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WIP: Using Simple Board Games to Teach Complex Concepts

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Teaching Complex Concepts with Simple Board Games

Abstract

Game-based learning has been widely studied and shown to be effective at increasing student engagement and retention in K-12 and college education. However, most studies at the college level, especially in STEM fields, have involved digital games, like videogames or computer simulations, not tabletop board games. Though digital games are undoubtedly more detailed and realistic, they are also much more difficult to set up and run, take longer for the students to learn to use, and do not lead to the same quality face-to-face interactions that are a feature of board games. This study examines whether a simple board game affects engagement and retention in the same way as a more detailed digital games. A simple board game, Markopoly, was developed to demonstrate the concepts of discrete-time Markov chains (DTMCs). Students in a required junior-level course, Probabilistic Operations Research, played Markopoly in class, performed analysis using DTMCs, and completed a survey to measure their level of engagement and interest in the game. Those survey results were analyzed in conjunction with their grades on the DTMC question on the final exam, to determine if their level of engagement in the game was correlated with better grades. Finally, their responses to that final exam question was compared to those from a previous administration of the class, to determine if the game affected their retention of the material. It was found that the students' engagement in the game had a significant positive correlation with their grades on the final exam. The average score on that question was higher than last year, but the difference was not statistically significant. However, the initial results are promising, and more administrations of the course should yield more data about the value of Markopoly, and board games in general.

Introduction

Game-based learning (GBL), a learning strategy that involves embedding games into lessons to enhance learning, has been widely studied for years and shown to improve student engagement and retention of material in many contexts [1]. This field, however, has been dominated by digital games – videogames and computer simulations. These digital games are undoubtedly useful for learning. They can provide everything from a simple driving game to a detailed, immersive world in which students are able to apply the lessons they're learning in class. However, they can also be expensive and time consuming to build and difficult for students to learn. Board games, on the other hand, can be created relatively quickly and inexpensively, and can often be played successfully in a single class period or less. In addition, board games create more opportunities for face-to-face interactions than digital games, increasing engagement and reducing distractions [2]. If board games can provide the same benefits to student learning that digital games do, even when being used to teach complex engineering topics, then they could be a good alternative for those classes in which digital games are too difficult or expensive to use.

For this purpose, the board game Markopoly was designed to aid in the teaching of discrete-time Markov chains in a junior-level industrial engineering class, Probabilistic

Operations Research (POR). Markov chains represent a form of mathematics and a way of looking at the world that most of the students have never seen before, and many of them struggle with the concepts – how to use them, what the different statistics mean, and which ones to use in which situations. Markopoly was designed to help guide students through the concepts using more open-ended questions than is typical for a class assignment. Four different versions of the game were played in class by groups of two to five players, and then analysis was performed afterward for homework, either individually or in groups according to the students' preference.

Related Literature

Compared to the hundreds of works available on the use of digital games in undergraduate education, less than 30 can be found studying analog or board games [2]. Of those, only a few deal with complex STEM topics, including one examining a game about fossilization and another with a game about public health biology. Results in these studies have been overall positive, particularly in the development of soft skills such as communication or teamwork.

Some studies, such as that of Clark et al., examined the effectiveness of game design, not just game play, in improving students' learning outcomes as well as their engagement and sense of community. In a large-scale study across civil engineering courses in three universities, students were asked to design their own games, which were then played by their fellow students in class. Through classroom observations, student surveys, and focus groups, they found a positive impact on engagement and performance with technical content, but no impact on students' desire to stay in the major or sense of community [3]

Several papers exist regarding the modeling of commercially available board games using Markov chains, including Chutes and Ladders and Risk [4], [5]. However, none could be found that have studied the use of these games in a classroom and measured student outcomes. The analysis of these games is more complex than was desired for the POR class, so Markopoly was designed as a simpler alternative.

Relevant Goals and Student Learning Outcomes

Markopoly was designed to help students learn to analyze discrete time Markov chains in a more effective, engaging way, fulfilling the first Student Outcome set by the Virginia Tech Grado Department of Industrial and Systems Engineering: "At time of graduation, ISE students are expected to have an ability to identify, formula, and solve complex engineering problems by applying principles of engineering, science, and mathematics." More specifically for the POR course, two learning objectives were targeted by the game:

- Construct and analyze discrete time, discrete space Markov chains and processes.
- Analyze the transient and equilibrium behavior of real-world systems using Markov chains.

The hypothesis of this study was two-fold:

- Students would find Markopoly to be a more interesting and engaging way to demonstrate their knowledge of Markov chains than a traditional assignment.
- Increased engagement when learning the material would lead to increased grades on the relevant exam questions.

Markopoly Setup and Rules

The game board has two sides. Side A, shown in Figure 1, was used in Games 1 through 3 and consists of a loop of 24 squares, a sequence of six colors repeated four times. Though the objective was different in each game, the gameplay was mostly the same. Each game started with the players rolling a six-sided die (d6) to determine their starting square, one of six numbered squares at the bottom of the board, and placing their pawn on that square. From there, each round proceeded as follows: each color on the board corresponds to a different type of dice:

- Blue (B): 6-sided die (d6)
- Green (G): 10-sided die (d10)
- Yellow (Y): 20-sided die (d20)
- Orange (O): 4-sided die (d4)
- Red (R): 8-sided die (d8)
- Purple (P): roll a d4, move 1 space for odd numbers and 2 spaces for even numbers

Figure 1: Markopoly board, side A

They would then move their pawn the number of squares indicated on the die. In Game 1 (Basic), a player received $100 for landing on a purple square and $50 for landing on a yellow square. After eight rounds, the game ended and the player with the most money won. In Game 2 (Race to the Green), the first player to land on a green square won. In Game 3 (Chase the Rainbow), the color the player started on was called their "money color." In each subsequent round, they received $100 if they landed on their money color. At the end of eight rounds, the player with the most money won. Side B of the board, shown in Figure 2, was used in Game 4 (Slides and Stepstools). Gameplay was identical to Game 1, except that when a player ended a turn on a square at the base of an arrow, they slid down the arrow to the square at its point.

Markopoly Analysis

After each group finished playing, the winner was asked to come to the blackboard and write down their starting roll. This was used to determine which first roll seemed to give a player the best chance of winning. The students were then asked to model each version of the game as a Markov chain, find the transition probability matrix (TPM) and use the analysis they learned in class to determine which first roll actually had the highest probability of winning the game. In Games 1, 3, and 4, they were also asked to calculate the expected amount of money made by a player in a given round if the game was continued for hundreds of rounds. To answer these questions, the students first had to determine what value to calculate from those taught in class, including expected visits, mean first passage time, and steady state probabilities. They

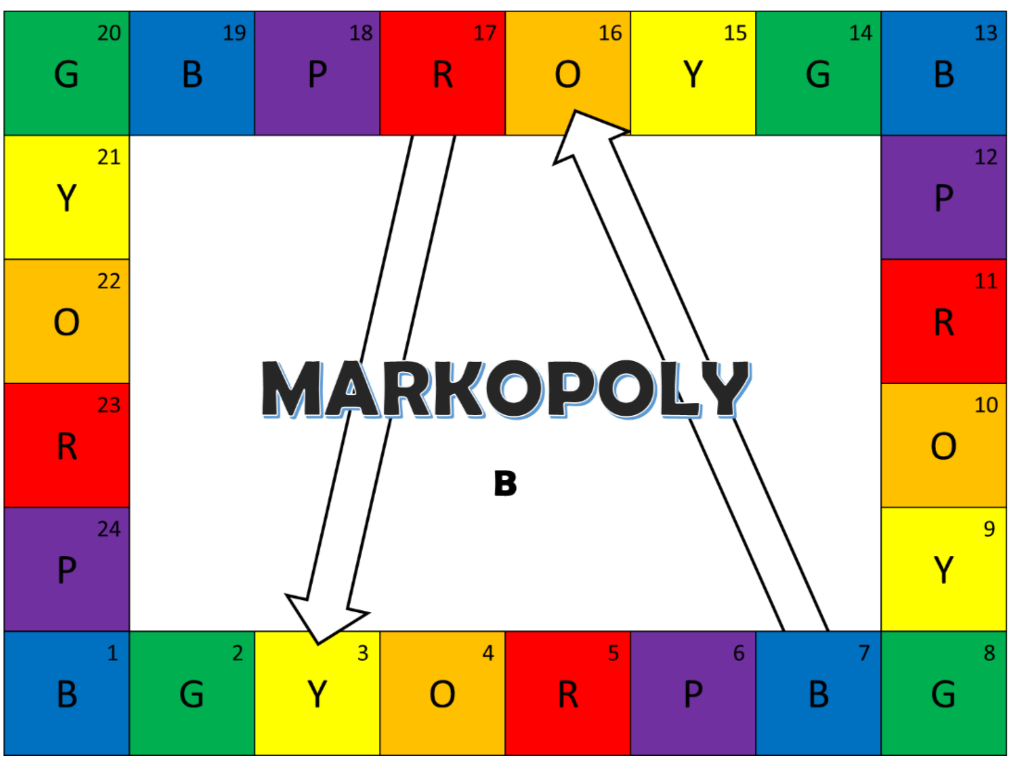

Figure 2: Markopoly board, side B

then had to perform the calculations and draw conclusions from the solutions. Those solutions were a small part of their final grade.

Gameplay and Analysis Observations

On the day the game was played, the instructor observed the students. Though the gameplay was simple, the students seemed very engaged while playing the game. They were interacting with each other in a way that they normally don't have the opportunity to do during class, and there were many conversations observed about the game, the class, and Markov chains. They seemed to find the instructions easy to follow, though there were some misunderstandings that will need to be clarified for future administrations of the class. The most common question asked of the instructor was, "How do you read a 4-sided die?" When asked informally for their opinions after the game ended, they were mostly very positive about it. They said that they enjoyed the game and playing it with each other, and that they thought the game was interesting despite the simplicity. Some specifically mentioned that they enjoyed the competitive aspect.

When the students began to work on their analysis assignment, it became clear that they struggled with the open-ended nature of the questions. In particular, they needed more guidance to determine which values they should calculate to determine the best starting roll. However, most students found the TPMs easily and were able to perform the calculations correctly once they received that guidance. The analysis also took longer for the students to complete than was originally intended for the assignment, mostly because they spent too long doing the incorrect calculations before receiving guidance.

Results

After completing the game and the analysis, the students were asked to complete a survey to measure their interest and engagement in the activity. The Usefulness and Interest portions of Brett Jones's MUSIC model, a validated survey instrument, were used with a Likert scale from 1 (Strongly Disagree) to 6 (Strongly Agree) [6]. The questions, along with the mean and standard deviation of the student responses, are as follows:

Question	Mean	Standard Deviation
The activity was beneficial to me.	4.58	0.82
The activity held my attention.	4.81	1.01
In general, the activity was useful to me.	4.53	0.84
I found the activity to be useful to my future.	4.11	0.95
I enjoyed the activity.	4.74	1.03
The knowledge I gained in this activity is important for my future.	4.17	0.89
The activity engaged me in the course.	4.97	0.87

The overall response was very positive, particularly on the Interest scale, indicating that the students found the activity engaging and enjoyable. The students' responses to the survey questions were plotted against their grades on the relevant problem on the final exam, and a two-tailed t-test was performed to determine if there was a statistically significant slope between the two, indicating that their response to the survey affected their outcome on the final exam problem. Questions 2 and 7 in particular showed a statistically significant ($\alpha = 0.05$) positive correlation with the students' grade on the Markov chain question on the final exam. Those students who found the game most engaging also appeared to derive the most benefit from it.

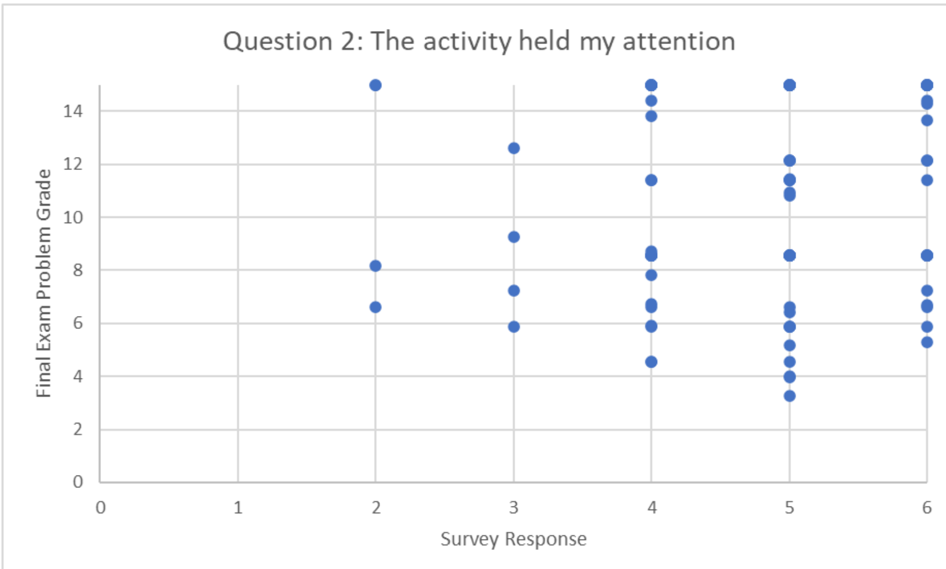

Figure 3: Response to survey Question 2 versus Final Exam Problem Grade

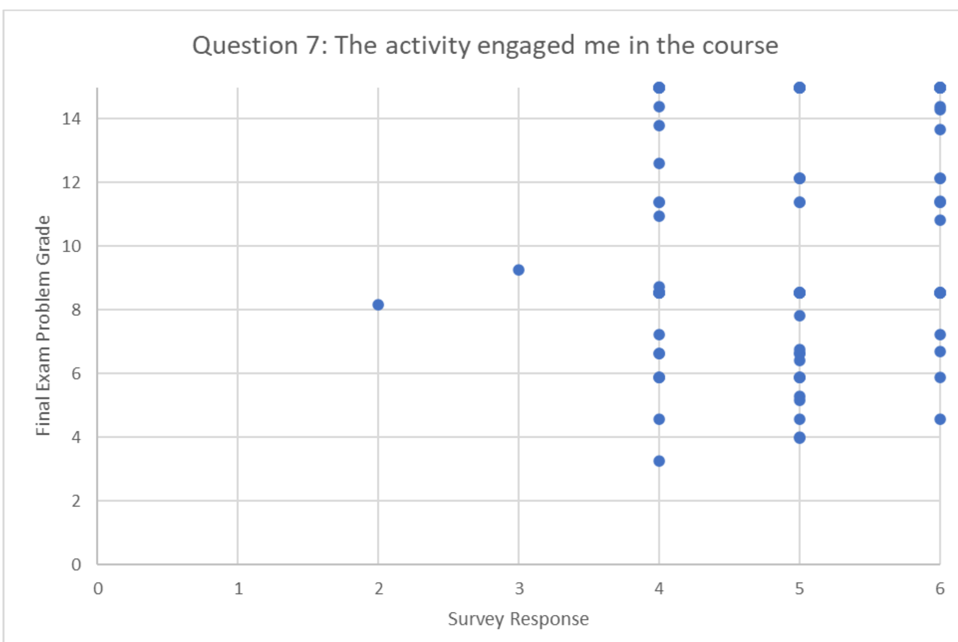

Figure 4: Response to survey Question 7 versus Final Exam Problem Grade

In addition to the survey, the grades from the Markov chain question on the 2023 final exam were compared to those on the almost-identical problem given in 2022. (See Appendix for question details.) Out of 15 possible points, the students in 2022 averaged 9.68 points with a standard deviation of 4.36. In 2023, the students averaged 10.46 points with a standard deviation of 3.69. Though the difference in grades between the two years does not rise to the level of statistical significance ($p = 0.14$), it is hoped that with more administrations of the course in the future, and therefore more data, a significant difference will be seen.

Future Changes

Overall, the Markopoly game in the Probabilistic Operations Research course was a success. However, some changes are needed for future administrations of the course. First, the students need more practice with open-ended questions prior to playing the game. Their biggest struggle was in determining what value to calculate, because they were used to being given that information. In addition, more guidance is needed before the students begin the analysis. If they were guided through the questions for one of the games, it could help them complete the rest of the exercises much more efficiently and successfully. Some students commented that the analysis was "too long," and it's possible that one or two of the questions could be removed without affecting the overall value of the game as a learning activity.

Extra Credit Games

At the end of the course, students had the opportunity to earn extra credit by creating their own board game related to a topic in the class. They were required to submit the rules, a game board design if applicable, and a sample of the analysis that could be done on the game, which had to use calculations learned in the course. A number of students submitted games, which ranged from simple dice-rolling to complex story games. Some were so well-done that they may be used in future administrations of the course to teach other topics, including conditional probability models and continuous-time Markov chains. Data from this assignment cannot be used in the current study, however, because it was offered only for extra credit. Therefore, the population that completed it is not representative of the class as a whole, and any data that could be collected from it would likely be skewed.

Conclusions

Games can be a fun and engaging way to teach complex concepts in a college-level course. However, the time and expense of designing, building, and teaching a digital game can often be too high to be feasible, especially for large courses. Even if an appropriate digital game already exists, the cost to the students and learning curve when beginning to play can be substantial. Board games, however, can be a good alternative to digital games in the classroom. They're relatively simple and inexpensive to set up, easy to learn, and fun to play during a class period. They also lead to more face-to-face interaction than digital games, which keeps players more engaged and less distracted.

When Markopoly was played in Probabilistic Operations Research, the student responses were very positive that they found the game engaging and interesting. Even putting aside any academic benefits, when students are more engaged in their classes, they are also more likely to feel a greater sense of personal well-being and connection to their community [7]. More work and data are needed to determine if Markopoly had a significant impact on their grades; however, the initial results are promising. With the overall success of Markopoly, board games will be developed for more courses in the future, including an Engineering Economy course in the spring 2024 semester. These games will be studied to determine in which courses they have the most impact, how best to incorporate learning outcomes into the games, and which aspects students find the most and least engaging.

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Appendix

Final Exam Discrete Time Markov Chain Problem:

A theme park classifies its crowd levels on any given day as busy (state 1), average (state 2), or not busy (state 3). The transitions from one state to another follow the TPM given below (the two-step TPM is also given). Today is Friday, and the theme park has average crowd levels (state 2) today.

$$P = \begin{bmatrix} 0.2 & 0.4 & 0.4 \\ 0 & 0.6 & 0.4 \\ 0.4 & 0.4 & 0.2 \end{bmatrix} \qquad P^{(2)} = \begin{bmatrix} 0.2 & 0.48 & 0.32 \\ 0.16 & 0.52 & 0.32 \\ 0.16 & 0.48 & 0.36 \end{bmatrix}$$

a. What is the probability that the park will be busy on Sunday?

b. How many days do you expect it to be before the park is busy **for the first time**?

c. How many consecutive days do you expect at average crowd levels before the park has a different crowd level?