IDC School of Design
अभिकल्प विद्यालय

Designing a Game based on Secondary School Mathematics

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Guide
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Approval

The BDes Design Project - 1 titled "Designing a Game based on Secondary School Mathematics" by Prita Raut is approved, in partial fulfilment of the Bachelor in Design Degree at IDC School of Design, Indian Institute of Technology Bombay.

Project Guide   Chairperson

Internal Examiner   External Examiner

Declaration

I declare that this written document represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and provided reference to the original sources.

I also declare that I have adhered to all the principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea or data or fact or source in my submission.

I understand that any violation of the above will call for disciplinary action by the institute and can also evoke penal action from the sources which have not been properly cited or from whom proper permission has not been taken when needed.

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Acknowledgements

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Abstract

Maths is a subject that plays a crucial role to help develop analytical and logical reasoning skills. However, it is perceived as a difficult subject by students and there is fear and anxiety associated with it which affects the interest students have in studying it. New ways of teaching and learning have come up which attempt to make studying enjoyable. In this project I have attempted to design a game to practise maths in a fun way.

TrigieTwins is a board game for students of Std 7th and Std 8th to practise the concepts of properties of triangles and congruence of triangles. In this players make pairs of congruent triangles and try to collect groups marked on the board along with trying to stop their opponent from winning by using power cards. This game can be played in the school with classmates or at home with siblings, friends or parents. For anyone who doesn't know the concept of congruence or properties of triangles, quick revision guide is provided that can be referred to play.

Introduction

Secondary School Maths Education

Maths is a subject that helps to develop logical reasoning and analytical thinking skills required in our day to day life. It also has a crucial part in other subjects like physics, chemistry, economics etc.

However, studies show that a considerable number of students have feelings of fear and anxiety associated with the subject due to the belief they have in their abilities and the perceived difficulty of the subject which has a negative effect on their interest to study maths.

What students learn in Std 8th and Std 9th forms the foundation for more advanced topics that they'll learn in the coming years so this is a crucial stage. This is also the stage where students lose interest in maths as more complex topics are introduced.

NEP 2020 and New Approaches to Education

As proposed in the NEP 2020, curriculum content will be reduced in each subject to its core essentials, to make space for critical thinking and more holistic, inquiry based, discovery based, discussion based, and analysis based learning.

Teaching and learning will be conducted in a more interactive manner. Questions will be encouraged, and classroom sessions will regularly contain more fun, creative, collaborative, and exploratory activities for students for deeper and more experiential learning.

Teachers often attempt to make studying fun and enjoyable using different methods to keep students engaged. Some of the ways include:

1. Conducting activities to demonstrate concepts
eg- activities involving paper cut outs is used to teach geometry

2. Using games or gamification
eg - motivating students to do their homework consistently by using some sort of reward system

3. Videos for better understanding of relevant topics
eg - video content for teaching 3D geometry

4. Mnemonics for memorising formulae
eg - mnemonics are used to remember formulae in trigonometry and rules of matrices

Literature Review

I went through some papers to understand some of the aspects of designing games based on maths so that I can keep those things in mind when I am ideating.

Papers on the effects of competition, collaboration and contextualised advisement were read to understand in what way can game mechanism be designed so that students who are fearful or lagging behind can learn from other players - classmates, friends, parents or teacher while playing the game. Some of the points are:

Flow Theory

- To create engagement using intrinsic motivation, feedback, balance between skills and challenge and a sense of control.

- Set of goals must be clear and task performed should be intrinsically rewarding. It can be solitary or in a group. It could be competitive or non-competitive. It could be athletic or artistic.

- The difficulty level and skill should match. Challenge should be just slightly greater than skill to avoid boredom but not so much that it will create stress or anxiety.

- There are two types of flow - microflow which is about a single game session and emotionally intense and macroflow which is the experience one gets over a period of time, after multiple game sessions like different levels in videogames.

Effect of Competition and Collaboration in educational games

- By collaborating, students can learn through discussion which is otherwise discouraged in a classroom setting.

- Competition and collaboration which seem contradictory occur simultaneously in team games.

- For below average students competition has a negative effect on learning happening in a collaborative setting and for above average students a positive effect on the learning happening in a collaborative setting

Effect of Competition and Contextualised Advisement

- Contextualized advisement is giving the participants guidance about solving a particular problem or helping make a decision in the game and is useful in games where students are expected to learn concepts by playing the game

- Here I can explore the possibility of involvement of the teacher or senior student for providing support in the game using some rules which can help guide students that can help students who are lagging behind.

Existing Games

I looked at various maths games like Go Fish trig, Interesting Integers, Variant: Limits, Back-2-Back, Vector Race, etc. having different intents like memorising, application of concepts and learning through experience to understand how they've incorporated the educational content and also look at the positive points and drawbacks.

Variant Limits / Experiential Learning

Variant is a video game based on limits and continuity from the Std 11 curriculum which involves using maths concepts to overcome obstacles which are in the form of contextualised puzzles to move ahead. Players can interact with the environment and manipulate elements and see the effect of it. In this game abstract maths concepts are put in a context close to real life so that it is easy for students to relate to.

## Interesting Integers / Application based
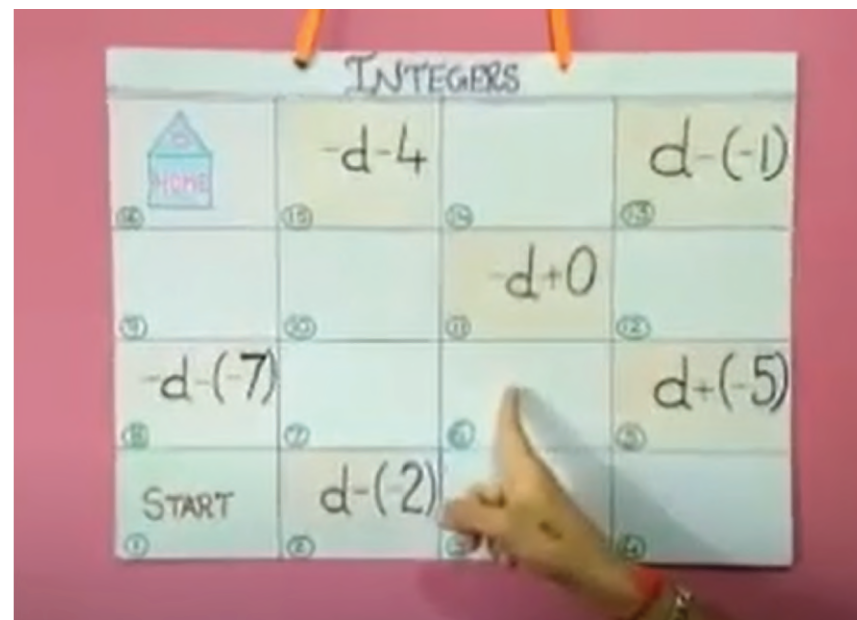
It is game meant for Std 6 students to practise rules of addition and subtraction of integers.

The game mechanics are based on that of snake and ladder where snakes and ladders are replaced by some algebraic expression. When a player lands on any expression, they have to substitute the dice number in it and move forward if the number is a positive number and backward if it is a negative number

Though this is less of a game by definition, it is still very useful for practising the integers in a fun way.

GoFish Trig / Memorising
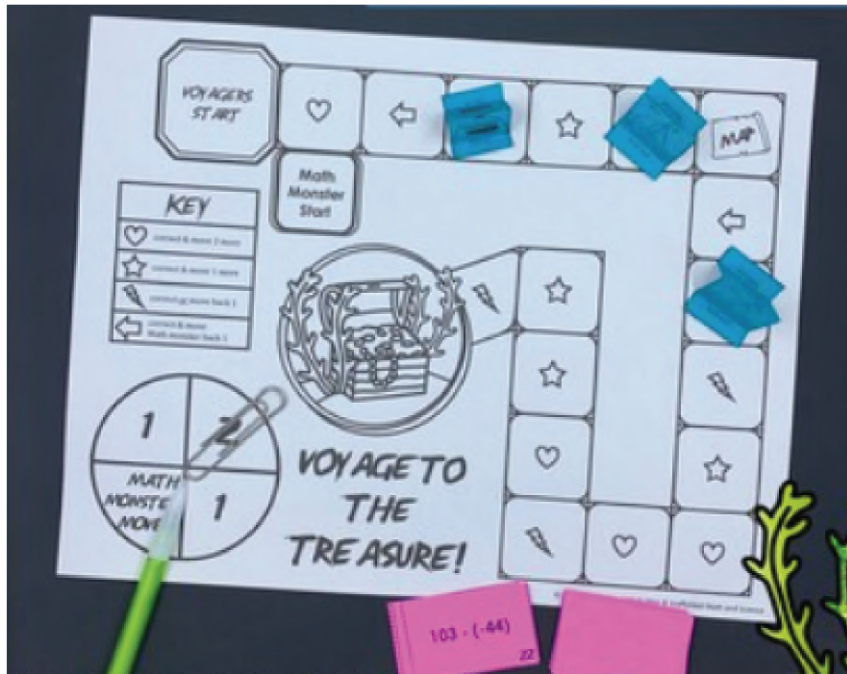
GoFish Trig is a game that helps in remembering trigonometric functions. Here the purpose is to memorise certain formulae and they have combined the fun element of an already existing game with the content that is to be memorised.

Objective

By looking at the existing games, I understood the three types of maths games - games for memorising, games for learning through experience and games to practise concepts already learnt.

In maths memorisation is done for formulae and certain principles. Games meant for memorising, the content to be memorised has to be repeated and the content may not become a part of the mechanics but act as something additional.

As understood through the literature review, learning concepts through the game itself which involves reflecting on the gameplay to develop understanding of concepts which requires active support of someone who is well versed with the topic like a teacher, parent, elder sibling. Toys or other tools can be more effective in these type of games as the main intention here would be to understand a concept through experiencing it.

For getting better at maths one has to practise it and after considering the points mentioned above, in this project I took the direction of games for practising concepts learnt in class and it can be an alternative to solving sums using pen and paper method.

Playing the game with classmates and friends for practising can promote discussion and peer-to-peer learning.

Selecting Topic

Target group for this project is secondary school students i.e. Std 8th to Std 10th. I went through the Mathematics textbooks for classes from Std 8th to 10th of the Maharashtra State Board and also text-books for classes one year before and after i.e. Std 7th and Std 12th in order to understand the topics covered there so that the level of the game can be maintained considering the prior knowledge and skill level according to flow theory. From this some topics were shortlisted as follows:

1. Properties in 2D geometry (7th, 8th, 9th)
2. Mathematical logic (11th)
3. Vectors (12th)
4. Sets (9th)

Out of the four, I decided to drop vectors as it is a more advanced topic and is included in the Std 12 curriculum. The core content and objective wasn't suitable for the kind of game I was looking at. Set theory was dropped as there were some existing games on that topic.

Finally I decided to go ahead with application of basic properties in 2D geometry as it was of moderate difficulty for the Std 8th students as compared to Mathematical logic which is considered an easy topic in the Std 11 curriculum.

I noted down all the topics and subtopics that is there in these chapters and what are the type of problems expected to be solved by the students.

Some considerations before starting with the design

1. It should be accesible and convertible to a simple game requiring minimum assets, or something that can be created easily using available materials in cases of resource constraints. eg - toys by Arving Gupta, pen and paper based games, textbook based games like book cricket, etc

2. Game that promotes conversation and explanation is good for peer to peer learning

3. If the game is to be played within a school, each period is not more than 30 minutes. So one game session should be over within that time. Moreover, the players shouldn't get mentally tired.

4. Add some real life context into the game, like where is this concept used in real life if possible

Preliminary Ideas

I started with ideating pen and paper based games and building up on it to come up with some preliminary ideas.

Game Idea 1 / Triangles

The game involves two decks of cards - 60 brown cards and 48 white cards having triangles with different data given about their measures. Some might have data about three sides or one side and two angles etc. Players have to match a triangle from one deck with a congruent triangle in the other deck to collect maximum points to win.

Medium - Board game
Topic - Properties and Congruence of Triangles
Type of questions in curriculum - Identifying test by which two triangles are congruent and if two are congruent, finding the dimensions of remaining
Number of players - 2 to 4

Basic Gameplay and Rules
1. Deck of brown cards are laid down on the table in a 10×6 manner and deck of white cards will be the draw deck. Initially each player will be given 5 cards which they will keep in their hands.

2. During each turn a player has to make a pair of cards having congruent triangles i.e. match one of the cards from their hand with one on the table. They also have to specify the reason and test of congruence.

3. After making a pair players have to draw one card from the deck which they can play during any of their subsequent turns.

4. Points that a player will earn on making a correct pair are mentioned on the brown cards(laid out on the table) and whoever collects the most points wins the game.

5. If a player matches an incorrect pair they have to keep the card from the table back onto the table and discard the card from their hand. It won't go back to the pile.


Design Decisions

Any card in hand will have multiple cards of different difficulty levels on the table that match. Points are dependent on the difficulty level of the card.

Some of them are easier, like in this example where it is straightforward that all the sides are equal and congruent and so the triangles are congruent by SSS test.

5 points

4 units
4 units
4 units

4 units
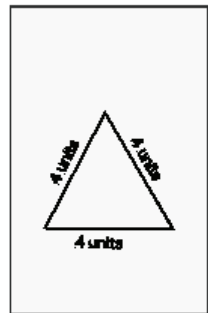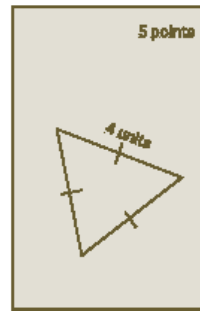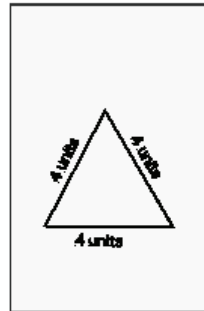
Some are a bit difficult which require mental calculation or concepts learnt earlier to verify the congruence. In this example where one needs to use properties of triangles in order to first understand the measures and then decide if the triangles are congruent.

10 points

4 units
4 units
4 units

4 units
60
60

There are also some tricky pairs like this one where one could state the test of congruence is SSA seeing the given data but that is not a valid test of congruence

4 units
4 units
4 units

4 units
60
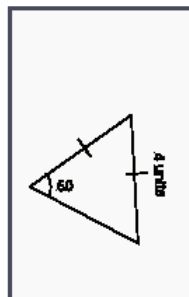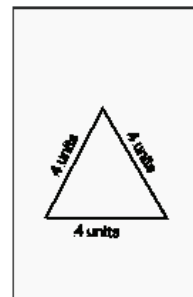
As there are multiple options for each card, even if a player is unable to match a difficult card they can still proceed in the game by matching any of the easy level cards
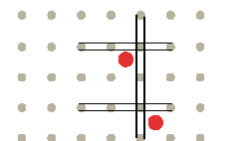
Game Idea 2 / Parallel lines and Transversal

The game consists of a geoboard, two game pieces per player and rubber bands for making segments.
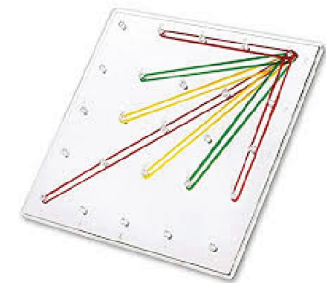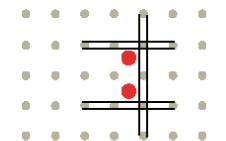
Players have to start from the middle of the board and make segments that are parallel or form a transversal. Players move their game pieces along the angles formed by parallel lines and transversal to reach the marked region along the border

Geoboard

of the gameboard and win. The angles occupied by the game pieces after a player's turn should be forming an interior, corresponding or alternate angles pair.
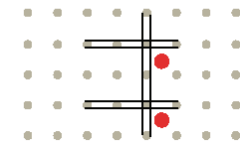
Alternate Angles   **Interior Angles**   **Corresponding Angles**

Topic - Pair of angles formed by parallel lines and transversal i.e. alternate, interior and corresponding angle pairs
Medium - Board game
Type of questions - Identifying the type of pair of angles, completing the pair and using properties of these angles to find measure of other angles
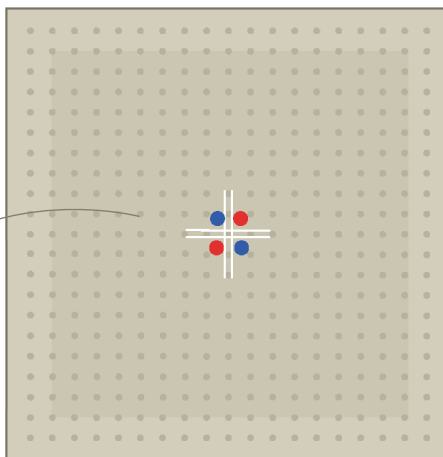**Number of players** - 2

Basic Gameplay and Rules

1. Gamepieces of both the players are at the middle region of the board as shown.

Player 1 • •   **Player 2** • •

2. During each turn the player can choose to add a new segment (using a rubber band) that will help them move forward in the game or move one end of an existing segment which can be a way to stop the opponent from making certain moves or not make any changes to the segments but only move a gamepiece.

3. It is mandatory for players to move one of their game pieces during each turn.

4. A segment can pass through a maximum of four pegs on the board.

5. Both the players cannot occupy the same place i.e. no two game pieces can be at the same angle at the same time.

Game Idea 3 / Quadrilaterals

In this game there are cards with diagrams of different types of quadrilaterals like square, rhombus, trapezium, parallelogram, etc with some of their dimensions and properties mentioned in notation form and on some cards in text form too.

Players have to identify the type of quadrilateral from the given data and make groups of 3 cards of different quadrilaterals. Some quadrilaterals can be categorised in two groups, so players can shift their cards from one group to the other group accordingly.
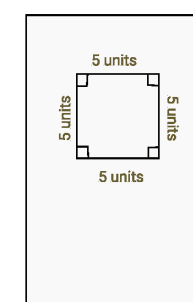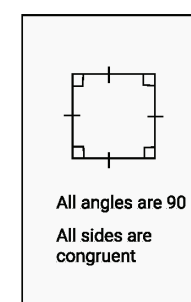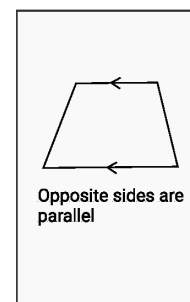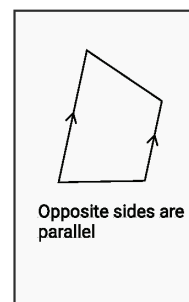
Topic - Types of Quadrilaterals and their properties
Medium - Card game
Type of questions - Identifying the type of pair of angles, completing the pair and using properties of thesecangles to find measure of other angle.
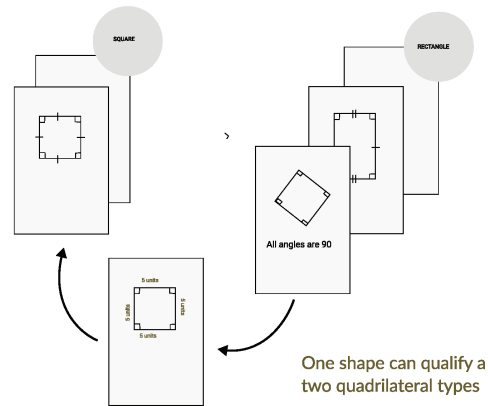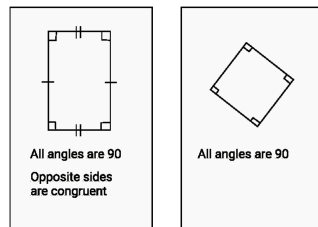**Number of players** - 2 to 4

10

Basic Gameplay and Rules

1. The deck of cards is shuffled and seven cards are distributed to each player. Rest of the cards are kept as the draw deck.

2. During each turn a player has to keep one card down , in front of themselves which will help them in making a group and after that pick up one card from the deck.

3. Players can re-arrage the cards that they have kept down i.e. move card from one group to the other quadrilateral group where it can fit

SQUARE

RECTANGLE

All angles are 90

5 units
5 units
5 units
5 units

One shape can qualify a two quadrilateral types

Rectangle or Parallelogram

All angles are 90
Opposite sides are congruent

All angles are 90

Square or Rhombus or Rectangle

All angles are 90
All sides are congruent

5 units
5 units
5 units
5 units

All angles are 90
All sides are 5cm
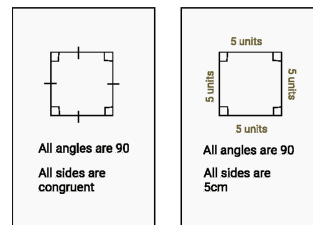
4. Reference cards with the properties and definition of each quadrilateral is available to all players.

Issues and Possible Refinements

After that the game was playtested and areas where improvement is needed were found. I came up with some ideas for refining them.

Issues in Game 1
Properties and Congruence of triangles

1. Player vs Player conflict is very little - Some way to make one player's move affect other player's game to a greater extent was needed. The first player has a huge advantage. Some of the ways to improve this can be as follows:
• Special cards to make players perform some tasks in the game
• After every turn players pass one of their cards to the next player
• One property from the previously matched triangles should be carried forward like type of triangle or the test of congruence.

2. Concept of one-to-one correspondence of the congruent parts is missing - It can be included as a part of power cards where opponent has to specify one-to-one correspondence or it can be included as a part of data provided on some of the triangle cards.

3. Too many cards - There are too many cards of different types and it was a hassle to segregate them each time and arrange them on the table. For this, the cards can be converted into a gameboard

Issues in Game 2
Angles formed by Parallel lines and Transversal

1. It gets very complicated and difficult to visualise the transversals and angle pairs formed as the game progresses and the number of segments increase. To solve this problem number of pegs can be reduced so that the possible number of segments is reduced. Another way is to limit the number of segments that each player can add. Another option was to use different colours for segments and using the same colour for parallel lines which will make it easy to spot them and identify the transversals and angles formed.

2. Randomising Factor - There is a high chance of the game going in the same way each time. Also, the first player has a huge advantage here. Dice or a twister can be used to determine the length of the segment that a player can make during their turn which would be a randomising factor

Issues in Game 3
Types of Quadrilaterals and Properties

Player vs Player conflict is very little - The problem in this is the same as the first game. Players interact with the system but it doesn't affect the other player's actions much. The game can be extended to triangles and its types.

Iterations

After the initial round of ideation for refinement of the three games, I analysed and evaluated the scope of further development based on the parameter of match between content objective and gameplay, complexity and fun. Based on this I decided to take forward the first game involving properties and congruence of triangles

Changes / Iteration 1

1. Game Board instead of Cards
There will be a board which has triangles of different dimensions and different data provided for each with some common sides instead of having individual cards laid out
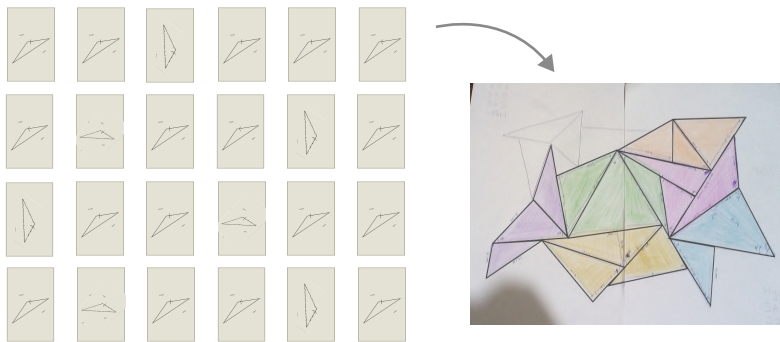
The triangles are divided into groups which are represented by different colours. A player will have to complete matching two such groups in order to win

2. Power Cards
In addition to the cards having triangles, the other type of cards would be power cards that give the players some powers to move ahead or block the opponent. Some of the power cards can be:

• Specifying the type of triangle for opponent - isosceles, equilateral, scalene etc to be matched by an opponent
• Drawing 2 cards from the deck
• Next person skips turn
• Exchange chip on the board
• Exchange card in hand

3. Triangle cards of opponent are visible
When opponent's triangle cards are visible, it helps in planning and blocking them. This also encourages players to match cards that other than their own cards. But this can also lead to players giving up if they can see that their opponent has good cards regardless of whether they are matched or not which can be tested.

Refined Gameplay and Rules / Iteration 1
1. The starting of the game is similar to the previous version with the change being that of introduction of the gameboard. The gameboard is arranged on a flat surface. There is a single deck of cards which is shuffled and five cards are distributed to each player. Remaining cards are kept as the draw deck. Players choose their marking chips (Change in game asset)

2. Before matching a triangle card from the hand with a triangle on the board, the triangle card has to be placed down on the table, visible to all players. This is counted as a separate move (New Rule)

3. During each turn a player has to make atleast one or maximum two moves which can include matching a triangle, keeping a triangle card down or playing an action card.

4. To match a card, players will move it from their front to the discard pile.

5. After each playing a turn, players collect two cards from the draw deck which they can play during any of their subsequent turns

6. If a player makes a mistake they skip the current turn and can match the card accurately in their subsequent turns. In case of dispute the correct answer can be cross checked from the provided solutions sheet.

Design Decisions in the refined gameplay

Some triangles that can be matched include two or more smaller triangles. If the bigger triangle is matched, players get to place a marking chip on each of the individual triangles that are a part
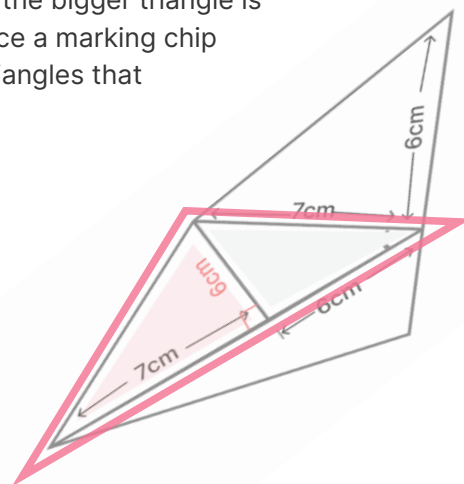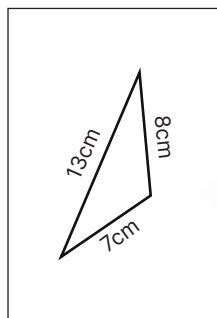
Some triangles do not have their complete information mentioned on the cards but require some adjacent triangle to be matched which will reveal complete information by the concept of correspondence of congruent triangles. This is another way to block an opponent. Players can hoard the cards that their opponents need.
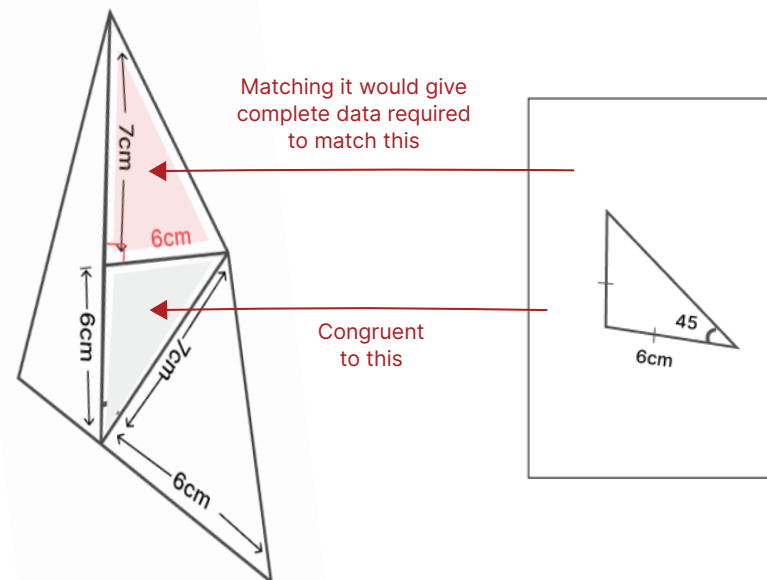
In each group there are triangles of three difficulty levels (mentioned in the previous version) to encourage students to attempt to solve problems of all difficulty levels.

Quick Mockup for testing

Gameboard

Group 1

Group 5

Group 2

Group 6

Group 4

Group 3

Triangle Cards

Marking Chips

Power Cards
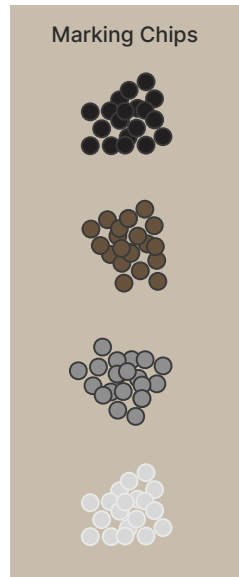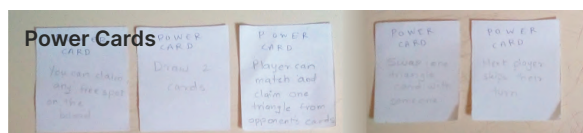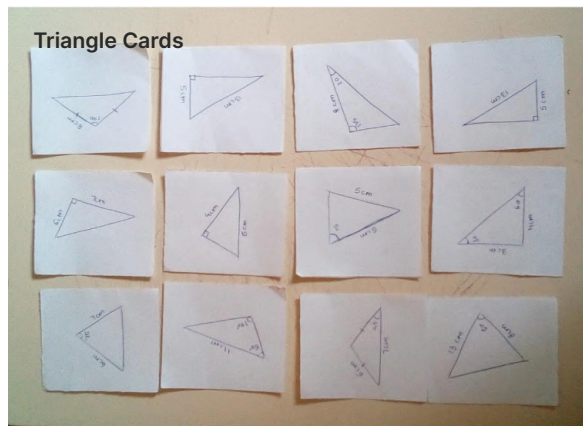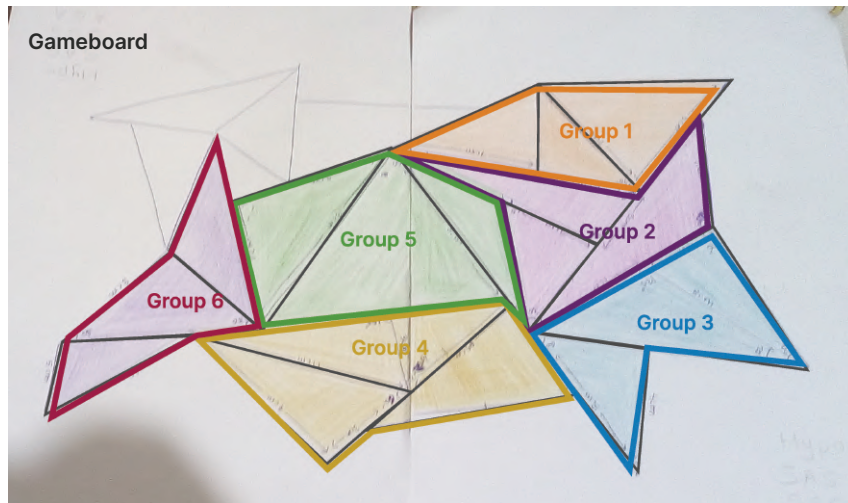
Testing the game

The game was tested with two students studying in Std 7th and 9th. Further refinements were done.

Issues and Refinements / Iteration 2

1. Each turn takes too long - Making two moves required more time to think and slowed down the game. For that, players play only one move during each turn and players didn't need to think of too

2. Process of matching is slow - Players don't have to keep the triangle card in front of them before they can match it. So, the triangle cards are not visible to the opponents.

2. Mental calculations take time and affect strategy - The dimensions involve simple calculations as the focus of the game is not to get better at arithmetic calculations

3. Replayability - The game board is made as four separate pieces that can be arranged to create different patterns of the game board. Some new triangles are formed at the intersections when different combinations are made.

2. Strategizing - On the game board, one can move their chips to other congruent triangles

Rough Prototype

Final Game

Name TrigieTwins

Topic Properties and Congruence of Triangles

Number of Players 2 to 4 / Can be played with or without a supervisor

Medium Card + Board

Contents of the Box
4 Game Board pieces, 20 Black Marker Chips, 20 White Marker Chips, 20 Brown Marker Chips, 20 Grey Marker Chips, 32 Coloured Triangle Cards, 32 Triangle Cards, 10 Power Cards, Rule book, Quick Revision Guides, Answer Key

How to Play

Difficulty levels

Beginner - Use all coloured triangle cards + All power cards

Intermediate - Use all cards from one of the decks + Any 7 cards from the other deck + All Power Cards

Advanced - Use all non coloured cards + All Power Cards

Setting up and Starting the game

Players can mutually decide who will shuffle OR in case of dispute, one card is given to each player and whoever has the lowest number on their card will shuffle. Person sitting to the right of the one who shuffled plays first.

Shuffling Cards

Five cards are distributed to each player and the rest are kept facing downwards as a draw deck. Players choose their marking chips. Players view their respective cards.


Distributitng Cards

Each player arranges one gameboard piece in the play area in any pattern with at least one complete edge touching the complete edge of one other triangle.

Arranging the board

Playing your turn

1. During each turn a player has to play one of the cards from their hand i.e. a triangle card which has to be matched with a congruent triangle on the board OR use a power card to avail the mentioned power. At the end of the player's turn they draw one card from the deck.

2. When a player wants to play a triangle card, they place it in front of them and mark the triangle congruent to it on the board by placing their marking chip with plain side (without dot) on top, on that triangle.
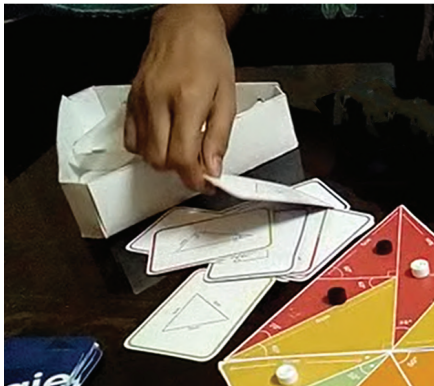

3. A player can play a power card by placing it next to the deck of cards and performing the said action.

4. Players must justify their match by mentioning the relevant sides and angles involved and specify the test of congruence.

If a mistake is made

1. A player can challenge their opponent if they feel their match is incorrect. If a mistake in matching triangles is found the player will skip the current turn and they can match that card later in their subsequent turns. However if the person who challenged is wrong, they'll have to skip their next turn.

2. If a player misses to pick up a card after their turn, they don't get a pick up a card later

3. In case of dispute regarding correct answer, answer sheet can be referred

Game Rules
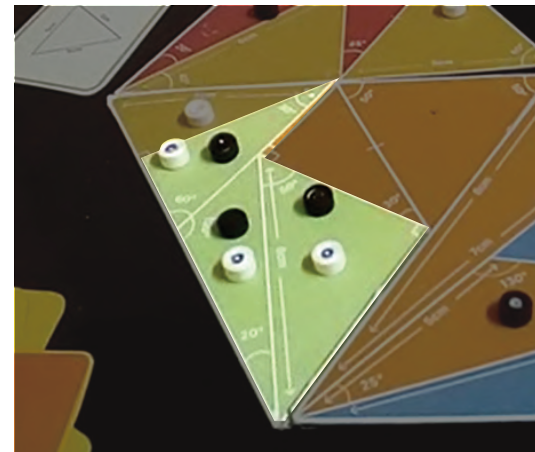
1. If one player has completed matching triangles in a group, other players can still try to match the group and both the players can count that group to fulfil their requirements

2. A player can move their marking chip which is placed on the board to another triangle on the board which is congruent. This would be counted as one move.

Moving Chip
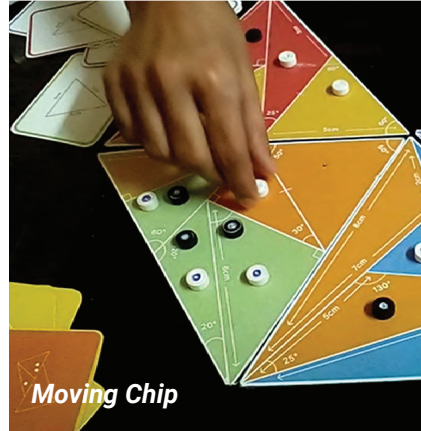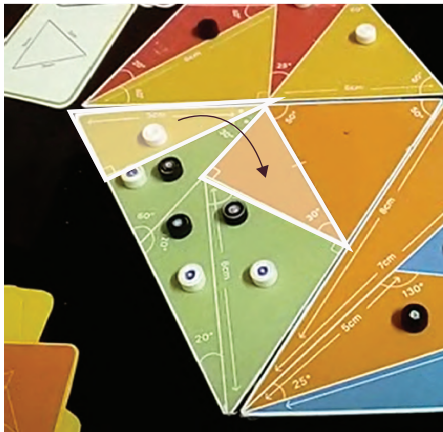
3. In case a player gets a card which they have already marked, they have the option to exchange the card by keeping it at the bottom of the deck and get a new card from the top OR retain the card to match to a different triangle on the board

Keep one card

Take one card

4. If a triangle consists of smaller triangles, the player will place one marking chip on each of the smaller triangle contained in the bigger triangle

Bigger Triangle

Smaller Triangle
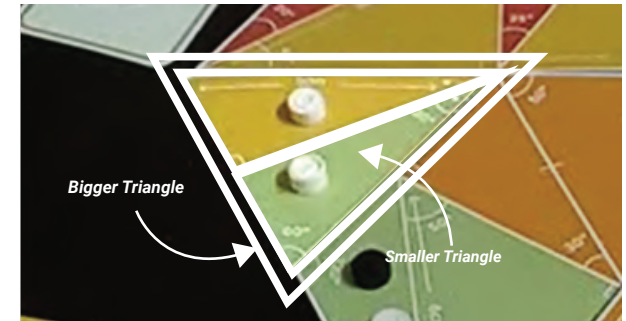
5. When a group is completely matched by a player, chips that completed that group are flipped i.e. have the dot side up which denotes that they are locked.
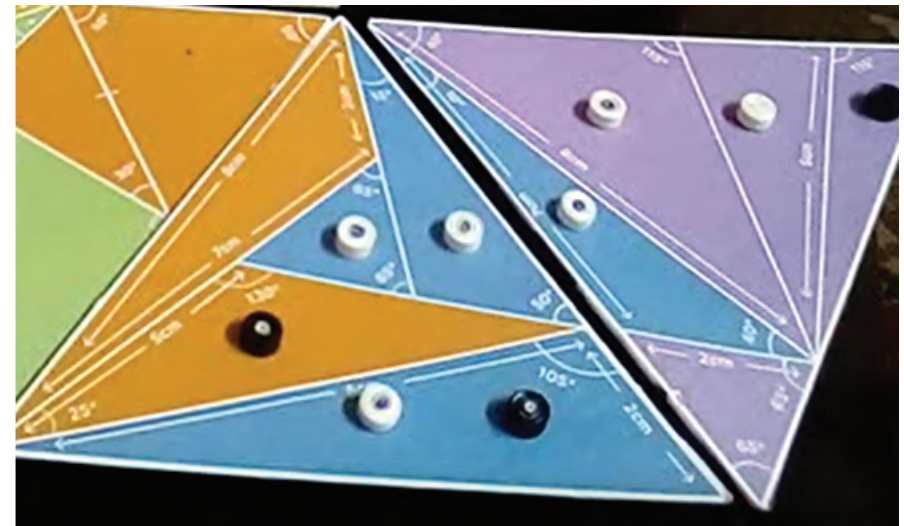
6. Opponents cannot make changes to any of the chips that form a complete group and are locked. The player to whom the chips belong can move any of the chips to another triangle. In this case the group won't be considered as complete and opponents can use power cards to change the position of the chips.

7. Colours on the cards represent one or two of the groups where a triangle congruent to that on the card may be found. There may be more congruent triangles in groups other than those mentioned.

8. The game can be played with or without a supervisor. A supervisor can provide hints and guide students in the game.

Advanced Rules

1. If two or more players have matched triangles in the same group, whoever completes the group first gets to keep it and the chips are locked by flipping them.

2. For winning, the two groups completed should be adjacent to each other i.e. at least two triangles from one group should have atleast two triangles of the other group adjacent to it.

Adjacent Groups
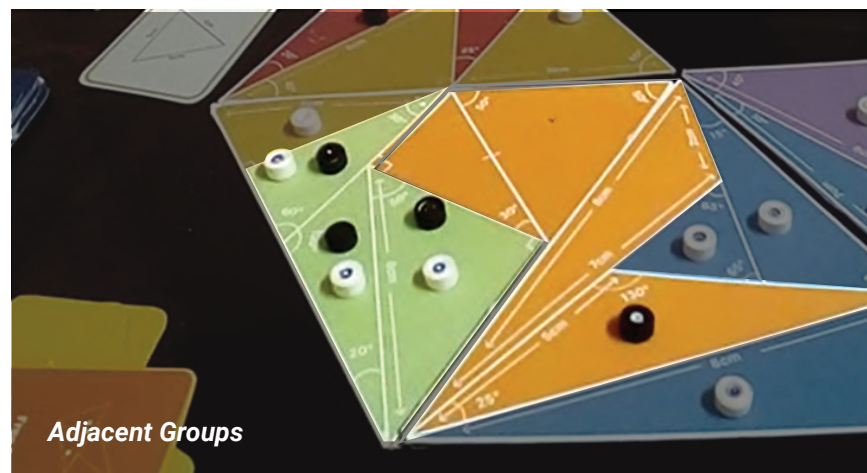
Quick Revision Guides

Players can refer to the quick revision guides for types of triangles, their properties and tests of congruence.

Power Cards

Free Spot - Players can place their marking chip on any one of the triangles on the board. Players can not claim a triangle consisting of smaller triangles.

Keep one, Take one - Players have to keep one card from their hand at the bottom of the draw deck and draw one card from the top of the deck

Swap Card - Player gives one of the cards from their hand of their choice to another player and draw a random card from the opponent's hand. Opponent can't decide which card to give.

Swap Triangles - Player exchanges one of their marking chips on the board with that of any other player

Remove a chip - Player removes a marking chip of any colour on the board. Players can not remove a locked chip

Lock your chip - Player can choose of chip which will be locked and opponent's cannot change affect it.

Evaluation

Two students studying in Std 7th and 9th played the
game twice. The gameplay and rules were not explained to them and
they understood the game by reading the rulebook. Feedback was
taken from the students and observations were noted down.

Results / Observations

The players took time to understand the rules. Players went through the quick revision guides at the beginning of the game.

One of the players had not been taught the chapter formally in school yet but was able to play the game by referring to the revision guide. They showed eagerness to learn so that they can be better at playing the game and can compete with their opponents in a better way.

In the first game session(trial round) only the basic rules were used by players and they focused only on matching their own cards and didn't make effective use of power cards or rules like moving chip from one triangle on the board to other. However as the players got comfortable and the game got intense, game rules to block the opponent or get an advantage were used effectively. The discussion between players also increased as the game progressed.

Number of problems solved - Each student had matched around 10 triangles which is equivalent to solving 10 sums.

Duration of each game session - Each game session lasted for around 30 to 45 minutes which was a bit more than what was intended.

The players were not following the rule of mentioning the test of congruence when the match was straightforward. However they were explaining the logic when a particular match required some calculation or use of properties.

Feedback

Student 1 / Std 7th / Not familiar with the concept beforehand
• Gave suggesion of having more gameboards so you can play with more number of boards depending on the number of players
• Liked the game based on maths as they learnt something while having fun.

Student 2 / Std 9th/ Familiar with the concept beforehand
• Doesn't like solving sums in pen and paper method
• Liked the fact that players can talk and joke which is otherwise prohibited during study time

The game is most relevant when played when students are learning the topic in school and can immediately practise the concept by playing this game.

Even though the intention of the game is for practising, students who are not yet taught can also play it and understand the concept while playing the game with someone who is well versed in the topic which was understood after testing. So it can be used as a tool for teaching and learning as well.

Conclusion

The goal of the project was to attempt to design a game as a fun way to practise some maths concepts from the secondary school level. A board game based on triangles considering the curriculum of Std 8 was designed, prototyped and evaluated after several rounds of iterations and testing.

The literature review helped in taking various design decisions for the game at various stages like the flow theory helped in setting the difficulty levels by selecting appropriate content considering the prior knowledge as well as designing the different layers of difficulty as the players considering microflow and macroflow. It also helped in understanding why certain parts of the game were not so fun and how it can be made better and also setting the objective of the project. Paper on contextualised advisement helped in understanding the perspective of players who are not already acquainted with the maths content whereas the one on competition and collaboration helped in making decisions about related to whether the game should involve teams or should it be an individual game.

The analysis of existing games helped in understanding the different possible directions and choosing one appropriately.

Though there was positive response during evaluation, testing with more participants is required. There is still scope for further improvement. The gameplay can be extended to incorporate concepts from other chapters in 2D geometry like quadrilaterals or parallel lines and an advanced version

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