OVERVIEW

Too much of chemistry is learned in isolation from peers. Pedagogical methods lack interactivity and collaboration with fellow students, and the sheer volume of content forces students to spend copious amounts of time alone going over lectures and textbooks and worksheets. I want to break this trend by creating a game that allows students to revise and apply knowledge from organic chemistry classes in a player-player interaction heavy, card taking frenzy- with a dash of corporate espionage. Catering to Bartle's socialisers, SYNTHESIS! Is a 2-6 player card game aimed at first-year university students interested in a fun way to consolidate their learning though 15 to 45-minute games.[1] It proved to be a hit with playtesters of the target demographic, who suggested the development of A-level-specific and second-year university level expansion packs...

LEARNING OUTCOMES

The biggest challenge in chemistry education is how to create effective, efficient, motivating, and enjoyable learning experiences.[2] It is especially difficult to motivate students to learn chemistry and pursue chemistry-related degrees and careers.[3] Though many peers on my course enjoy our classes, they want a chemistry degree as a gateway to other careers like, like finance or teaching. Most do not plan on staying in the field of chemistry, which was crucial to my idea generation process and what I wanted students to attain from the game. I wanted to make a game that would remind university students why they chose chemistry and prove that a career in industry is tenable. From this ideation, I was able to settle on my learning outcomes.

Utilising the apply, analyse, and create levels of Bloom's taxonomy, students should be able to:[4]

- Implement knowledge from first-year organic lectures to individually sketch a synthetic pathway.
- Develop a pathway with cards in order to assemble a route to a product, including all reagents, conditions, and intermediate products.
- Understand what a role in the chemical industry requires.

And if possible:

- Examine other synthetic pathways and compare it to other known routes.

GAMEPLAY

After designing and prototyping SYNTHESIS!, I conducted a market review on organic chemistry games- and one initially appeared very akin to my prototype. There are similarities (including the name) to the established chemical synthesis game React!. However, while the objectives of our games are the same, (making a synthetic route using university-level chemistry) mine is different in the regard that SYNTHESIS! does not teach organic chemistry like React! does; when designing it, I expressly did not want it to replace lectures. I meant for it to be used as revision - I leave it to players beforehand to better their own knowledge, as the effort students put in will be how much they get out of the learning experience. By encouraging students to voluntarily study outside of the game so that they can outmatch others when playing it, the fun and the learning aspects of this change from extrinsic to intrinsic- and players who undertake this extra learning will benefit from increased in-game creativity.[5]

The objective of SYNTHESIS! is to play all the cards needed for a synthetic pathway from a starting compound to a final product. To win, that pathway must pass a peer review from all other players.

Players act as leads of synthetic chemistry for their respective drug companies. Mechanics dictate the story of every game, and in SYNTHESIS! the themes are hand management, command cards, interrupts, multi-use cards, player judge, and take that, which are used to reflect the agendas in my learning objectives[6]:

Mechanic	Real-life conversion
Espionage!	Sometimes companies research the same concepts, and one will publish before the other. In that case, the other company must regroup and change their focus, as they have lost out on the ownership of the idea.
Tax!	Reagents and chemical compounds may undergo a sudden increase in price due to changes in availability and regulations. Removing a card from the game via Tax! represents this.
Each player selects a company to play for.	In industry, very little work is done individually. Teams of synthetic chemists work together on projects that are in the best interest of the company. This introduces students to the idea of future groupwork by making their in-game character a company representative.
Blank cards.	Different companies have high/low budgets and access to many/few resources. I could not make this specific to each company in the game, so these cards were placed in the deck. Each player with a blank is at an advantage to their opponents, which highlights the economic gap between big and small companies.
Discarding down by giving cards to other players.	In “one man’s trash is another man’s treasure” fashion, some information and supplies are defunct for some. That resource is

	then made available to others, which in turn is advantageous to others who need it as their missing piece.
Peer review required to win.	In order for any research to be published, peer review by other scientists must confirm the research is correct and rigorous.

Most importantly, the game is inherently unfair. Each final product requires 1-3 intermediate compounds, and those with only one intermediate compound will need fewer cards for their pathway than someone with three. Once again, this is an intentional feature to reflect the disparity in resources and capital from company to company. These applications are meant to prepare students for the reality of the synthetic chemistry industry in addition to their knowledge of organic chemistry.

DESIGN OF GAME

SYNTHESIS! is a card game- naturally this was the aspect I designed first. Keeping the colour scheme simple and bright to universally appeal to educators and students and overly vibrant colours tend to divert learners' attention away from the learning outcomes.[7] The main colours of cards played are yellow, red, and green- which are very distinct from each other in these hues. To ensure accessibility, colours I chose are distinguishable to students with colour vision deficiency as seen in the following image:

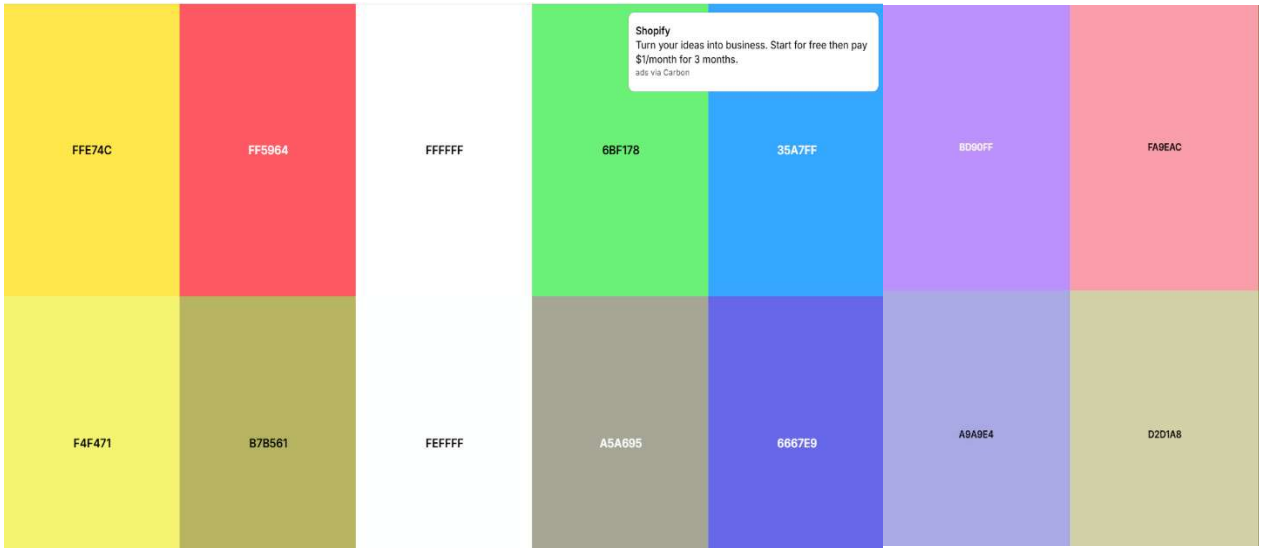


Fig. 1. The colour scheme of SYNTHESIS! passed through a protanopia filter on Coolors.[8]

The prototyped cards operate on the white-space principle.[9] All information on what each action card does is written on the card, and there are Quick rules cards which reduce the cognitive load on players.[10] each type of card has a different border colour in order to make it easier for players to remember card types through colour.[11] Blank cards that will

be written on will have a UV coating so that they can be written on with whiteboard pen, and erased after each game.

Table 1. Card prototypes vs. final design.

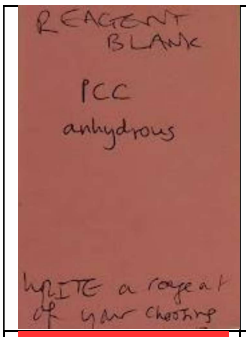
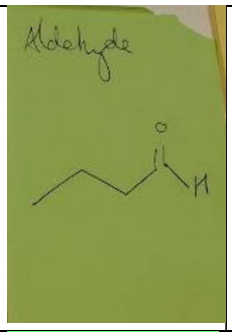
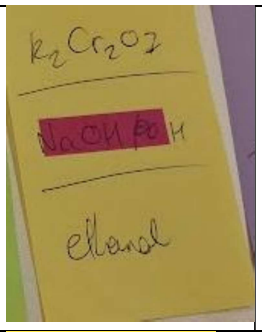
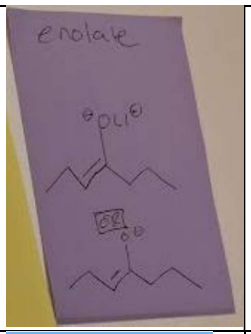
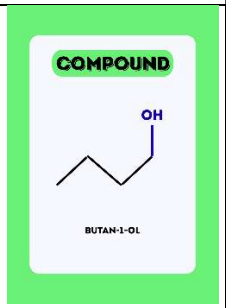
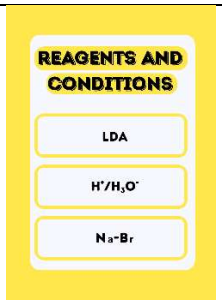
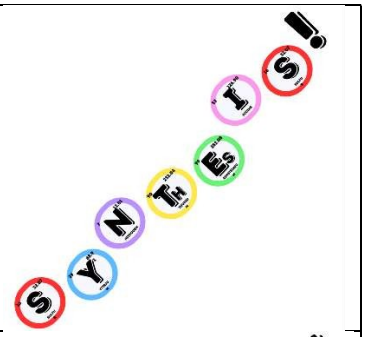
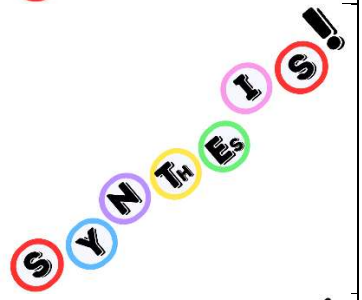
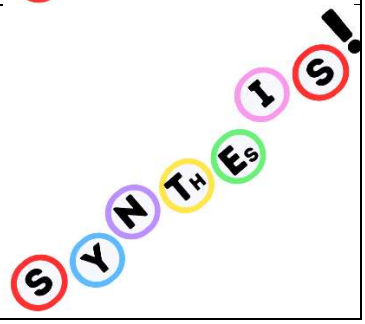
				N/A
				

Table 2. Design iterations for box title.

Too cluttered. Extra information about non-metals/transition metals/actinides draws away from the focal letters in the centre.	
Significantly less cluttered. However, it is now not obvious that these are letters from the periodic table, and that this is a chemistry game.	
Perfect. The eye is immediately drawn to the letters spelling the game's name, but when focussing on the details it becomes clear that this is a chemistry game.	

I wanted to use this title for the card backs, but it became clear that sizing would be a problem.

Table 3. Design iterations for card backs.

The details that confirm this is a chemistry game are now cluttering the title. It is okay to remove extra text because anyone who has bought the game will be aware it is a chemistry game.	
Text is now legible. But the shaded font may be difficult for players to see clearly at this size.	
Changing the font to the unshaded version of Intro Rust Base is clear and can now be read by all players.	

PROTOTYPING AND PLAYTESTING

Admittedly, this idea spent a long time in my brain before I put it to paper. However, meticulously working out the quirks in the gameplay and calculating the card ratios beforehand paid off immensely. The gameplay was incredibly smooth and had the right amount of unpredictability. But do not take my word for it- hear it from the chemistry students themselves...

Feedback from the target audience was overwhelmingly positive! Five playtesters wrote detailed notes on their playtest forms. Overall, the game was ranked very highly in player interaction, difficulty, balance, and educational value. The only criticism that came up in two forms was that eventually the game would be unreplayable as all routes would be worked out.

Table 3. Game iterations to show changes made via playtesting.

Problem	Solution
Players were unsure about whether they could draw their synthetic pathways before the game	Rulebook addition- five-minute, pre-game thinking time.

began, and how long they should be allowed to take.	
Once a player uses the Espionage! mechanic, they have nothing to lose by repeatedly guessing one player's, or others' final products- which results in the possibility of no players winning.	Limit the Espionage! mechanic to allow one-time use for each player.
Players were uncertain whether the Stop! card could be used out of turn	Specify this information on the card.
Players were unsure if they needed to play the starting compound in their synthetic pathway.	Clarify in rulebook- this is not the case.
A player with visual impairment was able to read their own cards, but not others', making it difficult for them to use Espionage!	Rulebook addition- all players should announce cards as they place them.

RESULTS/WHAT NEXT?

I have already designed the game logo, cards, and card backs online in preparation to make a physical prototype of SYNTHESIS!. I want to take this project even further than the module by competing in the IATL Den to fund and market this game to be sold. Future developments on this game will appear as I broaden my knowledge of organic chemistry! Once I complete second and third year, I will be able to make specific expansion packs for the chemistry learned by students in each year.

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10 J. Sweller, 2011, pp. 37–76.

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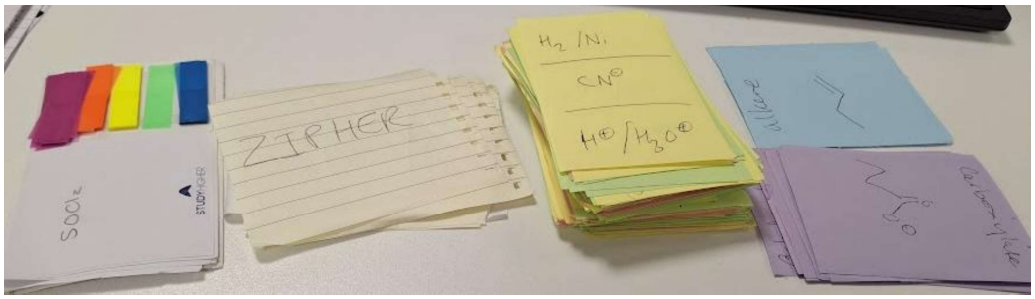
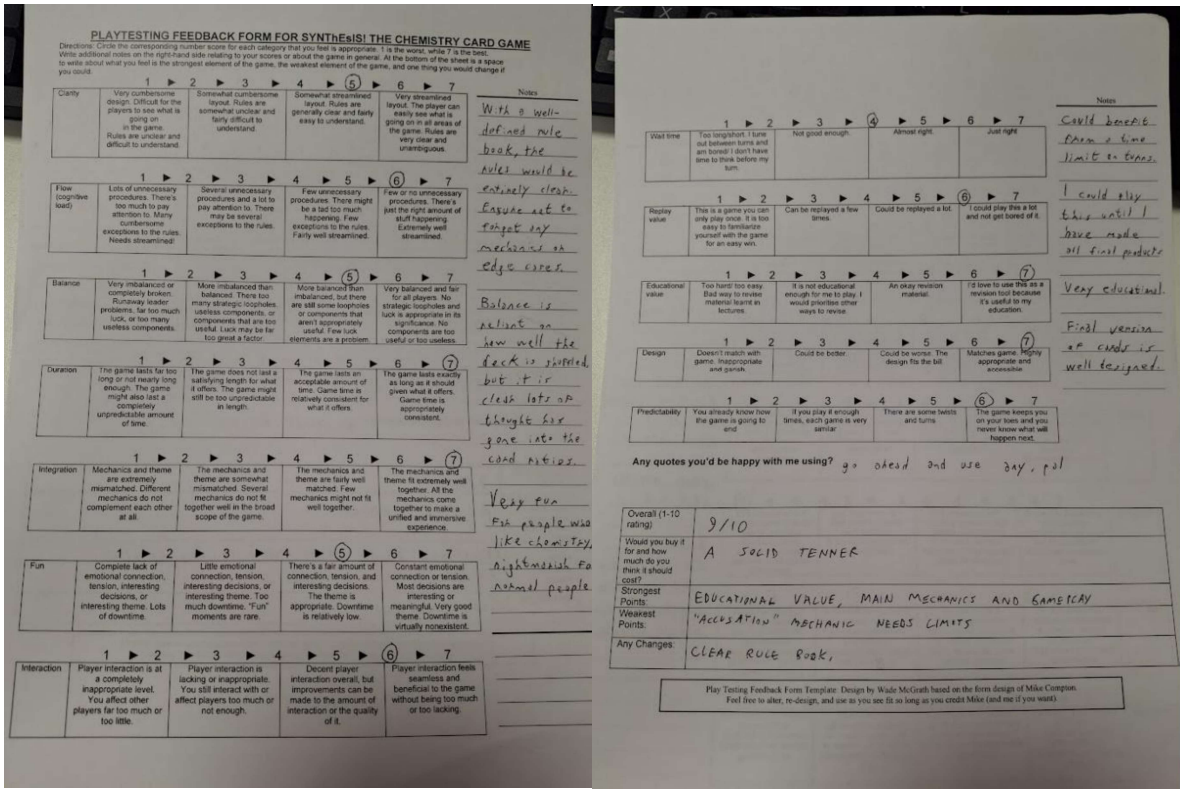
APPENDIX

Appendix 1. SYNTHESIS! prototype



Appendix 2. playtest form- design adapted from Mike Compton.



PLAYTESTING FEEDBACK FORM FOR SYNThEsIS! THE CHEMISTRY CARD GAME

Directions: Circle the corresponding number score for each category that you feel is appropriate. 1 is the worst, while 7 is the best. Write additional notes on the right-hand side relating to your scores or about the game in general. At the bottom of the sheet is a space to write about what you feel is the strongest element of the game, the weakest element of the game, and one thing you would change if you could.

	1	2	3	4	5	6	7	Notes
Clarity	Very cumbersome design. Difficult for the players to see what is going on in the game. Rules are unclear and difficult to understand.		Somewhat cumbersome layout. Rules are somewhat unclear and fairly difficult to understand.		Somewhat streamlined layout. Rules are generally clear and fairly easy to understand.		Very streamlined layout. The player can easily see what is going on in all areas of the game. Rules are very clear and unambiguous.	With a well-defined rule book, the rules would be entirely clear. Ensure not to forget any mechanics on edge cases.
Flow (cognitive load)	Lots of unnecessary procedures. There's too much to pay attention to. Many cumbersome exceptions to the rules. Needs streamlined.		Several unnecessary procedures and a lot to pay attention to. There may be several exceptions to the rules.		Few unnecessary procedures. There might be a tad too much happening. Few exceptions to the rules. Fairly well streamlined.	(6)	Few or no unnecessary procedures. There's just the right amount of stuff happening. Extremely well streamlined.	
Balance	Very imbalanced or completely broken. Runaway leader problems, far too much luck, or too many useless components.		More imbalanced than balanced. There too many strategic loopholes, useless components, or components that are too useful. Luck may be far too great a factor.		More balanced than imbalanced, but there are still some loopholes or components that aren't appropriately useful. Few luck elements are a problem.		Very balanced and fair for all players. No strategic loopholes and luck is appropriate in its significance. No components are too useful or too useless.	Balance is reliant on how well the deck is shuffled but it is clear lots of thought has gone into the card ratios.
Duration	The game lasts far too long or not nearly long enough. The game might also last a completely unpredictable amount of time.		The game does not last a satisfying length for what it offers. The game might still be too unpredictable in length.		The game lasts an acceptable amount of time. Game time is relatively consistent for what it offers.		The game lasts exactly as long as it should given what it offers. Game time is appropriately consistent.	
Integration	Mechanics and theme are extremely mismatched. Different mechanics do not complement each other at all.		The mechanics and theme are somewhat mismatched. Several mechanics do not fit together well in the broad scope of the game.		The mechanics and theme are fairly well matched. Few mechanics might not fit well together.		The mechanics and theme fit extremely well together. All the mechanics come together to make a unified and immersive experience.	Very fun for people who like chemistry, nightmarish for normal people
Fun	Complete lack of emotional connection, tension, interesting decisions, or interesting theme. Lots of downtime.		Little emotional connection, tension, interesting decisions, or interesting theme. Too much downtime. "Fun" moments are rare.		There's a fair amount of connection, tension, and interesting decisions. The theme is appropriate. Downtime is relatively low.		Constant emotional connection or tension. Most decisions are interesting or meaningful. Very good theme. Downtime is virtually nonexistent.	
Interaction	Player interaction is at a completely inappropriate level. You affect other players far too much or too little.		Player interaction is lacking or inappropriate. You still interact with or affect players too much or not enough.		Decent player interaction overall, but improvements can be made to the amount of interaction or the quality of it.	(6)	Player interaction feels seamless and beneficial to the game without being too much or too lacking.	

	1	2	3	4	5	6	7	Notes
Wait time	Too long/short. Turns out between turns and am bored! I don't have time to think before my turn.		Not good enough.	(4)	Almost right.		Just right	Could benefit from a time limit on turns.
Replay value	This is a game you can only play once. It is too easy to familiarize yourself with the game for an easy win.		Can be replayed a few times.		Could be replayed a lot.	(6)	I could play this a lot and not get bored of it.	I could play this until I have made all final products
Educational value	Too hard/ too easy. Bad way to revise material learnt in lectures.		It is not educational enough for me to play. I would prioritise other ways to revise.		An okay revision material.		I'd love to use this as a revision tool because it's useful to my education. (7)	Very educational.
Design	Doesn't match with game. Inappropriate and garish.		Could be better.		Could be worse. The design fits the bill.		Matches game. Highly appropriate and accessible. (7)	Final version of cards is well designed.
Predictability	You already know how the game is going to end		If you play it enough times, each game is very similar		There are some twists and turns.	(6)	The game keeps you on your toes and you never know what will happen next.	

Any quotes you'd be happy with me using? go ahead and use any, pal

Overall (1-10 rating)	9/10
Would you buy it for and how much do you think it should cost?	A SOLID TENNER
Strongest Points:	EDUCATIONAL VALUE, MAIN MECHANICS AND GAMEPLAY
Weakest Points:	"ACCUSATION" MECHANIC NEEDS LIMITS
Any Changes:	CLEAR RULE BOOK,

Play Testing Feedback Form Template Design by Wade McGrath based on the form design of Mike Compton.
Feel free to alter, re-design, and use as you see fit so long as you credit Mike (and me if you want).