IDC School of Design
अभिकल्प विद्यालय
IIT Bombay

Project 2 (P2)

Educational game design based on The Periodic Table

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Approval

The B.Des Design Project – 2 titled “Educational game design based on The Periodic Table” by Niharika Kumawat, Roll Number 18U130020 is approved, in partial fulfilment of the Bachelor in Design Degree at the IDC School of Design, Indian Institute of Technology Bombay.

Project Guide:

Chairperson:

Internal Examiner:

External Examiner:

Declaration

I hereby declare that this document contains my original ideas and exploration. I have adequately cited and referenced the original sources wherever they have been used as a part of this project. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/ source in my submission. I understand that any violation of the above will because for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Acknowledgements

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Lastly, I'm thankful to all my professors, family and friends for their constant support and encouragement throughout the course of this project.

Contents

Abstract

Chemistry is one of the most disliked science subjects in the Indian School scenario when seen from an understanding and memorization perspective. Students think of chemistry, as an abstract realm they have to deal with. Periodic table is an important topic in the chemistry course curriculum, connected to many other topics in chemistry and involves a lot of memorization. This project delivers an educational board game based on the concepts of “The Periodic Table” targeted at students of grade 9^{th} - 12^{th}. Thus, the aim is to provide a tool in the form of a fun and engaging game to help students learn, practice and memorize. The focus was on coming up with an actually fun game mechanics which motivates the student to play while also feeding them with the knowledge and concepts of the periodic table in a less abstract way.

Jr. Mendeleevs is a game based on the periodic table of elements for the students of class 9^{th} - 12^{th}. Players take the role of researchers and compete with each other to solve the problem cards dealt to them and discover the elements based on hints given on the cards. To discover an element, they’ll have to earn and spend the resources and discovery coins given to them. The game can be played at home or school with classmates, siblings or even parents. Players can also introduce problem cards of their own to increase the difficulty of the game once they’re well equipped with the basics.

Introduction

Chemistry as a subject

Chemistry is the study of matter and everything around us is matter. Thus, it is one of the three primary science subjects introduced in school, other than Physics and Biology. Understanding of basic chemistry is important for everyone. These concepts are taught in school, but get progressively complex and comprehensive in higher grades. Owing to the vast syllabus, chemistry becomes an intangible subject which they can't relate to and just something they have to memorize things in, to pass the examinations.

Conventional teaching methods barely experiment in terms of finding a way to make this memorization and learning fun or more relatable with the real world. An educational game approach can make this learning and practice fun.

The periodic table

Periodic Table is one of the fundamental topics in chemistry and the school curriculum. It concerns with the properties of all the existing elements thus is connected to many or most of the other topics involving these elements. As much as a good understanding of the periodic table is important, it is a very vast topic and contains a lot of information on the 118 elements that exist. It involves both understanding of the basic concepts and knowledge about these elements through memorization and practice. Thus, a game approach can be used to make this memorization more fun and for motivating the students.

Scope and Goal

This project in educational game design is an attempt of going away from conventional methods of teaching. It is curriculum designed and will be a learning tool in the form of a board game to make learning chemistry fun for school students.

Being a board game, it should motivate the players to learn and practice through the game and enable collaboration and interaction with other players. In the long run, it has a broader goal of making kids more curious and enable better conceptual understanding of chemistry.

Target audience

Periodic table as a topic is introduced in class 10^{th} but the basics of matter in the form of elements, metals and non-metals, etc are introduced in class 9^{th}. Thus, this game is designed for students of class 9^{th}-11^{th} covering the basics and touching more complex topics of higher classes.

The pre-requisite for playing the game is a basic understanding of metals, non-metals, etc and very common properties of the elements. Students will get equipped with the knowledge of periodic table, position, properties, and important uses of the elements by playing the game. Although the game is meant for school kids, it can also be played by adults for fun and also to help their siblings or kids learn.

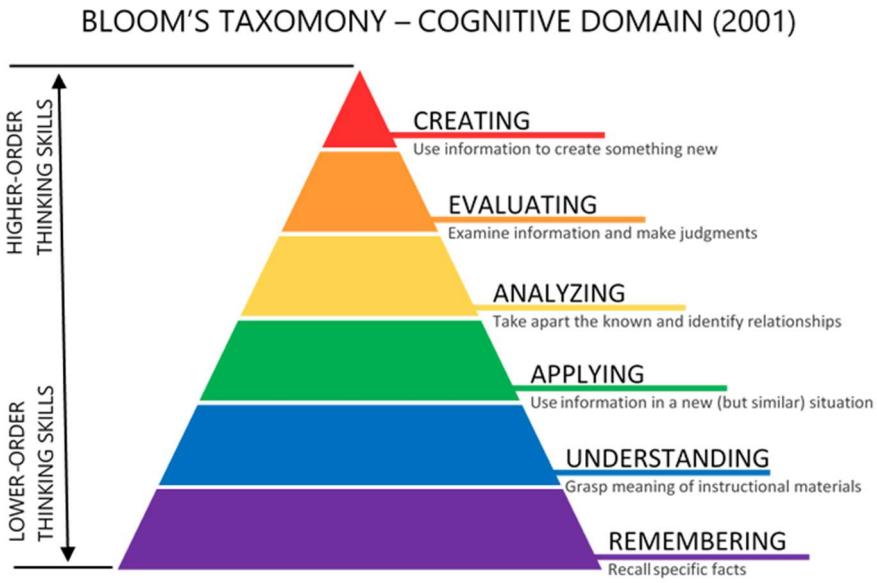
Literature review

Bloom's Taxonomy

Bloom's taxonomy attempts to put down a hierarchal system of classifying educational learning objectives. Thus, this framework is often referred to in both the development and evaluation of instructional games. Following are some of the highlights:

- Defines 6 different stages of learning objectives i.e. remembering, understanding, applying, analysing, evaluating and then creating.
- It's based on hierarchal learning from less complex to more complex levels
- This framework can be used to both design and evaluate educational games
- A correlation can be made to understand what game mechanics would fulfil which level of learning objective

Fig 1: Revised Bloom's Taxonomy Model (2001)



Kolb’s learning cycle

Another highly cited experiential learning theory is Kolb’s learning cycle. Following are some of the highlights:

- It defines a four-stage cyclic process of learning through which every person goes through for effective learning.
- These four stages of this cycle are concrete experience, reflective observation, abstract conceptualisation and then active experimentation.
- This cycle is the process by which an individual refines an experience into knowledge through discovery and active participation.
- Learning has happened when the newly learned abstract concepts could be applied in new situations thus plain memorization is not learning.
- This concept as well can be used to assess the learning potential of an educational game if it provides ample opportunities for all the stages.

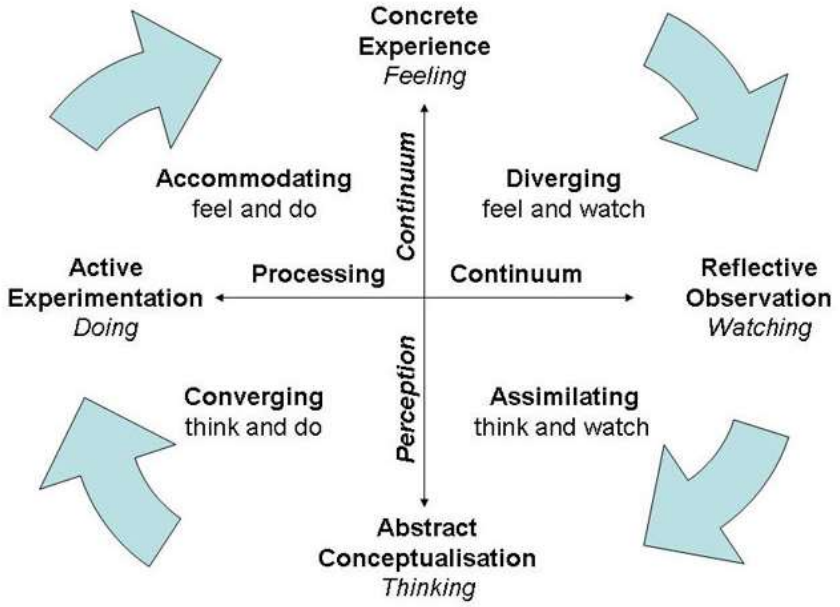


Fig 2: Kolb’s four-stage learning cycle

Perception action cycle

Perception action cycle explains the basic process of acquiring knowledge by doing things i.e., how humans interact with the world and then perceive the results of those interaction to learn new things.

- “When presented with new situations, our brain makes predictions based on past experiences, takes action based on those hypotheses, perceives the results and adjusts its hypotheses.”
- “The perception-action cycle is this continuous flow of information and action between the brain and the world around it. On and on it goes: sense, predict, act, adjust. Sense, predict, act, adjust.”
- Engaging perception action cycle for students can improve learning using physical action or mental pictures

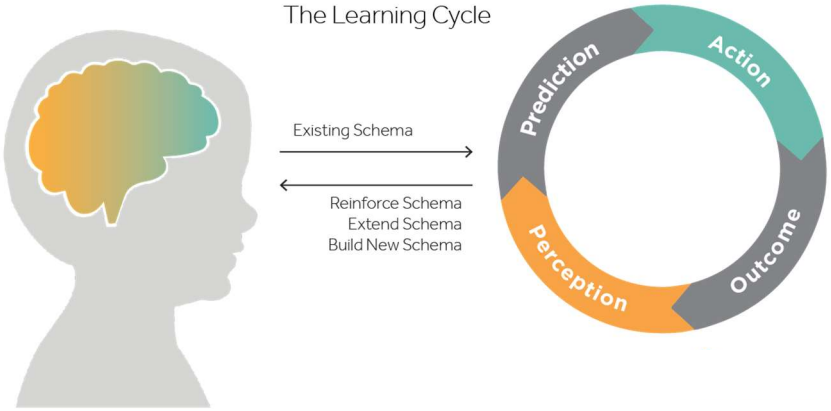


Fig 3: How a human brain perceives and processes a new experience

Educational game design principles

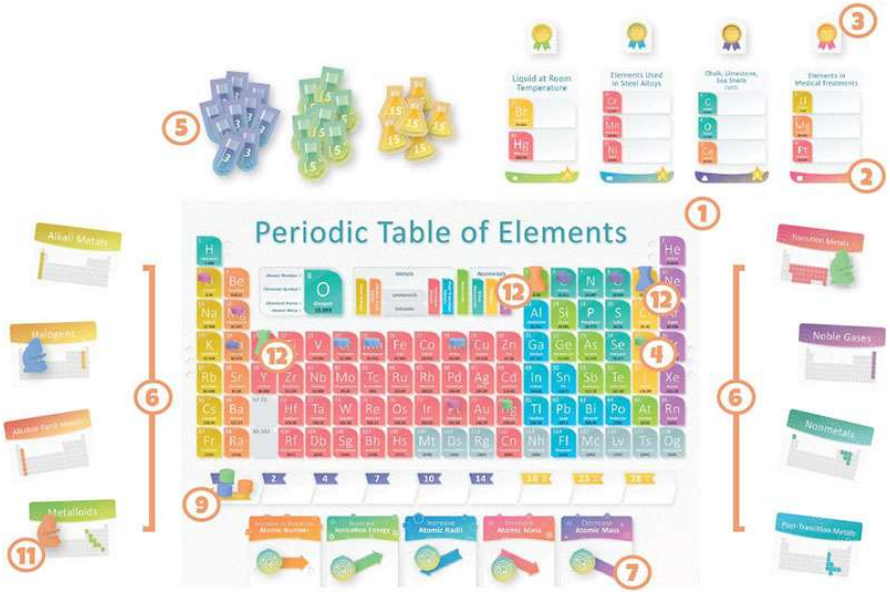
Looking at important aspects of educational game design to understand the basic principles and how they help in making a game engaging:

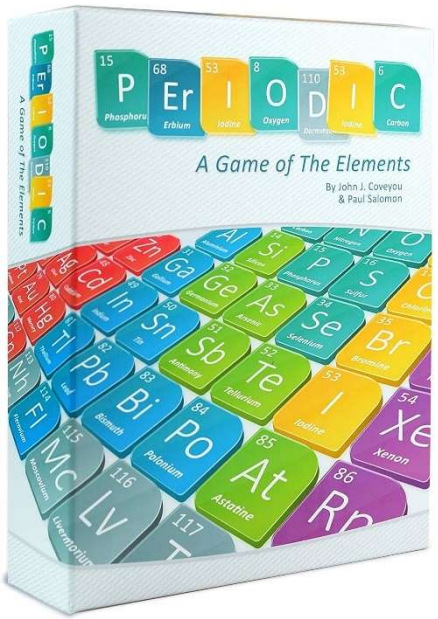
- Employing successful **motivators** in the form of challenge and internally regarding gameplay to keep the game engaging
- Challenges in educational games should be **repeatable** but the gameplay should be new every time to keep the players engaged
- Creating progressive and meaningful **goals**
- Enabling a blend of **strategy** as well as **randomness** to keep the gameplay fun
- Supporting the **learning** process with the game mechanics and gameplay
- Providing opportunities for **self**-**assessment** and **reflection** in terms of learning and gaining new knowledge
- Enabling **collaboration** in educational games as in conventional classroom setting can help students learn better and enjoy more
- Employing **game interaction** to make the play more fun and interesting

Existing games

I explored existing board games around the same topic of chemistry and periodic table to understand how these games employed various aspects of play and learning. It also helped me understand what works well with these games and what can be improved in the gameplay.

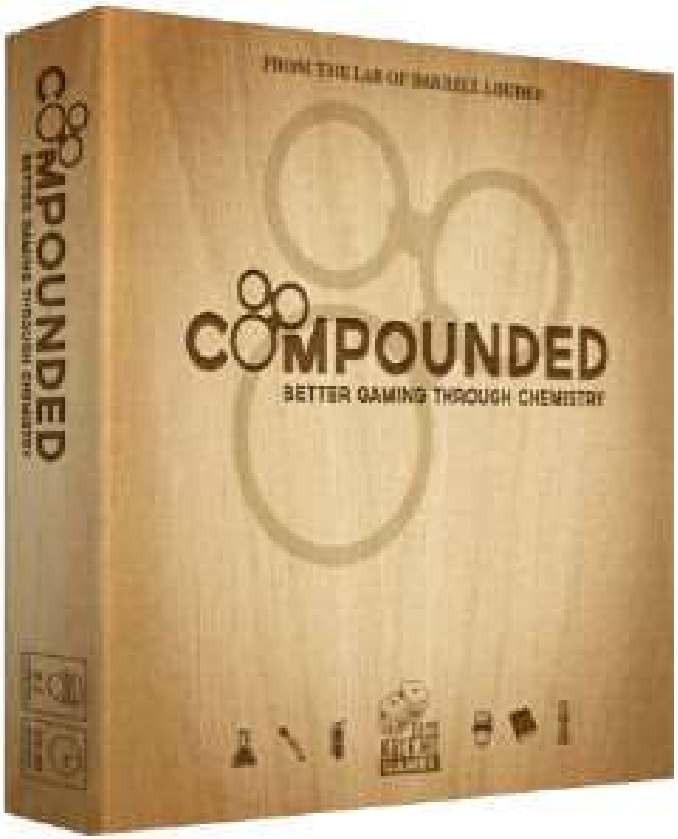
Periodic – A game of the elements





This game focuses on using energy as currency and periodic trends to move across the table. The goal is to score points by researching elements given in the application cards by navigating the table using various periodic trends. It doesn't require a prior knowledge of the periodic table. It’s not very comprehensive but a good game to familiarize with basics of trends across the periodic table. There’s a booklet for additional learning included.

Compounded - Better gaming through chemistry



It is a game meant for age group of 13 years and above. Players take the role of lab managers competing to make the most compounds before others. It involves trading and using elements to compete and make compounds given on the compound cards. It doesn't require prior knowledge of the periodic table. It only revolves around making chemical compounds given on the cards and their names.

Chimie Rush

Chimie rush revolves around the properties of the elements and their reactions. Players race through the board using dice and drive through obstacles provided by various elements and their properties. It doesn't require prior knowledge of the periodic. An additional handbook is also included to give interesting facts and information about all the elements.

Primary research

Semi-structured interviews with 5 students
(3 school students 2 college students)

Demographics

- **2** students from 10th grade
- **1** student from 12th grade
- **2** college students

Major questions asked:

College students:

- What are they pursuing or preparing for? What subjects do they have?
- Do they remember studying the periodic table and what all do they remember?
- Have the concepts you learned come useful in studies or in life later? How important do you find it to be? How have they used the knowledge?
- Tutored any students? This topic?
- How could this topic have been more interesting?
- Play/played board games? Educational games?

School students:

- What did they study recently in chemistry?
- Have they studied the periodic table and when? How was it compared to other topics?
- What all did they learn in the periodic table and how was it taught?
- Which topics were more interesting or easier to understand? How did you memorize them or study for exams?
- What kind of questions are asked by the teacher, in quizzes or in exams?
- How do you use the periodic table to answer those questions?
- Do you ask doubts in class and examples?
- Is the periodic table important in other topics?

- Classroom interaction and online classes?
- Play any board games? Tried educational games of any kind?

Glimpse of some answers

- *Chemistry lectures are monotonous and it's easy to get distracted*
- *The teacher just told us to memorize the first 20 elements with their atomic numbers*
- *Prefer watching videos on YouTube right before the exams to memorize it*
- *Huge jump from 10^{th} to 11^{th} grade in this topic*
- *Named reactions and exceptions are asked in exams*
- *The periodic table is worse than organic chemistry which just revolves around carbon*
- *The way this topic is taught in School is very bookish and less application-based*

Insights

- Boring and very theoretical topic
- Involves a lot of memorization as there are so many groups and elements
- Basics are easy but huge jump to details in the 11th grade
- Questions asked in school exams are more memorization based and less concept-based questions
- The detailed theory and concepts are only useful to individuals pursuing expertise in this field later while for others it’s mostly useless information and not useful in life later

Focus

Based on the insights from my readings and research, I tried to define my content focus and design focus for this game:

Content Focus

Theme being the periodic table, it will cover the following three major parts of the curriculum i.e.

1. The elements, their classification and position on the periodic table
2. Periodic trends
3. Important properties, reactions and real-life applications of these elements around us

Design focus

The aim is to design a game which will serve as a learning aid to both contribute to conceptual understanding as well as enable better memorization of concepts through practice. The aim is to make learning these concepts fun by incorporating principles of learning and game design and lastly is the hope to make this topic less abstract and a little more relatable with this game

Preliminary concepts

I started with ideating by keeping in mind the different learning objectives of the game and the game mechanics that ca supports it while making it fun.

Concept 1- Element 119

Game mechanics: Game of using and trading atomic mass unit (amu) as currency to accomplish various subtasks to collect 119 amu

- Players will be given an initial amount of amu's
- Players will move across the board to accomplish various tasks involving elements properties and reactions to score more amu's
- The goal is to reach 119 amu's and you can name your own element 119 and define its properties

Learning objectives: Basis of periodic table being atomic number which is the number of protons in the nucleus of an atom. Also, to understand the applications of various elements.

Number of players: 2-4 players

Concept 2- The chemistry of life

Game mechanics: Using given elements to solve situations and problems presented by the games to score the most points

- Players will start with some randomly assigned elements
- Problem cards related to real-life will be drawn for which players will have to use the elements in hand to solve the problem and earn points and other special cards
- The goal is to finish the cards in hand the earliest and score most points

Learning objectives: To understand the basic properties and real-life applications of various elements. Also, to understand the similarity and differences between various elements based on periodic trends.

Number of players: 2-4 players

Concept 3- Periodic trails

Game mechanics: Scoring problem cards by making discovery trail from element to another.

- A problem card will have an application mentioned with the two most important elements for that application
- Each player will start with one random element tile with them
- On their turn, a player rolls the periodic trends dice to be able make discovery trails along that path to achieve the problem cards they're dealt.
- Player can claim to have solved a problem card once they have made trail connecting the two elements mentioned on the problem card and score points
- Player with the highest score once each of them have finished their discovery trails will win the game.

Learning objectives: To understand the basic periodic trends and the common applications of various elements around us.

Number of players: 2-4 players

Initial playtesting and outcomes

After analysing all the preliminary concepts and shortcomings of each, I went ahead with ideating a concept which is an amalgamation of the preliminary concepts and an improved version of concept 1 i.e., “Element 119”.

Element 119

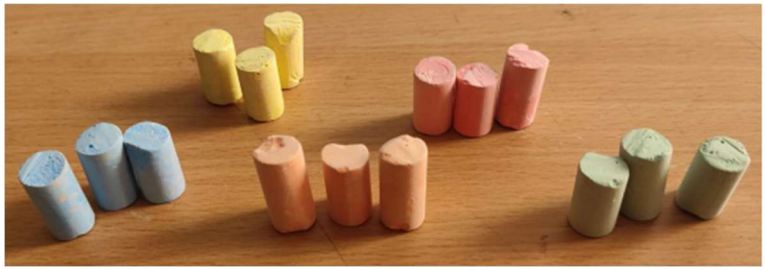
Game mechanics: Game of using and scoring atomic number unit (ANU) as currency by scoring problem cards with the goal of reaching element 119 the fastest

Basic gameplay:

- Each player has 3 pawns and starts with 10 ANU each
- Before the problem cards are turned, each player goes turn wise to place one of their pawns at each turn by spending ANU to reach an element on the board. (Only one pawn can be placed on one element)
- Each player gets 2 ANU at the start of each turn
- Two problem cards are turned and game starts when each player has all three of their pawns on the gameboard
- To move a pawn ahead players can either use ANU, or move another pawn back or both of them together
- Score is based on the period of element scored, example 1 for Hydrogen, 2 for Lithium, 3 for Sodium
- Players compete to score maximum ANU from the player cards to reach element 119

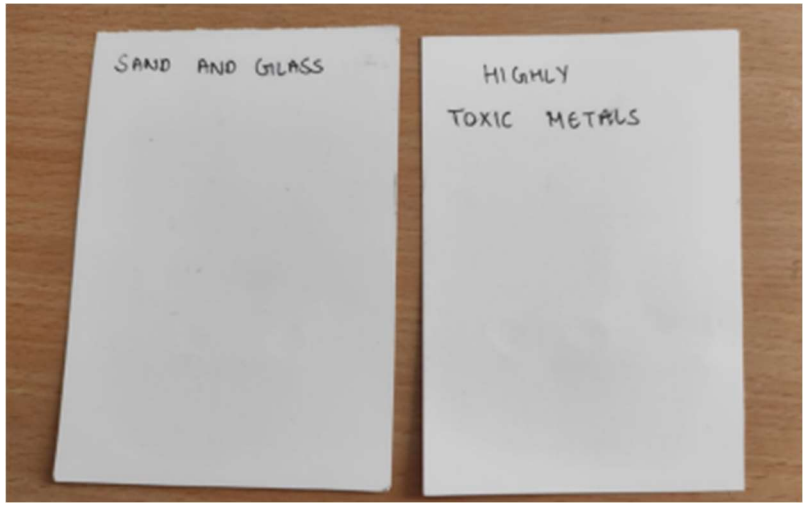
Rough prototype:

Player pawns

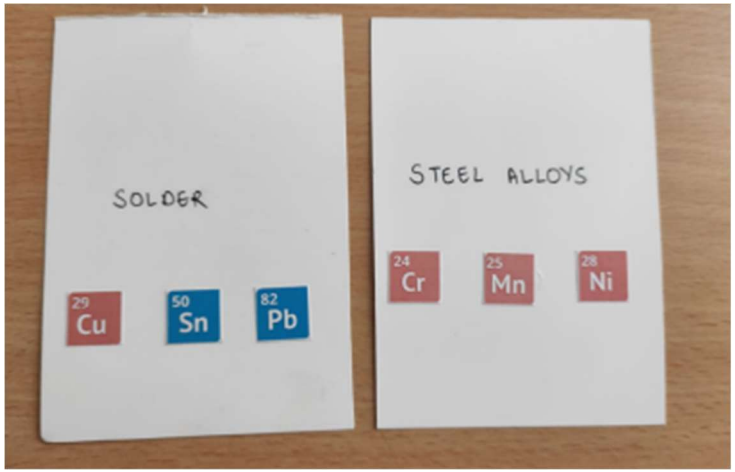


Currency ANU

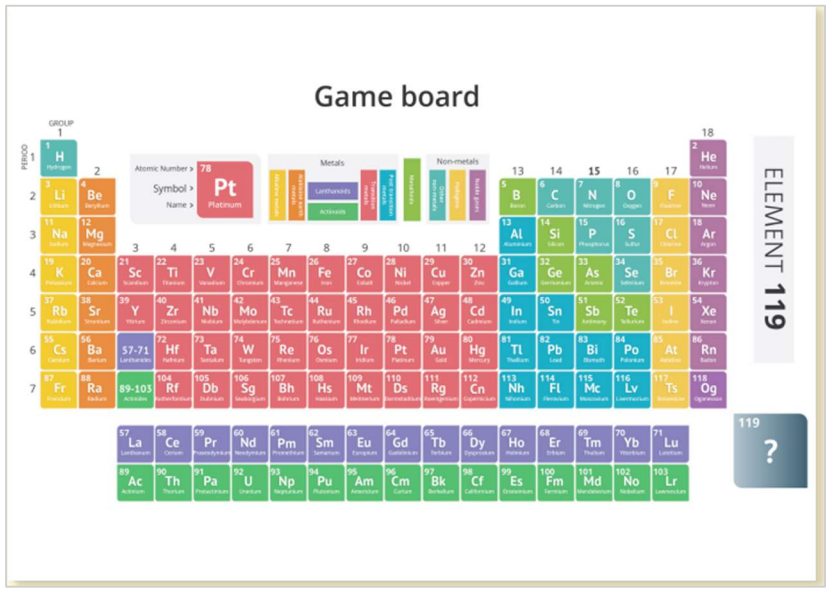
Problem cards front



Problem cards back



Game board



Players: Students of grade 7th

Experience:

- Students only know about individual elements
- Haven't studied the topic yet
- Explaining the game didn't take time
- One gameplay took almost 35-40 mins

Feedback:

- Found the gameplay interesting because of the constant conflict of who scores a problem card first and earns currency
- The gameplay was very long and repetitive
- Flow of the board was confusing for students

Issues identified:

- Absence of markers to help explain the board flow
- Slow scoring scheme
- The game was very calculative thus the focus was just on the atomic number
- Low player interaction and predictability makes it repetitive and more like a race
- Information overload

Considerations for revision:

- Managing information, adding layers
- Increasing player interaction for increasing fun
- Increasing randomness with special cards and power-ups
- Adding more dimensions of skill

Iteration and playtesting

The first playtesting helped me a lot to understand what mechanics worked and what didn't. Moving forward, I refined the game concept based on the consideration and adding modifications from older concepts.

Concept – Junior Mendeleevs

Game overview: This is a game of discovering elements of the periodic table. The players will need to earn and spend resources to discover elements by using their knowledge of the periodic table and properties of the elements. Player scoring the most point by discovering the elements wins the game.

Number of players: 2-4 players

Basic gameplay:

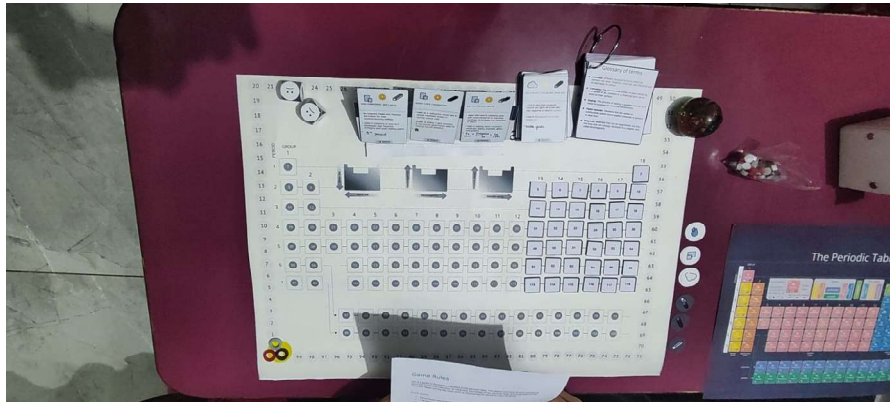
- Three problem cards are dealt to the centre of the board for all players to identify
- In a turn, the players can either roll the dice to earn resources or spend the resources they have to either refer to the book of elements or identify an element using their discovery coins.
- Score is earned based on the problem cards identified.
- Game is played till one of the players finishes their discovery coins and player with highest score wins the game.

Prototype:

Resource dices

Resource coins

Game board setup

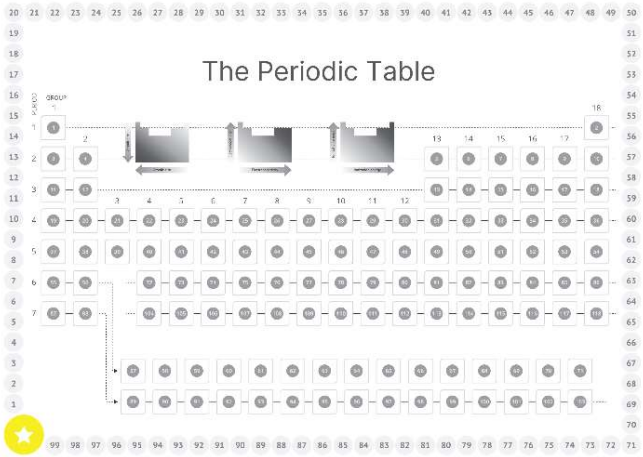


Reading of rules before playtesting

While playing

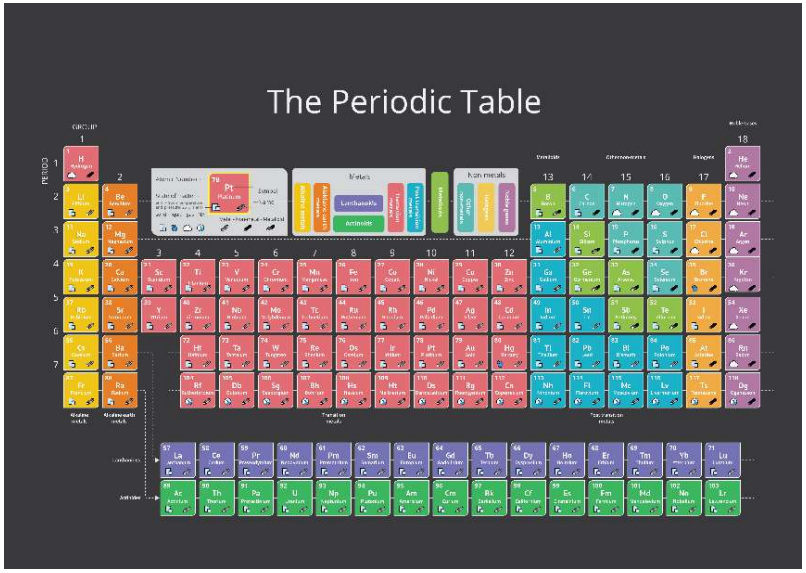
Problem cards

Gameboard



Book of elements for reference

Reference periodic table



Experience:

- A lot of game interaction
- Only one of the students was well equipped with the topic
- Players understood the rules easily but took a while to get the hang of it
- One gameplay took almost more than a hour because the players were delaying their turn end trying to think

Feedback:

- Found the gameplay really fun and competitive
- Enjoyed testing their knowledge of chemistry and how well they remember
- Very excited to play the game again
- Enjoyed rolling the dices and turning the tiles and putting their coin

Issues identified:

- Some graphic icons like for the score were interfering with the other important icons on the problem cards
- Game session was way longer than expected
- There was only one reference table for all the players but even in the idle time, players wanted to look at the table

Considerations for revision:

- Revising confusing icons
- Setting a timer for a turn
- Keeping one reference table for each player

Final game

Name: Junior Mendeleevs

Named after Dmitri Mendeleev, also known as “The father of the periodic table” known for formulating the periodic law and creating the first version of the periodic table currently used.

Game world: This is a game of identifying elements of the periodic table. Players will play the role of junior researchers in a chemistry lab. A bunch of samples of elements have been given to them and their job is to identify these samples and put them in the right position on the periodic table. The players will need to earn and spend the resources they get to identify elements by using their knowledge of the periodic table and the properties of the elements. The player scoring the most point by identifying the elements wins the game.

Learning objectives:

- Position and atomic number of elements
- Physical and chemical properties of elements
- Important application and availability around us
- Periodic trends

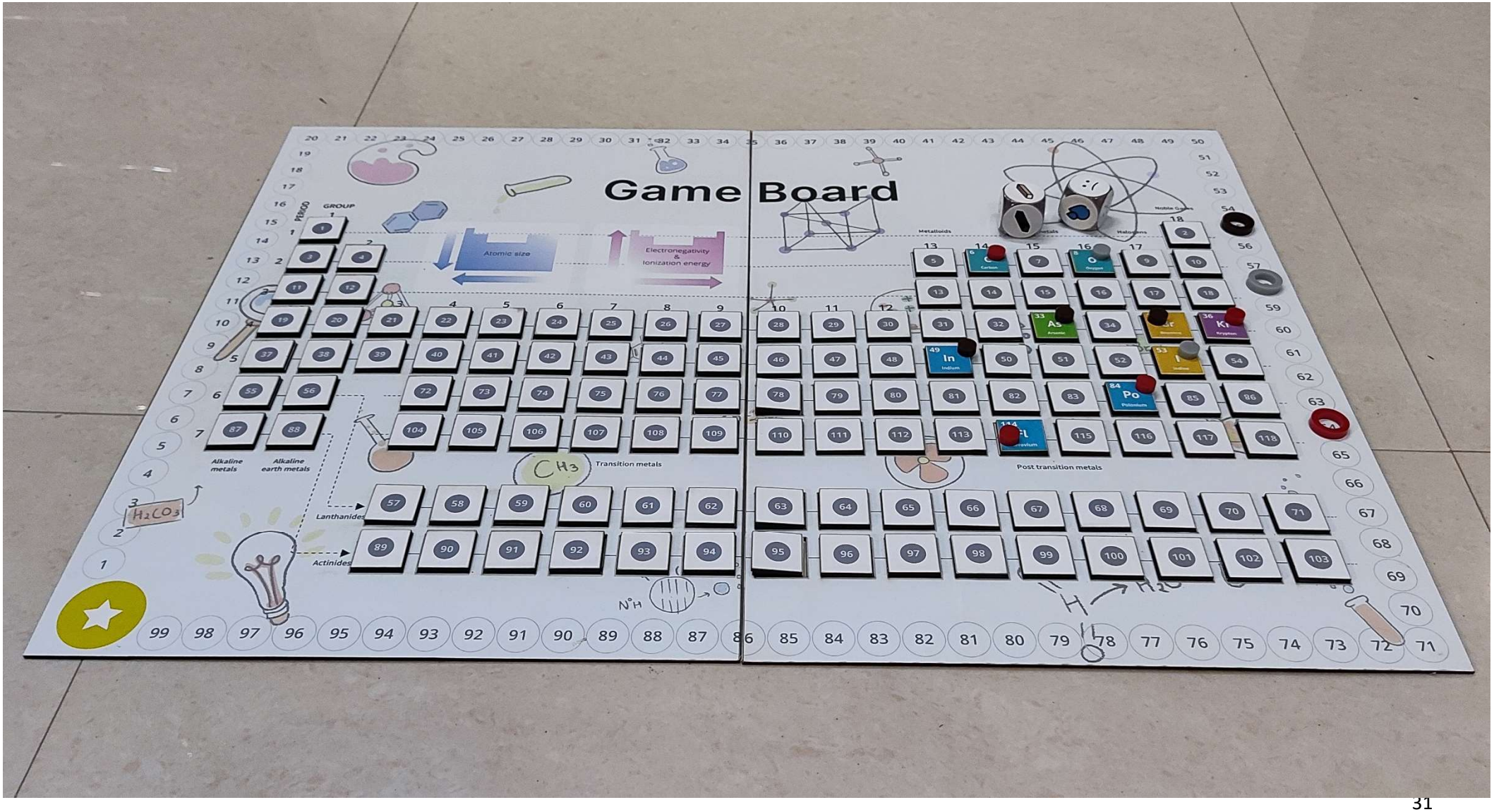
Number of players: 2-4 players

Medium: Board game with cards

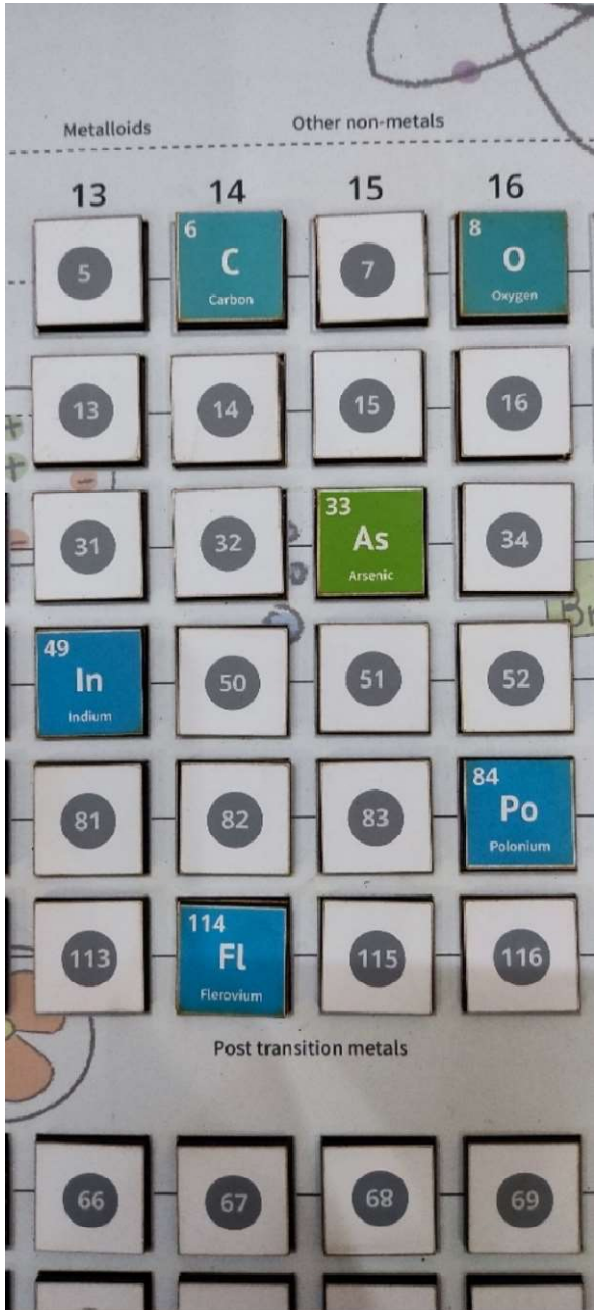
Game assets: Playing game board, 118 element tiles, 4 reference periodic tables, problem card decks, Book of elements, 18 resource cards (solid, liquid, gas, metal, non-metal, metalloid X 4 each), 2 resource dices, big scoring rings X 4, circle discovery tokens X 25, rule book, problem cards holder

Final outcome

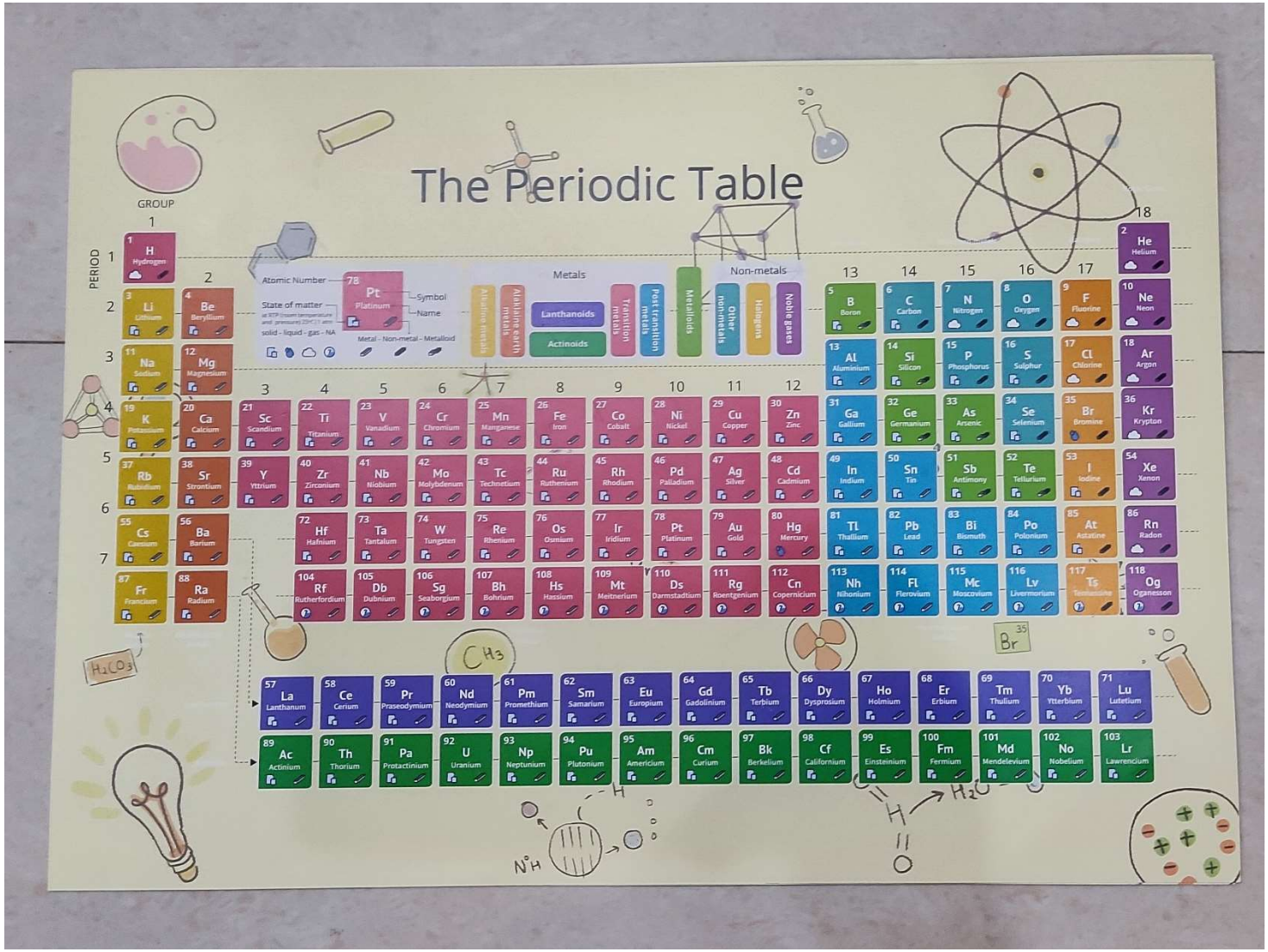
Game Board: a blank periodic table with element tiles on it



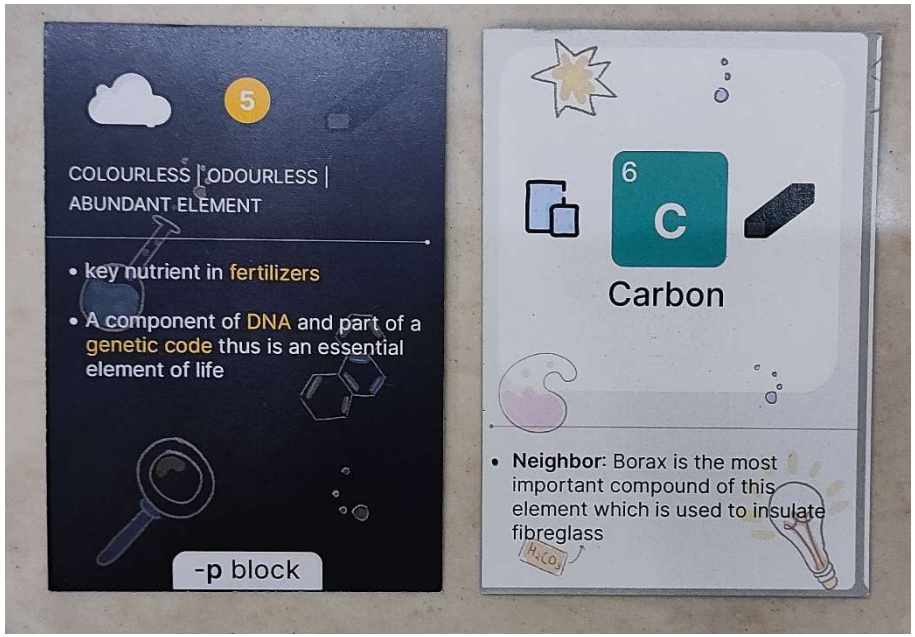
Element tiles: these tiles fit into the gameboard and has two sides; the blank side only has the atomic number while the other side has the name and symbol along with the atomic number. The tiles are turned as players start solving problem cards



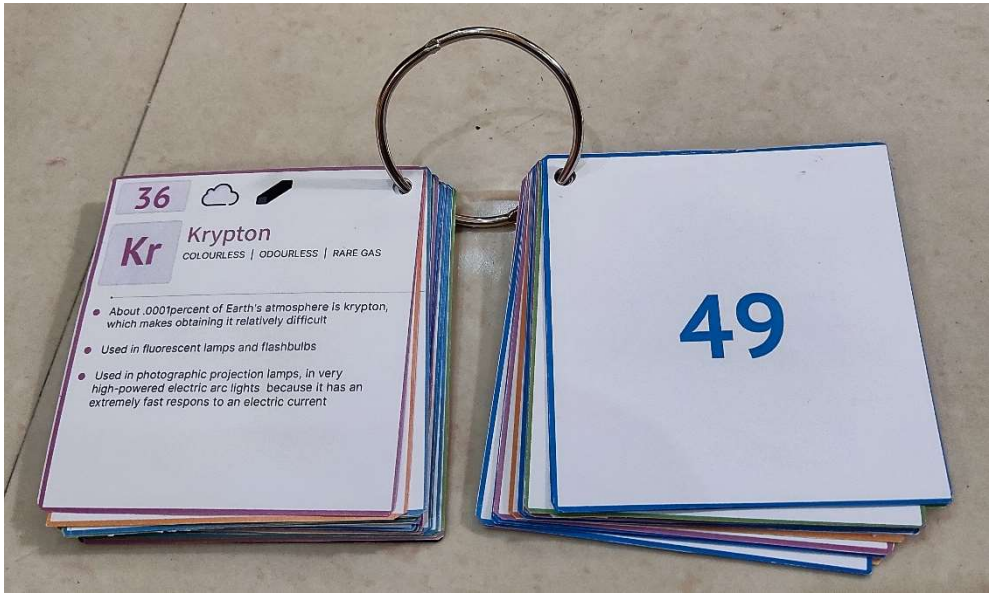
Reference periodic table: which can be used by players at any time



Problem cards: These cards have two sides, the one on the left, black side defines the physical and chemical properties and uses of an element using which the players have to identify the element. Once identified, a player can turn that card to see if the answer was right or not



Book of elements: This is a reference manual which can be used during the game by players by spending their resource coins. It is used when a player is suspecting an element on a problem card but is not entirely confident about it. It includes the physical and chemical properties and applications of all the elements.



Resource dices: These dice are rolled together to earn resources

Scoring rings: the rings are used to keep track of the score

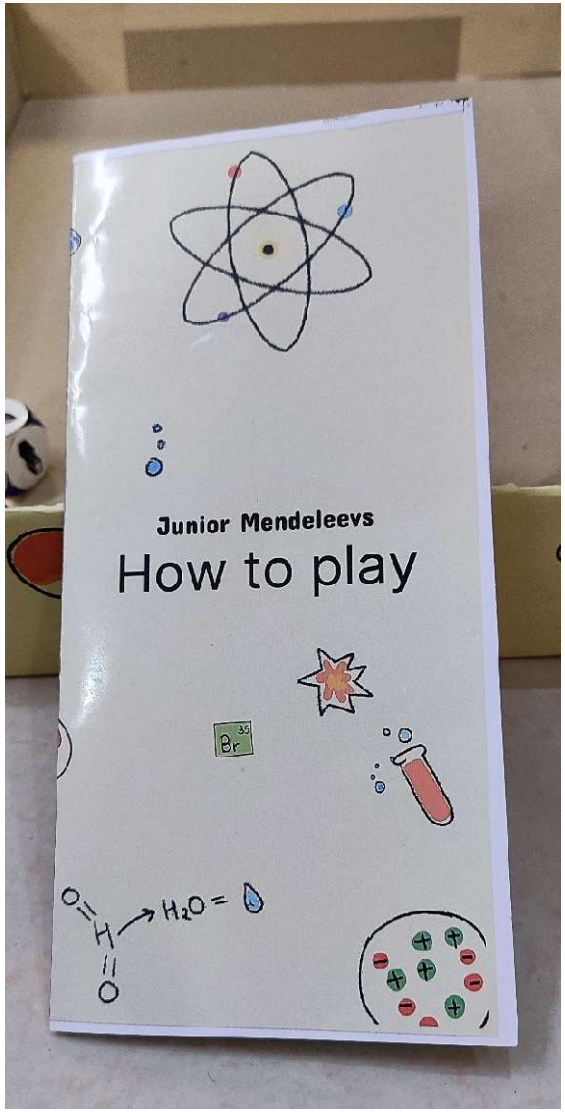
Discovery coins: These are used by players to mark the elements identified by them on the board and are part of currency of the game

Resource coins: These are resource coins which are earned and spend by players to identify an element or refer to the book of elements, this is the currency of the game

Problem cards holder: The card holder holds the card such that only one side is visible to the players

Hourglass: This is a 1-minute timer to time each player's turn, if delayed, the turn will be skipped

Rule book:



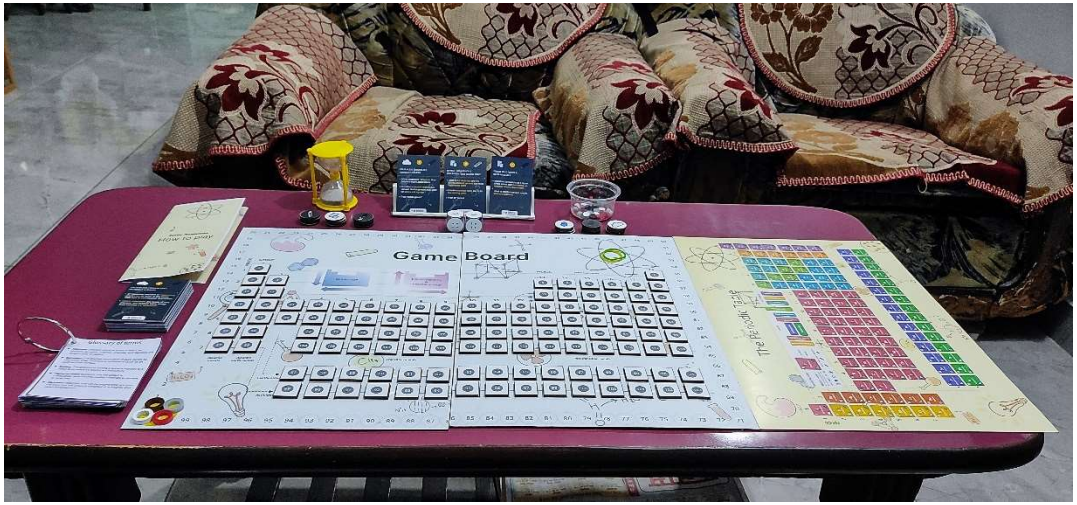
How to play

Difficulty levels:

- BEGINNER: Play one block at a time with 10 discovery coins
- INTERMEDIATE: Play a combination of adjacent blocks at a time (example- s & d block, d & p block, d & f block) 15 discovery coins
- ADVANCED: Play the entire periodic table at once with 20 discovery coins
- CUSTOMIZE VERSION: Players can also add problem cards of their own that they want to learn about in the problem card deck and play with discovery coins according to the number of blocks playing

Setup:

- First step is put down the two parts of the game board with tiles
- Distribute one reference table each to all the players
- Setup the problem card deck with black face up
- Keep the book of elements near the gameboard
- Setup the resource bank near the board
- Keep each player score ring on the start i.e., bottom left corner of the game board
- Each player starts with 10 discovery coins



Game play:

- 3 problem cards are drawn from the deck and kept white face up Infront of all the players
- Players read the cards and the aim is to compete and figure out which card belongs to which element
- Youngest player or the loser of the previous game starts the game
- In a turn, a player can do either of the following 3 things
    - **Roll the two dices** to get **resources** from the resource bank. The player **can't keep more than 5 resources** with themselves. If a player with 5 resources gets another resource, he can choose to keep that resource by discarding one his previous resources or the player can simply skip
    - Spend **one** of the **resources** drawn on the elements tile to **check the card of that element from the elements deck**. After reading up information on that element, the player puts the deck back down
    - When a player succeeds in solving a problem card, they can spend **one** of the **resources** drawn on the problem card and **a discovery coin** to **claim discovery of an element from the problem card by saying "I claim this card to be <u>XYZ element</u>** (ex- copper)". Once claimed discovery, the player can turn the card to check if he claimed the right element without showing it to the other players:
        - If the **claim was right**, the player shows the back of the card to other players, claim that card and gets to **turn that tile** on the game board, put his **discovery coin** on it and **move their score ring** based on the score mentioned on the problem card claimed. Another card is picked out from the problem card deck and kept in front of the players.
        - If the **claim was wrong**, the player will have to **keep the problem card** back to its place without showing it to other players and **give up on the resource and discovery coin** spent on claiming it. That player can't claim the same card again.
- The player can pick a resource of his choice if the bank runs out of the resource, he got on dice roll
- Players can also trade resources with each other
- The game is played till each player finishes their discovery coins and player with the highest score wins the game.

Final playtesting

With four 11th & 12th grade school children

- By letting the students read the rules, setup and play the game
- Making observations and taking feedback

Observations:

- The three previous players explained the rules to the new player themselves
- Around 25 element tiles were turned at the end of the game
- Again, there was a lot of interaction, trying to figure out the element and get information from other players
- This game was more competitive as it had more players
- Players themselves discussed at the end what all they got right and the mistakes others made
- The game session lasted for around an hour as expected
- Had trouble pronouncing the names of some elements

Learning:

- Learned about new elements which they haven't heard of
- Realized that bromine and mercury are the only liquid because the liquid resource coin was not very useful
- Old players identified some elements quickly as they remember the properties of the element from previous playtesting
- Some elements with overlapping uses could be differentiated by their physical properties only, so players gave attention that that too now after getting it wrong a few times

Feedback and suggestions:

- Was more fun with 4 more players
- Had fun and felt like they were doing something productive
- Gave a remark that they'll study and do better next time
- Suggested adding some surprise problem cards from some other block which is difficult but has a very high score to make it more fun

Conclusion

The goal of the project was to mix learn and play by designing a board game which is equally as fun to play as much as it helps in learning. For the project, I took the topic of periodic table, which I believed it to be a very important topic and also one which is considered very boring and tedious by the students.

Primary research with the students and literature review helped me design and iterate the concept better at each step. Understanding of game design principles, like effective use of conflict and randomness to make the game interesting also helped me analyse my output better. Reviewing the existing games helped me visualise my game mechanics better and how my game can serve to the shortcomings of the existing games.

Even after positive response from all the playtests, I believe more testing with more varied participants will help fine tune the game even better. There’s a lot of places to improve and innovate in the game. As theirs a never-ending list of compounds and reactions around us, the game can always be extended and customized to introduce more complex concepts and uses. The game may be played and experimented with to encourage students to learn and further to be more curious about the elements around them.

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