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# Lessons and Improvements: Three Years of Using Board Games as Learning Tools in Probabilistic Operations Research

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## 1. Introduction

In large undergraduate lectures, especially in difficult math-heavy courses, it can be challenging to get the students to engage: with the instructor, with the material, and with each other. Game-based learning, the use of games or game elements in a classroom to enhance learning, has been shown to improve both student engagement and retention of material [1]. However, most prior research has been performed on digital games, like video or computer simulation games. These are able to provide detailed scenarios and complex storytelling, but they also have some downsides, especially for a classroom environment. They can be very expensive to buy, and even more expensive to create or customize. The gameplay can have a steep learning curve for many students. Finally, they do not provide the level of social interaction and communication between students that is provided by analog games [2], which can be incredibly beneficial for community-building and mental health.

Board games are also a wonderful way to illustrate concepts of probability, and were therefore a natural addition to a large junior-level Probabilistic Operations Research (POR) course. The first, Markopoly, was introduced in the fall of 2023 as a learning tool when discussing discrete-time Markov chains. The second, the Great Cave Escape, was developed by a group of students in 2023 to illustrate concepts of recursive expected value models and was first played in class in the fall of 2024. After each, the students were asked to analyze some aspect of the game as a homework assignment. After two years student feedback, it was determined that the educational aspect of the games was satisfactory, and the analysis provided adequate larger-scale examples of the concepts discussed in class. However, the enjoyment was lacking – many students simply found the games boring to play. To remedy that, an undergraduate researcher joined the project in the fall of 2025 and studied board game design. With his suggested changes implemented, the playability of the games improved greatly, as did the student response to the games. More work is still needed to further improve the games and collect more data on their effects on student learning.

## 2. Game Based Learning and Game Design

Game-based learning (GBL) attempts to improve student engagement and understanding by introducing the use of games or game elements to a class. These have generally proven to be effective across many disciplines, from the humanities to science and engineering. By making class more “fun” and providing incentives like points and achievements for completing tasks, instructors can stimulate students’ interest in the topic and encourage them to engage more with the material and the course. It’s important to note that GBL is an umbrella term that includes everything from playing virtual- and augmented-reality video games in class to including game elements into a normal class, like awarding points or achievements for completing normal course tasks [1].

Digital games have dominated the game-based learning literature, to the point that it is difficult to find any recent studies at all involving non-digital, or analog, games. In this context, an "analog" game is one in which the majority of gameplay takes place without the use of technology, though digital timers and scorekeepers may still be used. Recent systematic literature reviews have been conducted on digital games [3] and online games [4], but very little could be found about analog games. It may be that the heavy focus on digital games within the last five years has been caused in part by the move to online learning during the pandemic, and the need for new learning strategies to suit the new environment. Within the literature on digital games, student engagement and motivation have been common topics.

Though digital games have many advantages, such as the ability to model more complex systems, they also have many weaknesses as an educational tool. They are expensive and time-consuming to create, often have a steep learning curve, and are generally played alone. Even when the game is played as a group, players are often in different physical locations, communicating, if at all, with a text or voice chat. Analog games, on the other hand, are relatively inexpensive to set up and can often be played in one class period. Most importantly, they encourage face-to-face interaction among the players, which can be incredibly important for community-building and mental health. In fact, in one study of analog games and their digital equivalents, the participants overwhelmingly preferred the analog version, especially in the realm of social interaction and interpersonal communication [4]. When the goal is to encourage the students to engage not just with the material, but with each other, analog games can be a better vehicle for that than digital games.

While GBL has been widely explored, much of the existing literature emphasizes educational outcomes rather than the underlying qualities that make a game engaging to play. This distinction is critical, as a game that effectively presents instructional content but lacks meaningful engagement may fail to sustain student interest. Prior research suggests that educational games must balance learning objectives with sound game design principles in order to be effective learning tools [5].

Recent studies examining board game design provide insight into how modern games achieve this balance. Large-scale, data-driven analyses of commercial board games reveal a clear shift away from mechanics that rely heavily on randomness, such as dice rolling, toward mechanics that emphasize player agency and strategic decision-making [6]. Mechanics, including hand management, worker placement, and variable player powers, have become increasingly prevalent because they allow players to influence outcomes through planning and informed choices. Importantly, this work demonstrates that successful games are not defined by the number of mechanics they include, but by how effectively those mechanics interact to form a cohesive system [6]. Research further indicates that games with higher player ratings tend to rely on well-integrated mechanic interactions rather than increased complexity alone, reinforcing the importance of intentional system design.

In addition to individual decision-making, board games have been studied as environments for collaboration. Research on collaborative board games highlights the importance of balancing individual autonomy with shared goals, ensuring that player actions have traceable consequences, and assigning differentiated roles to encourage cooperation [7]. However, the literature also identifies design pitfalls, such as over-centralized decision-making or limited replayability, which can reduce player engagement and undermine collaborative learning experiences [7].

More recent work has begun to explore the application of board games within engineering education specifically. Studies involving purpose-built board games for engineering students demonstrate that games can support peer instruction, conceptual understanding, and reflective discussion when gameplay is explicitly aligned with learning objectives [8].

Collectively, these literatures suggests that effective educational board games must be designed with both learning outcomes and player experience in mind. Prior research establishes that board games can model complex systems, support collaboration, and foster engagement, but also emphasizes that these benefits depend on thoughtful mechanic selection and integration.

## 3. Markopoly

When Markopoly was designed, the intention was to provide a more engaging, effective way for students to learn about discrete time Markov chains than a traditional assignment. The two learning objectives of the class that were targeted with this activity were:

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

Some commercially available games were considered to fill this need, such as Chutes and Ladders and Risk. In fact, papers have been published modeling both of these as Markov chains [9], [10]. However, the analysis of these games is more complex than was desired for an undergraduate-level POR class, so Markopoly was designed as a simpler alternative. It consists of three different games played on two different game boards.

### 3.1 Markopoly Game 1: Basic

This game is played on Side A of the board (Figure 1), which consists of a loop of 24 squares with a repeating pattern of six colors: Blue, Green, Yellow, Orange, Red, and Purple.

The game begins with each player in turn choosing a color to start on and placing their pawn on the corresponding numbered square on the bottom of the board. Each pawn must be on a different square – players cannot share colors. This color will belong to that player for the rest of the game. When a pawn lands on a color belonging to another player, they give that player one coin. If a pawn lands on its own color, nothing happens. Players move around the board by rolling dice according to the color they're on, then moving their pawn the number of squares indicated, counterclockwise around the board:

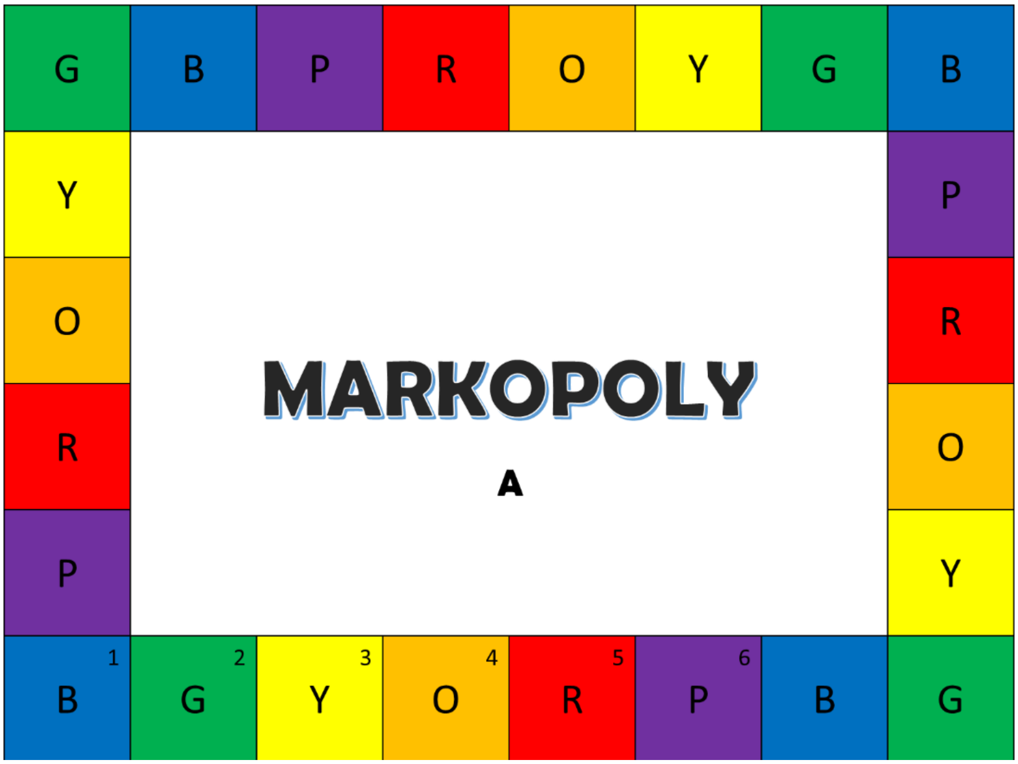


*Figure 1: Markopoly board, side A*

- 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

At the end of eight rounds, the player with the most coins wins.

After the class ends, the students are asked to model the game as a discrete time Markov chain with six states corresponding to the six colors, then calculate which starting color is the most likely to win the game.

### 3.2 Markopoly Game 2: Race to the Green

The gameplay in Game 2 is mostly the same as Game 1, but with a different objective. Players still choose their starting color, but they no longer get coins when another player lands on it. Instead, the first player to land on green wins, and the game ends. Again for the analysis, students are asked to calculate which starting color is most likely to win the game.

### 3.3 Markopoly Game 3: Slides and Stepstools

The gameplay of Game 3 is exactly the same as Game 1, but played on Side B of the board. When a player lands on squares 7 or 17, they slide down the arrow to squares 16 or 3, respectively. Because the probability of landing on each color is no longer constant, the Markov chain now must have one state for each square (22 states total, because square 7 and 17 are excluded). Therefore, the analysis of Game 3 is identical to that of Game 1, but with a 22x22 transition probability matrix instead of a 6x6.

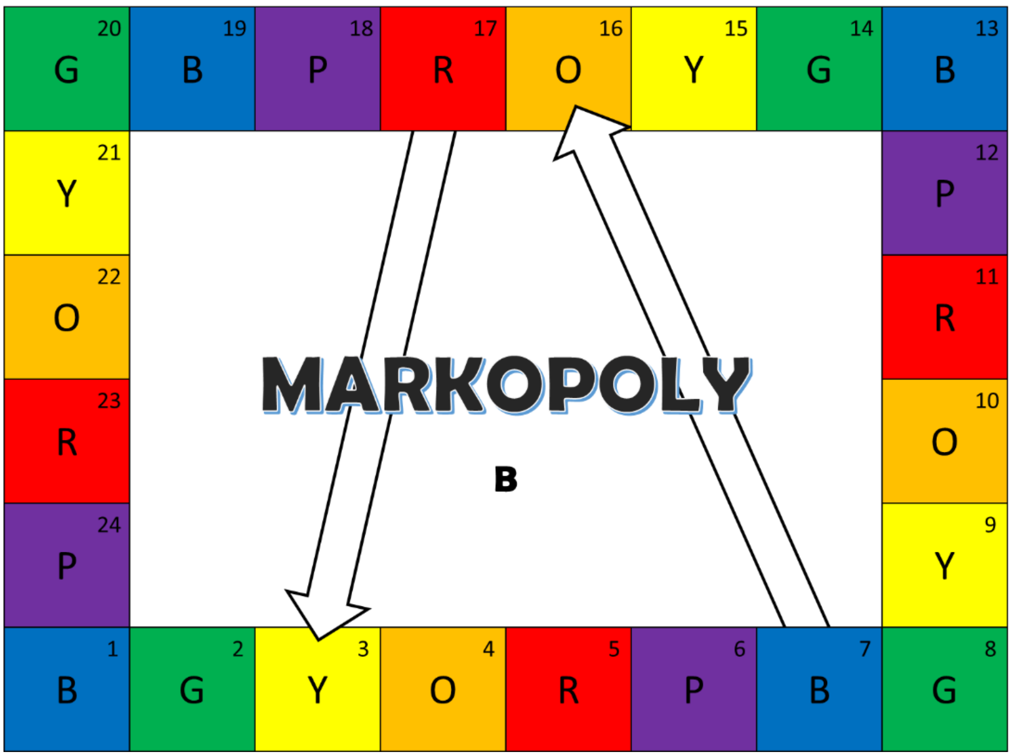


*Figure 2: Markopoly board, side B*

### 3.4 Changes for Fall 2025

In the original version of Markopoly Games 1 and 3, the players rolled a 6-sided die to determine their starting location, and earned coins by landing on purple or yellow. However, while students enjoyed the interactive nature of the game, as well as the break from the normal lectures, they complained that the players had no agency in the game. Everything was completely controlled by random rolls of the dice, and the players had no opportunity to make decisions that could affect the outcome of the game. Essentially, they felt that they were watching the game happen rather than participating in it.

Another issue with the original version is that, while the different colors did have different expected rewards, the distinction was very small (from +3.74 coins for red at the highest to +3.24 coins for purple at the lowest in Game 1, for example). When playing the game, it seemed again that random chance determined the winner, no matter their starting color.

To alleviate these issues while still keeping the random chance that allows the game to be analyzed as a Markov chain, aspects of choice were added to the beginning of the game. Now, players can choose their own starting color, and different colors have much more widely varying expected rewards in the eight rounds of gameplay (from +3.05 coins for blue at the highest to -2.44 coins for yellow at the lowest for Game 1). This allows the players to feel that they have some control over the outcome of the game, and makes the choice of starting color feel much more meaningful.

This improvement was very well received. It was mentioned several times in the student feedback, as well as verbally during the game day in class, that students liked being able to strategize what color they chose. Also, the number of complaints about the randomness of the gameplay and the lack of agency went down considerably.

### 3.5 Survey Results

After the game was played and the analysis was completed, the students were asked to complete a survey to measure their interest in and engagement with the game. 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) [11]. Unfortunately, due to some unforeseen issues with scheduling and technology, the survey for Markopoly was not able to be sent to students until the day after the semester ended. Therefore, the response rate was very low (25 responses out of 160 students). While that renders the results much less meaningful than they would be otherwise, they are still being included here for whatever insights they can provide. The questions, along with the mean and standard deviation of the student responses, are as follows ($n$ = 25):

| Question | Mean | Standard Deviation |
|---|---|---|
| The activity was beneficial to me. | 5.00 | 0.50 |
| The activity held my attention. | 5.13 | 0.88 |
| In general, the activity was useful to me. | 4.79 | 0.58 |
| I found the activity to be useful to my future. | 4.21 | 0.76 |
| I enjoyed the activity. | 5.21 | 0.87 |
| The knowledge I gained in this activity is important for my future. | 4.71 | 0.73 |

| | | |
|---|---|---|
| The activity engaged me in the course. | 5.25 | 0.72 |

*Table 1: Survey results for Markopoly game*

Though the sample size was very small, the responses were very positive, especially for the questions related to the Interest scale. Notably, these results are significantly higher than those received during the first year that Markopoly was played. For instance, the last question, "The activity engaged me in the course," had a mean of 4.97 in 2023, and a mean of 5.25 in 2025. This can likely be attributed, at least in part, to the improvements made to the game to give the players more agency, which greatly adds to the playability.

## 3.6 Future Changes

Though Markopoly is much better received now than it was in its original form, changes can still be made to improve the analysis. In particular, the analysis of the third game is now much more complex than it was originally, and students needed much more help and guidance than they have in the past. It may be possible to create a different game that uses Side B of the board and has similarly engaging gameplay, but simpler analysis.

Another area of Markopoly that needs improvement is the story aspect. Overall, games that tell a story are more engaging than those that don't, but Markopoly has never had one. It's possible that student engagement could be greatly improved by adding a storyline to the gameplay.

# 4. The Great Cave Escape

The Great Cave Escape was originally designed as an extra credit project by three students enrolled in POR in the fall of 2023, to illustrate recursive expected value problems. It was intended to address the following learning outcome:

- Use conditional probability, conditional expectation, and conditional variance to analyze real-life systems.

In this game, the players have stumbled into the central cavern of a cave system and are trying to escape. The game board represents a map of the cave, with four different passageways out of the central cavern and a series of branches off of each of those passageways. The players take turn rolling a four-sided die (d4) to determine which passageway they take. At each junction, they roll either a d4 or a d6 to determine where they go next. Each dice roll is considered one turn.

When they reach one of the lettered circles at the end of the branches, they read a scenario from the game instructions (see examples in Figure 4 below), which tells them if they return to the central cavern, lose one or two turns and then return to the central cavern, or escape. The game ends when the first player escapes and the round is completed. After the class, the

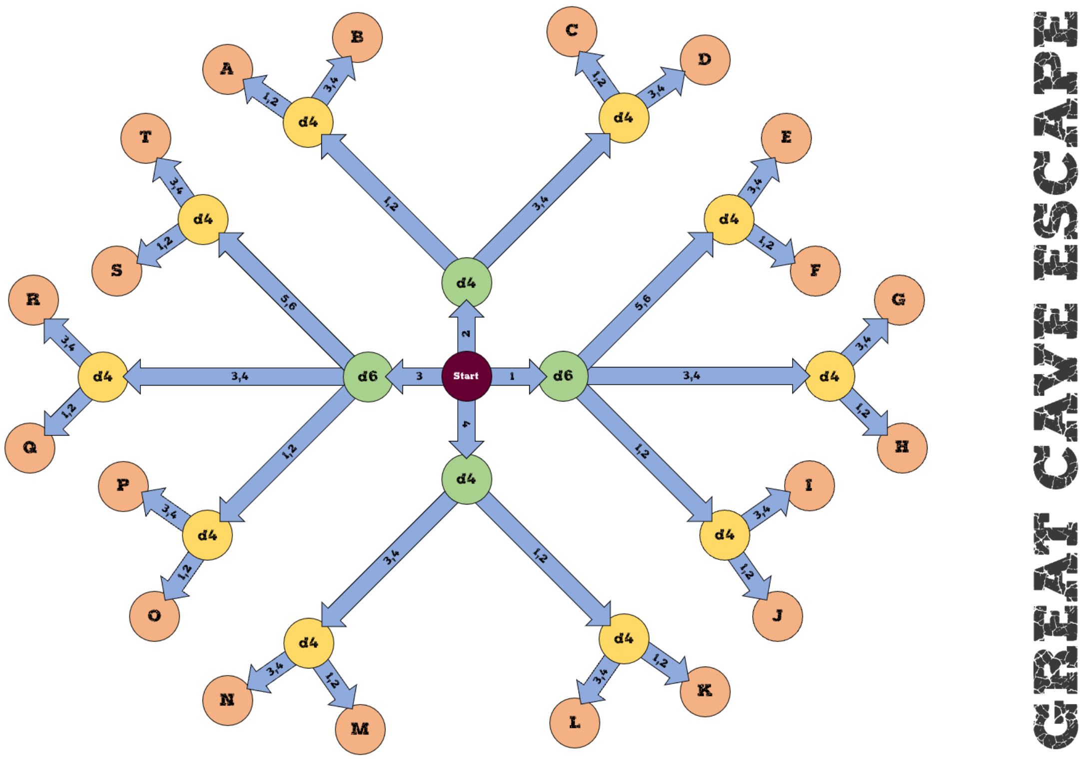


*Figure 3: Great Cave Escape Board*

students are asked to use a recursive expected value model to determine the expected number of turns it takes to escape the cave.

## 4.1 Survey Results

As with Markopoly, the Interest and Usefulness portions of the MUSIC model were sent to students after the game and analysis were complete, happily with a much higher response rate. The questions, along with the mean and standard deviation of the student responses, are as follows ($n$ = 146):

| Question | Mean | Standard Deviation |
|---|---|---|
| The activity was beneficial to me. | 4.75 | 0.65 |
| The activity held my attention. | 5.00 | 0.91 |
| In general, the activity was useful to me. | 4.65 | 0.75 |
| I found the activity to be useful to my future. | 4.19 | 0.91 |
| I enjoyed the activity. | 5.20 | 0.85 |
| The knowledge I gained in this activity is important for my future. | 4.29 | 0.94 |
| The activity engaged me in the course. | 5.16 | 0.67 |

*Table 2: Survey results for Great Cave Escape game*

The results are very positive, especially on the Interest scale, indicating that the students found the game to be engaging and entertaining.

**Scenarios:**

A. You find a slide in the rocks. You trip and get knocked out while falling down. When you wake up, you are in the starting room.

B. **ESCAPE!** You reach the end of the tunnel and find a ladder. Upon climbing it, you escape onto the surface.

C. You find a magical door in the rocks. When you walk through it, you find yourself back at the start and the door gone.

D. **LOST!** You wander into a room of venomous snakes. You are bitten before you can escape, and get lost in your confusion. Lose a turn and return to the start.

E. **[POSSIBLE] ESCAPE!** You find a bridge leading out of the cave, but the troll won't let you cross until you've answered his question. Roll a D6. If you roll an even number, you answer correctly and escape. If you roll an odd number, you return to the start.

F. **LOST!** You enter a room, but while exploring it a large rock collapses across the entrance, trapping you. You get lost trying to find your way out. Lose 2 turns and return to the start.

G. You stumble upon a mysterious ancient fountain filled with glowing water. Curious, you take a sip, but the water has a strange effect: it causes you to forget where you are. Dizzy and disoriented, you wander back to the start, still unsure of what just happened.

*Figure 4: Example Scenarios*

## 4.2 Changes in Fall 2025

As with Markopoly, the main complaint about the Great Cave Escape in its first year was the lack of player agency. Because the players could make no choices, they could not actually affect the outcome of the game and therefore felt that they were watching it happen instead of playing. Unfortunately, that aspect cannot really be altered while still keeping its ability to be modeled as a recursive expected value problem. However, more complex scenarios were added in the fall of 2025, including some that were “Possible Escapes,” requiring another dice roll to determine if the player escaped or returned to the central cavern. When there were originally only two escape paths, you knew from your first dice roll whether or not escape was possible. Adding more escape paths added more suspense to the game, because future dice rolls still mattered.

In addition, the conditions for winning were changed to allow some player agency. Originally, the first player to escape the cave won. In the improved version, players bet on the outcome before the game began. For instance, a player might say, "I bet that the blue or black pawns will escape." Then, if the blue pawn escapes, the player earns 4 coins. If both the blue and black pawns escape, the player earns 8 coins. The more pawns the player bets on, the lower the payout if they escape. The player with the most coins at the end of the game wins. In this way, though the players cannot actually affect the outcome of the game, they can affect whether or not they win.

This betting system was well-received by the students overall. As with Markopoly, they said that they liked the ability to strategize, even in a small way. Many also said that it added to the competitive aspect of the game; though they were only moving their own pawn, they were "cheering on" others based on the bets they placed. Some said that the instructions for the betting and the concept were unclear, so more work must be done in the future to clarify the rules.

### 4.3 Future Changes

Despite the improvements, one of the main complaints about the game still is that it is repetitive. Once the students had played a couple rounds, some felt that they had grasped the concept and didn't really want to play to completion. Others found it frustrating that they had to keep referring back to the list of scenarios over and over. To make the game more engaging and eliminate the list of scenarios entirely, card decks will be used in the future to determine what happens when you reach the lettered circles, with different decks for different groups of letters. In this way, the random chance of returning to the central cavern or escaping will be preserved, but certain scenarios won't be tied exclusively to certain letters. This should improve the playability without overly complicating the analysis.

## 5. Lessons Learned and Conclusions

Several lessons have been learned after three years of embedding board games into upper-level industrial engineering classes:

- **While an educational board game must be educational – that is, it must illustrate the desired concept and result in improved learning – it must also be an entertaining *game*.** The goal of the games is not just to provide a larger-scale example for the students, but also to encourage the students to interact with each other and build community within the classroom. If students are bored by the game, they're more likely to retreat to their phones or computers and stop engaging. Therefore, the entertainment value and playability of the game is key to achieving the goal of the study. Much of the existing literature in game-based learning focuses on the educational aspects, so separate research must be done in the literature on entertaining game design. In this case, that research was done by the undergraduate researcher, who then worked to make the games more interesting and fun to play.

- **To make games more entertaining, players *must* have some agency.** When the games were purely based on random chance and dice rolls, the players felt that they were watching it happen rather than participating. Even small choices, like the choice of starting square in Markopoly or the choice of which pawns to bet on in the Great Cave Escape, add some strategy and agency to the game and make it much more enjoyable for the players. Students would rather have slightly more complicated analysis if it means that the game is more entertaining.
- **Games should tell a story.** Overall, based on student comments and in-class observations, students find the Great Cave Escape more engaging than Markopoly. It's likely that this is due, at least in part, to the story aspect. Players are not just trying to gather coins, they're trying to escape a cave. They don't just land on a colored square, they're chased by a dragon or rescued by a wizard with a magical portal. That means that, instead of just sitting or playing on their phones between turns, players are more likely to stay engaged with the game and with each other, which helps with the goal of community-building in class.
- **Prizes add to the competitive aspect of the games, but they should be kept small.** The typical prize in POR is vinyl stickers, which can be bought in bulk online for a very low price. This allows students to feel that they're competing for something, which helps keeps some engaged. However, it's also small enough that those who don't win don't feel that they're "missing out."

Analog games have great potential to improve student learning, engagement, and community-building in college courses, without the drawbacks of digital games. However, while even badly-designed games can be a nice change of pace from the usual lecture (Markopoly was well-received in its first year, even though it was considerably less engaging), better game design can greatly increase student interactions with each other and with the material, leading to potentially better outcomes. More work is needed in the future, to improve the existing games, develop and improve games for other courses, and gather more data on the effects of the games on student learning.

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