Overview

I set out to create a serious tabletop game which teaches molecular bond stability, one of the core principles of higher chemistry.

RetroSynthesis is a chemical card game where teams of players attempt to link up material cards to build the most stable molecule between two points. All the while contending with environmental changes, sabotage from other players and bonus cards. The different cards are all based on real molecules and have behaviour and rules which reflect their real-world use within chemical industry.

The game accommodates 4-8 players split into teams of two, though could accommodate more if team size is increased. It is aimed towards A-level and first-year undergraduate chemistry students, being sold to teachers. The game is meant to be played in class and be followed by discussion with an academic supervisor.

Gameplay

The objective of RetroSynthesis is to be the first team to reach the end, while also having the most stable chemical. Teams take turns building their molecule by placing their material cards, which each have individual rules for how they connect and behave. Players will also have their decisions informed by rule changing environment cards and harmful sabotage cards. (Additional information can be found in the rulebook)

Learning Objectives

While in my research I found numerous serious chemistry games, they were all aimed at lower secondary student. They were generally based around elements. While important, there isn't application to further chemistry in these games. A large part of advanced chemistry is formation of large stable molecules for specific purposes. As such I set out to create a game which increases understanding of how different molecules interact to increase stability, encourage students to be able to work together to discuss and analyse the formation of their compound and finally demonstrate that during chemical synthesis, the most direct route is often suboptimal.

When designing serious games, Belotti (2011) said "Feedback to user input is the key point to all educational products"[1]. The scoring system I created for the game, wherein different molecules add or subtract to your molecules stability teaches, allows for students to track the immediate effect of their decision on the stability of the molecule. This immediate feedback means learning can be done during the game to improve understanding for future turns. By the end, they will be able to analyse their successes and failures to see which bonds made for a stable molecule. This unlocks the penultimate level of Bloom's taxonomy, evaluation.

The goal of interaction is done via it being a team-based game which requires planning and foresight. There are multiple materials that have a negative impact but can be switched to a positive impact if the correct moves are made during future turns. As well, players can plan the direction of their molecule to reach powerful bonus tiles. It has been shown that discussion with peers leads to better evaluation and foresight[2], and the teams will have to discuss for smart play.

Finally, to achieve my goal of demonstrating the complexities and nuances of molecular design was achieved through my distribution of cards. I ensured that there aren't enough cards to make a straight line to the end. Players are forced to take complicated paths to maximise point gain, making them come up with creative shapes and materials for their compound. I believe this engages the creation tier of Bloom's taxonomy, making them assemble something new from their own understanding of the topic, leading to strong understanding.

Design of the Game

The first major decision I made was to use cards to generate randomness within the game. A study by Howard-Jones showed "gaming uncertainty can transform the emotional experience of learning. This may improve engagement and, more importantly, may also improve encoding and later recall"[3]. Making the players use different materials each time increases engagement by needing active analysis and problem solving unique to each element and scenario.

These cards are all based on real chemical materials and environments. However, the sabotage cards, which allow you to negatively impact another player are based on wacky scenarios. This is not only to fit in the theming of my game taking place in a chaotic science fiction laboratory, but also the same paper by Howard-Jones found "it has been reported elsewhere that memory for items encoded in a positive emotional context is improved, compared to neutral or negative contexts". I did not wish to encode scientific concepts to the negative parts of the game, whereas the point scoring materials, bonuses and environments are.

The reason I chose the aesthetics for my game is because I believed the pixel art sci-fi theming would create a hectic and playful tone. These compounds that the players are making are likely nothing that's ever been done before and should appropriately feel like you're constantly one bad decision away from chaos. This game should also feel fun and arcade like, trying to get the highest score possible. The narrative of the game, being scientists escaping a lab, with students taking the role of said scientists, is also to encourage fast paced movement towards the finish.

I decided that each different card type should have a unique symbol on the back of the card. While they are all unique colours, there may be some issues of red-green colour blindness if the symbols weren't used. Care was also taken that due to the text heavy nature of some cards that editions of the game would be offered in the "Open dyslexic" font type.

Finally, it was decided that the game would be operated in teams, as opposed to individually. This was for two reasons. Firstly, it would reduce the amount the supervising teacher would need to split their attention and allow more students to play with fewer copies of the game. Secondarily, Devries[4] explains that "team-based games give students increased motivation due to motivation not only to impress on an academic level, but to provide value for their team and gain social approval." Therefore, this team style of playing the game would encourage students to be more engaged and active in their participation.

Playtesting

A noticeable problem I found with during initial internal testing was an overload of information to keep track of during the late stages of the game when the molecule had grown large. Understanding Sweller's cognitive load theory[5], I knew this would harm long term memory retention of the game. To remedy this, I created the sector system. Based on sectors in an actual scientific facility, I split the board up into more manageable chunks of three rows each. I then went back and changed the text of cards and rules to only care about the materials in a specific sector, greatly reducing the cognitive load.

General observations during early iterations showed that the average game time went on for approximately 50 minutes. This was unideal due to the preferred running of the game requiring a game to be played, discussion with a teacher, then another round considering what they discussed. The solution was simple, shortening the length of the board considerably, but making it wider to compensate. This not only made games faster to reach the end, but the increased width led to more interesting molecular pathways being explored.

As well as the lengthy game time, I also noticed that the game would become repetitive towards the end, especially when there was a clear winner already. If a player considers themselves to have no chance at winning, they will become disengaged, and RetroSynthesis would be ineffective as a serious game. Due to this I implemented the environment system. This adds unique rules every 3 tiles and only come into play when the first player enters that sector. Since the frontrunner must make their move before revealing the rule, it's much more likely to disadvantage or harm them than it is the players behind.

Finally, prototype testing by myself left me feeling the material cards felt drab and unmemorable. Many studies, such as this one by Madigan[6], show improves knowledge retention when information is accompanied by visuals. As such, I decorated the material cards with pixel art of their real-world applications *(Appendix figure 2.)*. This greatly increased the memorability of cards and made them stand out from each other.

Results

Overall, I found it rewarding to design a game for the space in which I did. There were some inherit limitations of the medium, namely the true complexity of chemical stability requiring simplifying for education through a serious game. However, for the target audience, I believe it's at an appropriate level and effectively engages the audience to help them learn through serious gameplay. For future innovations on the product, I would want to move it to a print and play model. There is no component of the set that couldn't be transferred to a paper format. This would allow teachers to print to necessity for varying class sizes. As well as that, new cards could be made to reflect molecules not included in this iteration of the game, even encouraging teacher to be able to make their own to align to the specific module they're currently teaching.

References

1. F. Bellotti, et al., *Proceedings of the 5th European Conference on Games Based Learning*, 2011, 26-34
2. P. Lameras, S. Arnab, I. Dunwell, C. Stewart, S. Clarke, P. Petridis*, Br J Educ Technol,* 2017, **48**, 972-994
3. A. Howard-Jones, S. Demetriou, *Instructional science,* 2008, **37,** 519-36
4. D. devries, *Educational Technology,* **37**, 1980
5. J. Sweller, P. Chandler, *Cognition and instruction,* **8**, 1991, 351-362.
6. S. Madigan, *Psychology Press*, 2014, 65-89.

Appendix

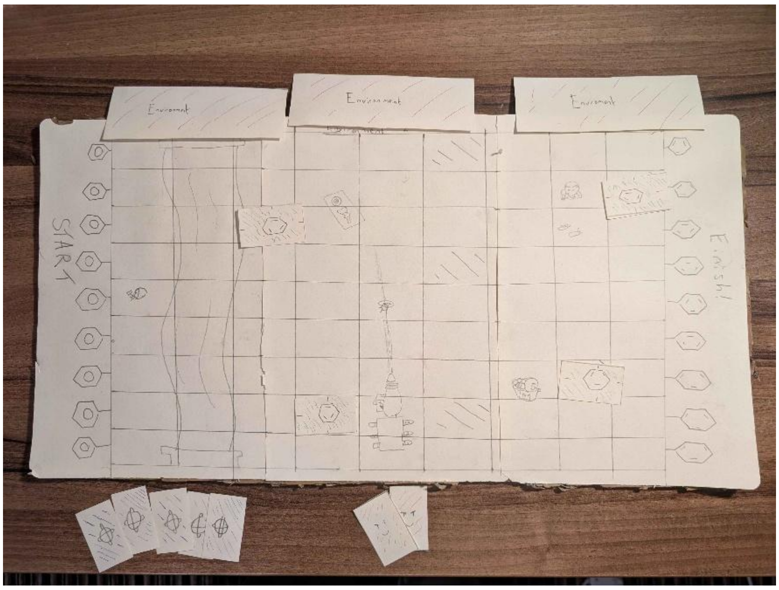

Figure 1. Physical prototype of game board and cards

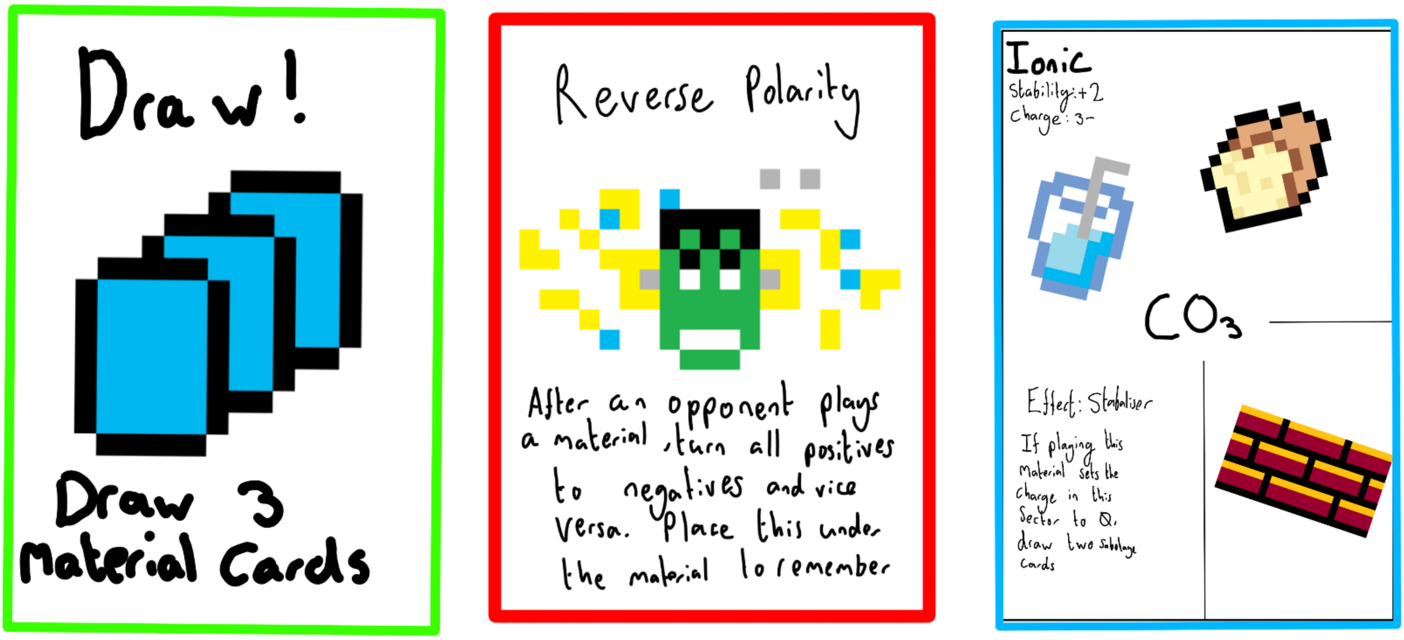

Figure 2. front of cards mockup

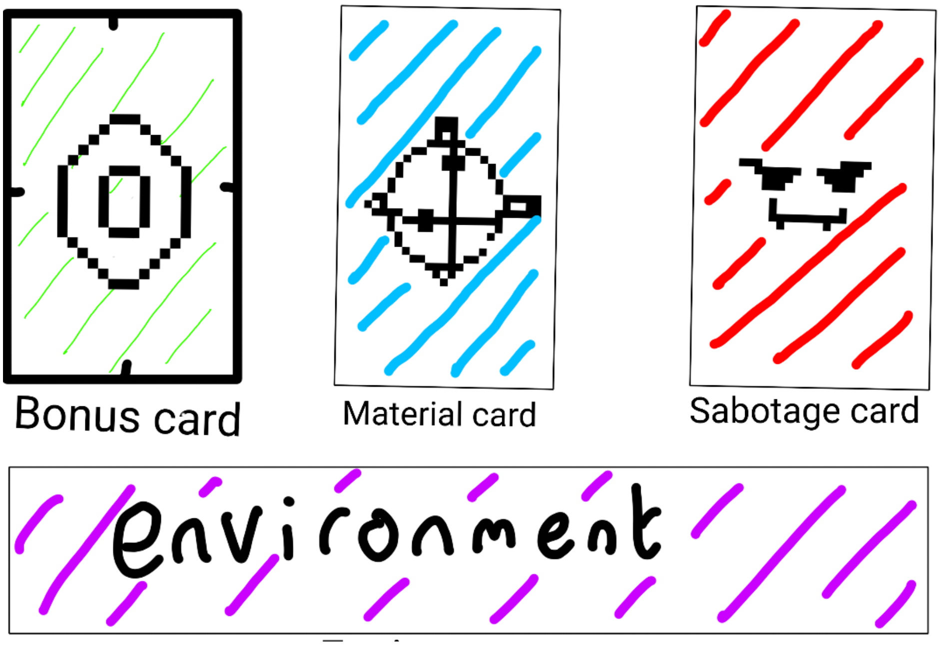

Figure 3. back of cards mockup