional methods and through gaming methods.

$$\mu \neq \mu_0$$

Here we perform a Z-test for tested mean μ_0.

$$z = \frac{(\bar{x} - \mu_0) * \sqrt{n}}{\sigma}$$

Critical region:

$(-\infty, -2.576] \cup [2.576, \infty)$

all real numbers less than or equal to negative 2.576, excluding negative infinity, and all real numbers greater than or equal to 2.576, excluding positive infinity.

TABLE I. RESULTS OF HYPOTHESIS TEST

Details of Hypothesis Test	
Variables	***Values obtained***
Significance level (α)	0.01
Sample mean ($\bar{x}$)	8.594
Tested mean (μ_0)	5
Population standard deviation (σ)	1.0399
Sample size (n)	106

Decision:

Given the obtained Z-score value, it is statistically inferable, with a 99% level of confidence, that H0 is rejected and H1 is accepted, indicating that game-based learning may have (potential) benefits for students relative to more traditional teaching methods.

The results suggest that learning through gaming can be a valuable and effective option compared to traditional learning methods, with positive effects on different aspects of the learning experience. Further research can explore the potential benefits and limitations of using gaming for learning in various settings and for different types of learners.

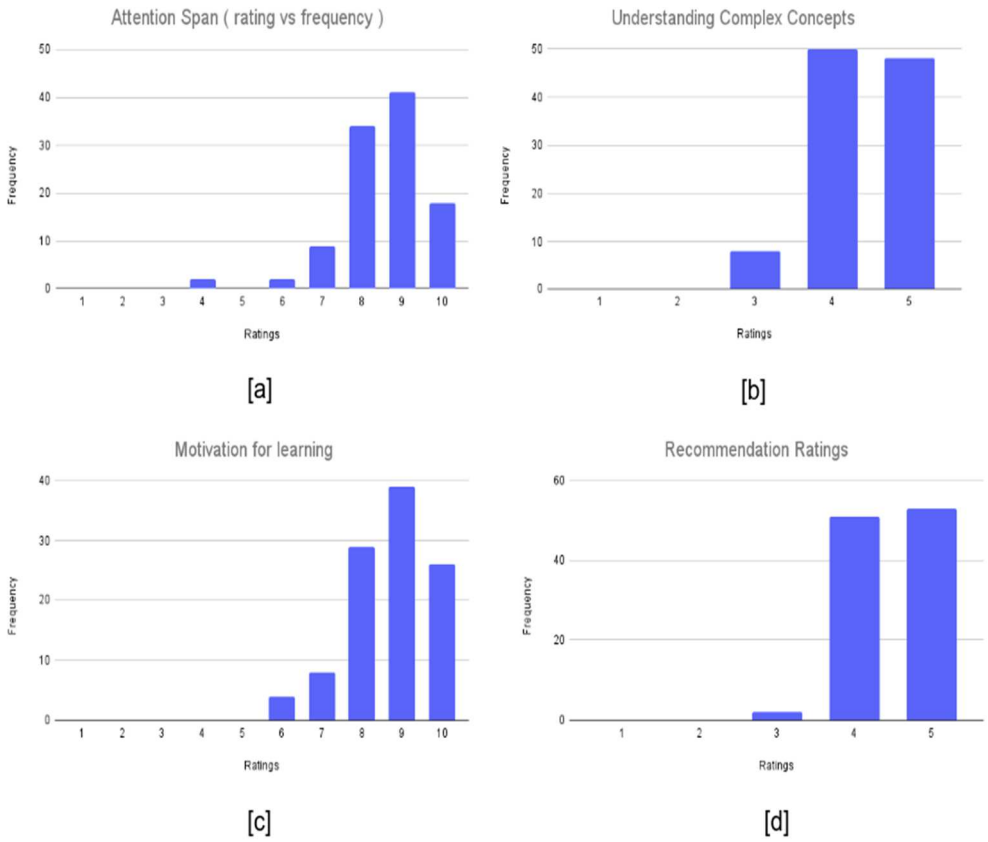

Fig. 7. Survey results of four questions to assess the efficacy of game-based learning in comparison to traditional learning methods

The efficacy of game-based learning in contrast to traditional learning methods was evaluated through a user survey consisting of four questions. The first question asked the participants to rate their attention span and focus while learning through gaming compared to traditional methods(refer figure 7a) . The second question aimed to determine the effectiveness of the game in helping the participants understand complex concepts, again compared to traditional methods (refer figure 7b). The third question asked the participants to rate their motivation to learn on a scale of 1-10, comparing game-based learning to traditional methods (refer figure 7c). Finally, the fourth question evaluated the likelihood of the participants recommending the game to someone else compared to traditional learning methods (refer figure 7d).

This indicates that participants were more motivated, more likely to recommend the game, found it more effective in understanding complex concepts, and had better attention span and focus while learning through gaming compared to traditional methods.

Based on these findings, it is known that learning through gaming can be a beneficial option instead of traditional learning methods, with positive effects on various aspects of the learning experience. Further research is required to understand the benefits and limitations of learning based on the gaming with reference to diverging set of learners as well as various different contexts.

V. DISCUSSION

A. Comparison with Previous Research

This study work stands out for putting a strong emphasis on assessing game-based learning's efficiency when used to teach graph theory ideas. While game-based learning has been studied in a variety of domains, this research focuses specifically on graph theory, a branch of mathematics that examines graphs and their features. The paper illustrates a game-based learning strategy designed to make graph theory ideas engaging and interactive by using the Treasure Hunt game as an example.

When comparing the findings with previous research, it is crucial to consider the specific context of teaching various subjects through game-based learning. While there may be limited research specifically focused on game-based learning for specific subjects, it is beneficial to examine studies related to game-based learning in general or other fields. Previous research in these areas has generally shown positive outcomes, indicating that game-based learning can enhance student engagement, motivation, and learning outcomes compared to traditional teaching methods [13-16]. By exploring the broader scope of game-based learning, we can gain insights into its effectiveness and potential benefits across different subject areas, fostering a more comprehensive understanding of its impact on education.

The results of the user study in this research paper demonstrate that learning through gaming was more effective than traditional learning methods for teaching graph theory concepts. This finding aligns with previous research that suggests game-based learning can improve student motivation, attention span, and understanding of complex concepts. By engaging students in a game-based environment, the Treasure Hunt game effectively captured their interest and provided an interactive experience that facilitated the learning of graph theory concepts.

B. Implications for Educational Practices

The implications of these results are significant for educational practices. Traditional methods of teaching graph theory often involve abstract concepts and can be challenging for students to grasp. Teachers can make learning more pleasant and approachable by incorporating game-based learning strategies, which in turn improves students' understanding and recall of graph theory ideas. The findings suggest that integrating game elements into graph theory education has the potential to enhance student engagement and motivation, which are crucial factors in successful learning outcomes.

C. Limitations of the Study and Suggestions for Further Research

Although the study produced encouraging results, it is important to understand its limitations. The user study's sample size and the demographics of its participants could be a possible restriction. The study may have involved a small group of participants from a specific educational setting, which could limit the generalizability of the findings to a broader population. Additionally, the study might have focused on a specific game, the Treasure Hunt game, and may not have considered other game-based learning approaches or variations in game design.

To address these limitations and expand the research in this area, future studies could consider larger and more diverse samples of participants from different educational backgrounds. They could also explore a variety of game-based learning approaches and designs to investigate their effectiveness in teaching graph theory concepts. Comparative studies that directly compare different game-based learning interventions with traditional methods could provide further insights into the benefits and limitations of game-based learning for graph theory education.

Furthermore, additional research could examine the long-term retention of graph theory concepts learned through game-based approaches. It would be valuable to investigate if the engagement and motivation generated by game-based learning result in improved long-term understanding and application of graph theory concepts compared to traditional methods.

VI. CONCLUSION

Based on the conducted research, it can be inferred that game-based learning surpasses traditional learning methods in terms of effectiveness when teaching graph theory concepts. The Treasure Hunt game serves as an illustrative example of an engaging and educational game that effectively imparts graph theory concepts to players as they actively participate.

The game incorporates various graph theory concepts, including unweighted graphs, directed graphs, trees, and graph types such as the wheel graph, complete graph, bipartite graph, bridge (cut edge), and cut vertex. The game's unique and challenging gameplay, along with its incorporation of various graph theory concepts, makes it both fun and educational.

To compare the effectiveness of game-based learning to conventional learning techniques, a survey was done. The survey results showed that there was a statistically substantial distinction among the two methods. Game-based learning was found to be more effective in terms of motivation, recommendation, understanding complex concepts, as well as attention span and focus during the learning process.

The findings suggest that incorporating gaming as an alternative to traditional learning methods can be effective and yield positive outcomes across different dimensions of the learning experience. There is scope for further research to explore the potential advantages and limitations of game-based learning in diverse contexts and for different learner profiles. With ongoing technological advancements, game-based learning approaches have the potential to transform education, making it more engaging and effective for students.

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