Final Design Report

By Team 334 (Section 011)

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Abstract

Studies have shown that elementary-aged children's critical thinking and problem-solving skills are significantly worse than those of previous generations at their age. The rise of handheld devices most likely causes this A majority of the activities kids are engaging in on their devices aren't stimulating for the brain, leading to underdeveloped problem-solving skills. Our project, a functional prototype of a puzzle-oriented board game for children ages 2-12, was designed to combat this issue while incorporating at least one laser-cut component, at least one 3D-printed component, and one Circuit Playground Express from Adafruit Industries. The final design is composed of a 3D-printed body, two plastic buttons, a battery pack, a CPX, and laser-cut wooden tiles that are painted in a variety of colors. The buttons fit into two holes in the body, the CPX sits on an indentation that has holes for wire access, the battery sits inside the game body (under the CPX), and the tiles sit in the playspace of the game body. To validate our final design, three types of tests were conducted: a user survey, mass and volume calculations, and test trials of the game. All tests were designed to evaluate a series of metrics that were created during the first stage of project development. While it is unclear whether we reached our original goal of increasing critical thinking skills among children, almost every other metric was met, and efforts should be continued in the development of this project.

Introduction: Background and Significance

Most people ages 30 and older can relate to playing board games as children and family game nights being a part of their childhood. However, with the rise of technology and screen time, we have seen a significant decrease in board games played by the younger generation. In correlation, a recent study suggests that the overall attention span and critical thinking skills of kids in the younger generation have become worse [2]. This decline in board game playing is more than just a change of entertainment. It has concerning effects on children regarding their cognitive development. Board games were a common way for kids to practice problem-solving, patience, and strategic thinking and improve their interpersonal skills [9]. In the age of digital media, kids instead spend much of their time online, during which the brain isn't challenged as much,h if at all [7]. Without these traditional forms of mental exercise, kids in the new generation have missed important opportunities to improve their critical thinking skills. This has become a growing problem among parents and educators looking for the newer generation's mental strength.

Though many board games sharpen critical thinking skills, a particular category of board games, known as Eurogames, is known for this. Eurogames are known for three key things: "thematic subject matter, off-board play, and several ways of winning." Examples of popular Eurogames include Catan and Ticket to Ride [1] (Appendix A). In both of these games, there's a central theme that turns gameplay into an immersive experience that provides those, as mentioned earlier, "off-board play," meaning most of

the game is the interactions between players and the strategy each player decides to use [1]. Games that are flexible in design, scoring system, and ways to win, such as Catan's modular game board and varying Victory Point system, are efficient tools for developing and sharpening critical thinking and problem-solving skills [8] (Appendix A). Each game is completely different from the last, posing new challenges that force players to come up with different solutions and overall creating new mental exercises with each game that keep the players engaged and sharp. However, not many Eurogames are easy for amateurs and kids ages 2-12 to understand as they're marketed for more seasoned players and older audiences.

There are a wide variety of games with a focus on critical thinking, such as "Risk" [3], "The Oregon Trail" [4], "Catan" [5], "Clue" [6] (Appendix A), and many more. With such a wide range of potential benchmarks and a need for tools that develop critical thinking in kids ages 2-12, we can fine-tune our game to precisely what we are aiming to achieve (Appendix B). We have determined that there is a strong appeal for tabletop games that incorporate lights and sound into their design (Appendix B), and using this information, we can adapt our game to meet market demand. The use of lights and sound coupled with manufacturing processes, such as 3D printing and laser cutting, may help promote an interest in STEM in addition to developing critical thinking and problem-solving skills. Based on the previously stated information, we are confident that there is a strong market for games focused on critical thinking.

Project Scope

To create a functional prototype of a puzzle-oriented board game for children ages 2-12 that promotes critical thinking and problem-solving skills that incorporates at least one laser-cut component, at least one 3D-printed component, and one Circuit Playground Express from Adafruit Industries.

Wants and Constraints

The goal of this project was to create a board game to promote critical thinking and problem-solving skills, which prompted the first and most important of the wants. The next four wants were based on user-centered research and benchmarking that highlighted the key factors consumers looked for in a product: affordability, portability, quick and easy gameplay, and visual interest (Appendix A, Appendix B). The constraints were pulled from the semester project proposal,t and they all hold the same level of importance.

Wants:

- Improves Critical Thinking Skills:
    - The board game must improve the critical thinking skills of the player over time, so there should be puzzle- or problem-solving elements to the game.
- Affordable:
    - The board game should be affordable to make it easily accessible for any potential consumer with kids.
- Portable:

    - The board game should be lightweight and portable to allow for easy transportation for young children and to promote on-the-go play.
- Relatively Quick Gameplay:
    - Gameplay should be relatively quick to keep the attention of the player and to allow for gameplay at any convenient time.
- Visually Appealing:
    - The board game should be visually appealing to catch the attention of potential consumers and to be visually stimulating for young players.

Constraints:

- Uses 3D Printed Material:
    - The board game must contain 3D Printed Material but no more than 3,168 cm^3 in volume.
- Uses Laser-Cut Material:
    - The board game must contain laser-cut birch plywood but no more than 900 mm^2 in area.
- Uses Circuit Playground:
    - The board game must utilize the Adafruit Circuit Playground Express in gameplay.
- Limit Minimum Size of Parts:
    - To prevent choking, no piece can be less than 5 mm^3 in volume.

Design Metrics

The wants and constraints detailed above are listed in the Metrics Table in order from top to bottom as most important to least important based on our target value justifications (Appendix C).

Metrics Table:

Wants	Description	Metric	Target Value
Improves critical thinking skills	The game needs to have an impact on the critical thinking skills of our target audience.	Knowledge test	60% increase in score on a critical thinking assessment after playing the game.
Affordable	The product needs to be within a reasonable price range.	Cost of goods	<$25
Portable	It needs to be small enough that it can be transported comfortably.	Mass and volume	< 3lbs and < 3125 cm^3
Relatively quick gameplay	Each round of the game needs to be short	Time spent per game	20-25 mins

	so as not to lose children's attention.		
Visually appealing	The game needs to look nice and finished; appearance should make people interested in playing.	User survey	>70% of people would buy the game based on appearance alone
Constraints	**Description**	**Metric**	**Target Value**
Uses 3D printed material	Some components of the game need to be made of PLA and produced by a 3D printer at the Makerspace.	Volume	< 33 x 24 x 4cm
Uses laser-cut material	Some components of the game need to be made of wood and cut using a laser cutter at the Makerspace.	Size	< 300 mm x 300 mm
Use Circuit Playground	The game needs to utilize at least the CPX part of Circuit Playground.	Present	True
Limit the minimum size of parts	Parts cannot be smaller than a certain size due to the lack of motor skills in children and to prevent a choking hazard.	Volume	5mm^3

Concept Generation and Selection

Preliminary Concepts:

- **Concept 1:** Two players are given the same picture and have to recreate it using certain pieces before the other player does. The pieces can only move in certain directions based on their color. A multiplayer component is built into the game by comparing the number of moves required for each player to reach the final state shown on the Play card. The lights on the CPX will show blue when it's player 1's turn. After each move, the player should press a button to indicate that a move has been made. Repeat the action for each turn made until the state shown on

the play card is achieved. There will be a second button to indicate player change. Once pressed, the CPX will shine red, and Player 2 can repeat the actions of Player 1. Once the player change button has been pressed a second time, the CPX will flash the color of the winning player.

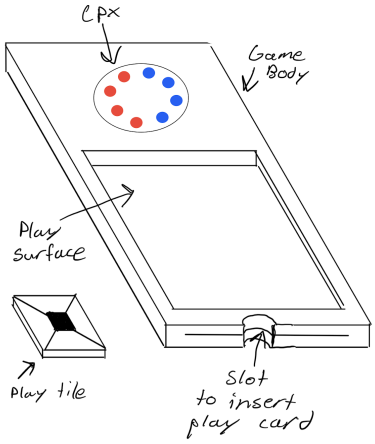
- **Concept 2:** Players move their respective pieces around a board and receive different scenarios based on where they land. They are rewarded points based on the player's response to the scenario. The game would be adventure-themed and would be multiplayer,r with up to 5 people playing at one time. The players would compete with one another to reach the end of the game. They would make progress depending on what their solution to the challenges were. The players roll the dice, and depending on which space they land on, they would reveal a challenge card. The game involves building resources and adventure teams to reach the end of the game. The game only ends when one player has reached the end of the game.
- **Concept 3:** This is a cafe-themed Monopoly and Catan fusion where players manage their cafes that sell three items: coffee, bread, and donuts. The objective of the game is to grow the most profitable business until all other players are forced to file for bankruptcy. This is a multiplayer game that can accommodate up to 4 players. Players would move around the board according to the spin of a die (the CPX), encountering situations that help or hinder them, which could include running out of creamer or receiving a huge order of donuts. There will also be eight lots around the board for players to buy and expand their businesses. The game would continue until all players, but one goes bankrupt.

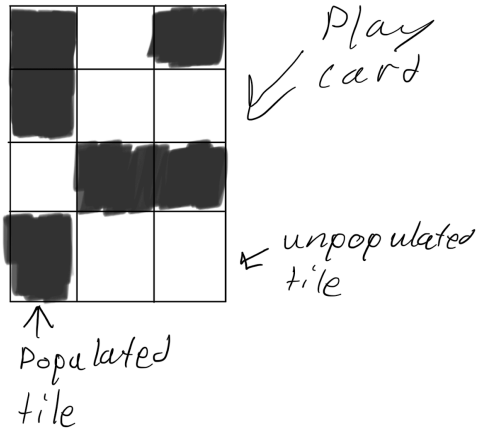
Concept Selection

For this project, we required a concept that would generate high levels of critical thinking while also being simple enough for children to understand it and maintain interest in it. We needed an idea that required minimal components for the sake of cost efficiency, as well. For these reasons, we decided that Improves Critical Thinking, Affordable, Portable, Quick Gameplay, Visually Appealing, and Easy to Learn were all relevant metrics for our weighted decision matrix. The Decision Matrix is Weighted rather than Pugh because,e as a team, we decided it was the more intuitive method, and we felt that it better reflected our decision-making process. Using the decision matrix, we took the weighted average of each concept based on our assigned weights and metrics and scored concept 1 at 0.5, concept 2 at 0.26, and concept 3 at 0.28 (Appendix D). This told us that Concept 1 was the choice that best aligned with our metrics and constraints.

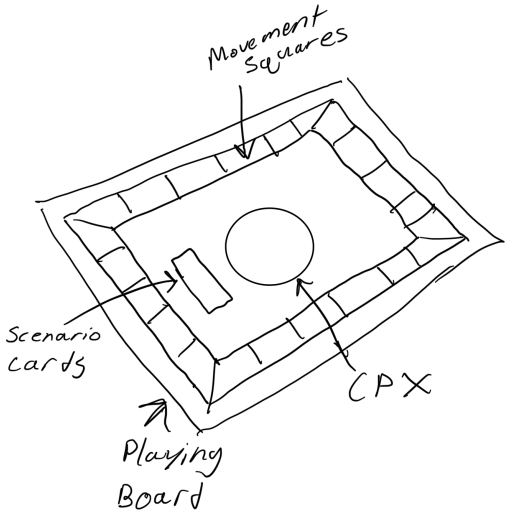
Concept Images

Concept 1:

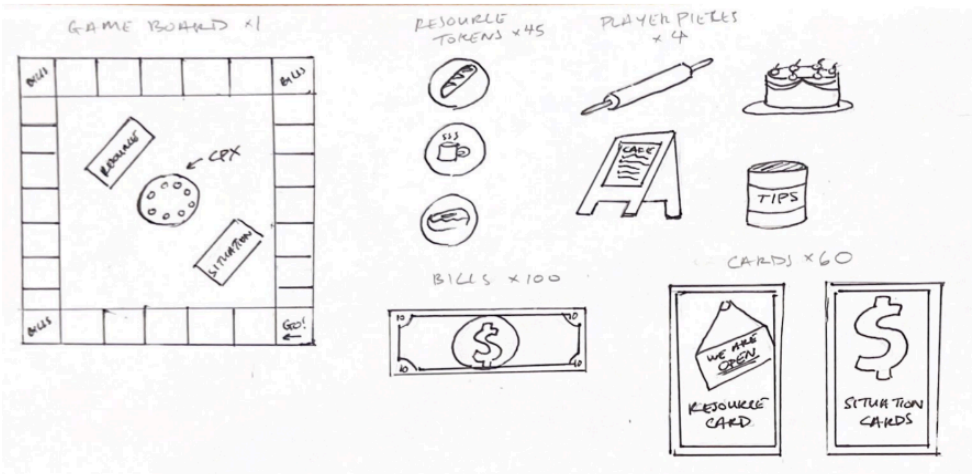




Concept 2:

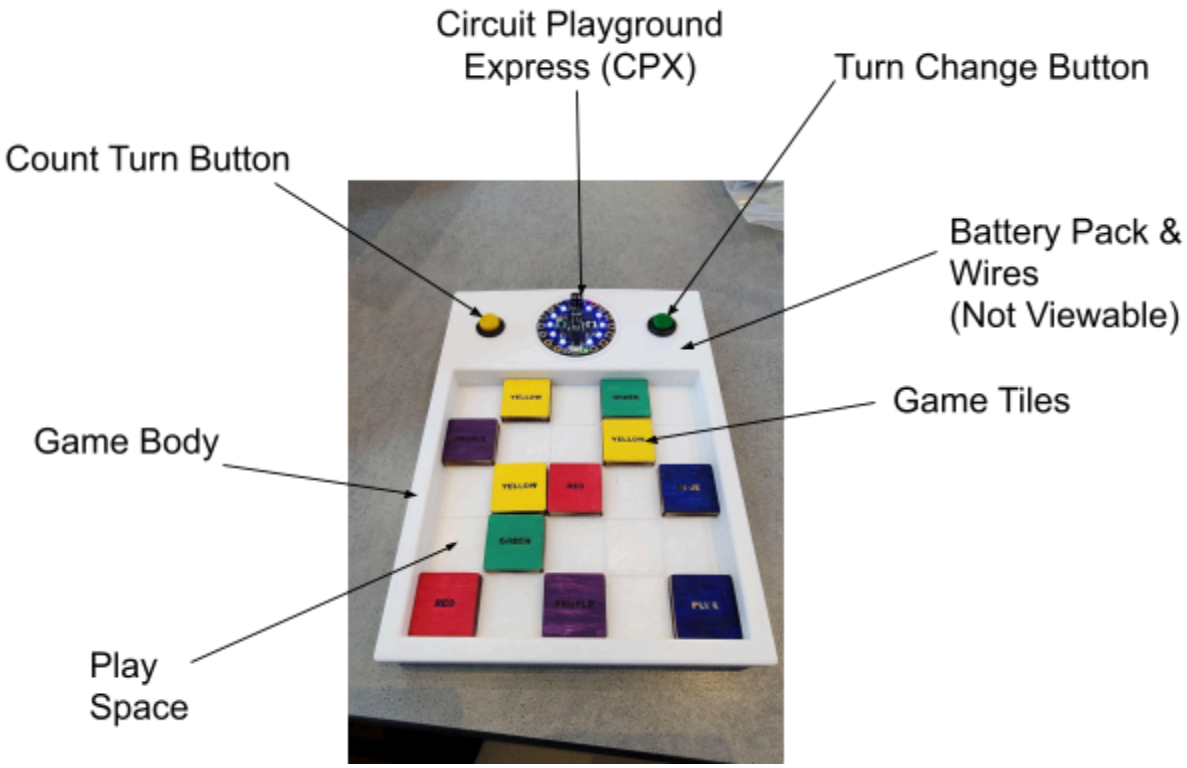


Concept 3:



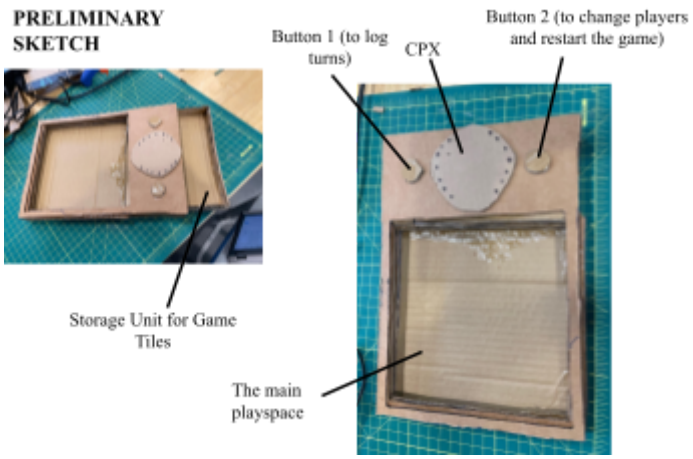
Final Design

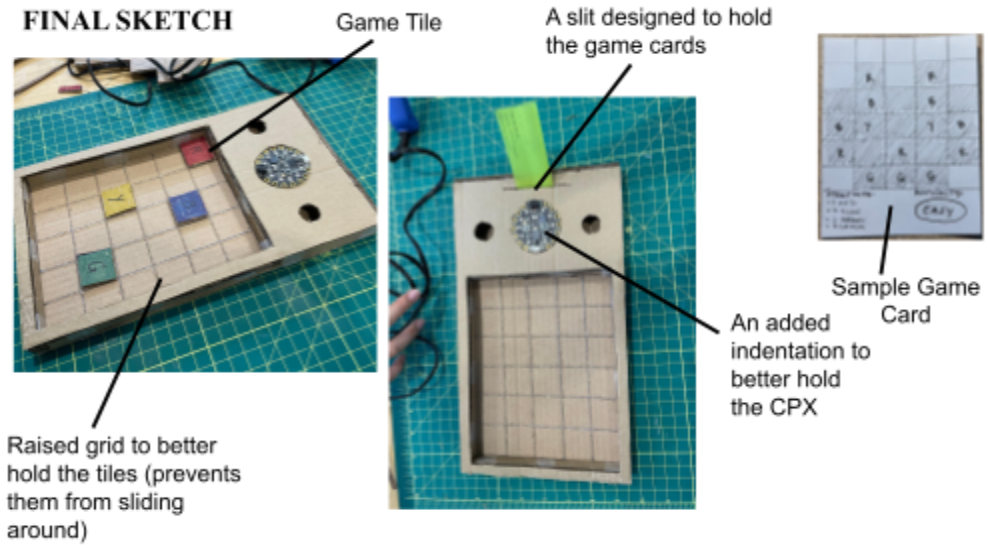
Overview



Inspiration was taken from a handful of games (Appendix A) that performed similar tasks to the intended task we were trying to design for this project. We came up with three unique concepts to choose from. Our selection was driven by its ability to promote efficient thinking while also being portable and easy to play. A Survey was conducted (Appendix B) to gain insight into what features may appeal to our target audience.

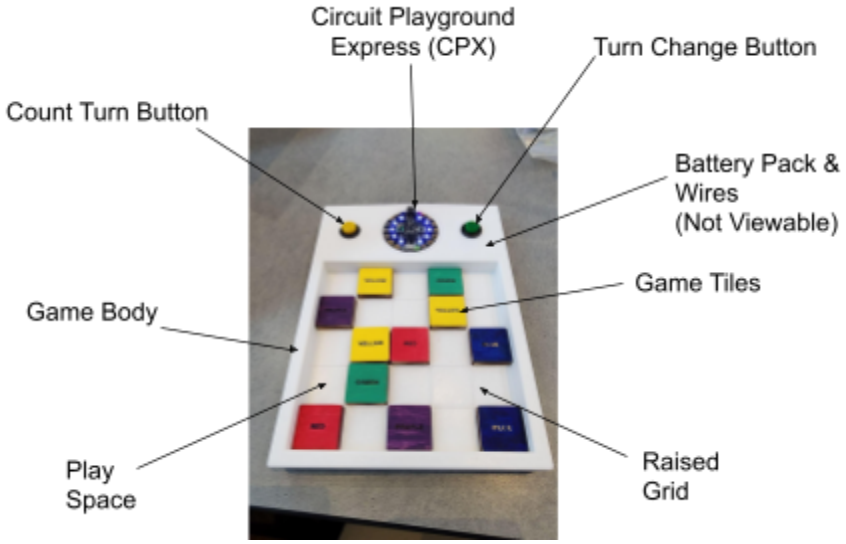
Early Prototype





We first made a CAD drawing of the prototype and used that to get the dimensions for our 3D sketch. Then, using cardboard from leftover packaging and rubber cement, we cut out the individual components and assembled them into our 3D sketch. We learned that cardboard is quite difficult to work with because it tends to warp, and its thickness makes it hard to cut to exact measurements. We reexamined our sketch and realized it was too large for the 3D Printing bed. As a result, we scaled it down by about 2 inches and added a grid pattern and card-holding slot at the top for improved gameplay. We also changed some of our designs to accommodate wire management better. After adjusting our CAD drawing to get the new measurements, we cut out pieces of cardboard for our Final 3D sketch. We signed up for a table at the maker space and used that time to glue the pieces of our model together with hot glue. By the end of our process, we learned that prototypes are necessary visual aids for revising a project.

Final Prototype



The final prototype is composed of a 3D printed body, two plastic buttons, wiring, a battery pack, a CPX, and laser-cut wooden tiles that are painted in a variety of colors. The buttons fit into two holes in the body, the CPX sits on an indentation that has holes for wire access, the battery and wiring sit inside the game body (under the CPX), and the tiles sit in the playspace of the game body. Any functionality for the prototype is detailed in Appendix K. Some major design decisions adapted from lessons learned with early prototypes include a raised grid to hold the tiles, holes in the indent for the CPX, a cover for the CPX, and the compartment that holds the battery pack, holes for the buttons, and a slit for holding game cards. The materials for the final prototype were procured from the Makerspace, Amazon, and Professor Haritha Malladi. From the final prototype, we learned that while things may not work out exactly as planned, adjustments can be made, and everything will turn out fine in the end. We also learned that PLA and screws do not agree with each other. For future prototyping, many optimizations could be made to the design of the game body, such as improved accessibility to the battery, better tolerances on the playing field for holding the tiles, a larger and deeper slit for holding game cards, and improved covers for the internal electronics compartment and the main control board. Additionally, the CPX cover is currently opaque rather than transparent. This was a communication issue, and next time, we will need to ensure that a resin printer is used. The body for our game also does not quite match our design. Again, this was a communication issue, and some details got lost in translation.

Design Validation

To validate our final design, three types of tests were conducted: a user survey, mass and volume calculations, and test trials of the game. The user survey was used to gauge the improvement of a player's critical thinking skills post-game. The mass and volume calculations assessed the portability of the final design as well as whether the design abided by the set constraints for materials. The test trials of the game were conducted by a proxy group to estimate difficulty and record playing time to determine how long gameplay would be on average.

Tests

Walk-A-Mile Immersion Test

- **Procedure**
    - Following the outlined instructions (Appendix K) for the game, two team members will play two rounds using the same pattern card each round. Both players will be timed while playing each round. While the game is being played, any team members not actively playing the game will observe the game and seek out potential improvements. Data from these trials can be found in Appendix J.

Major Takeaways

- All test subjects deemed the game fun.
- There is a slight learning curve, but once the rules are learned, the game is challenging but enjoyable.
    - It only took each player roughly one playthrough (5-8 mins) to learn the rules of the game.

Cost of Goods and Life Cycle Inventory

By using the provided "Cost of Goods" calculator to estimate the cost per unit, our final design was calculated to be $163.64 per unit or $1,636,400 per 10,000 units (Appendix H). This was mainly due to the operating costs of the 3D printers, as our entire game board is 3D-printed PLA. A potential way to bring our design down to a reasonable cost of manufacturing is to use private or personal printers instead to reduce operating costs. Performing Life Cycle Inventory calculations revealed that our design would require 483,000 kg of water, 143,000,000 m^3 of natural gas, 4,380 kWh of electricity, and 76,000 MJ of alternate forms of energy to manufacture 10,000 units. Furthermore, the manufacturing process for 10,000 units would produce 28,300,000 kg of CO_2 emissions, 1,270 kg of Volatile Organic Compounds, and 0.661 kg of Manganese (Appendix I).

Conclusions

Overall, the product meets the majority of requirements, and further efforts in its production could be seriously considered. Abandonment of the project at this stage would be a waste. The project currently meets 7 out of 9 metrics. It is portable, visually appealing, has small pieces that are not choking hazards, utilizes a CPX, uses 3D printed material, uses laser cut material, and has relatively quick gameplay. Our tests on whether the game increased critical thinking skills were inconclusive; however, the test group for the game was significantly older than our intended target audience. The cost to manufacture one game would currently be $163. This is mostly due to the labor and time costs of operating the 3D Printer, so there are potentially some design and production changes that would lower the cost of manufacturing. Further costs would be reduced by removing unnecessary features from the Circuit Playground Express, such as the accelerometer, infrared transceiver, microphone, and I^2C bus, as these features are not relevant to the tasks performed by our game. For the most part, the electrical components of the game are entirely functional, but it can also technically be played without the CPX at all (Appendix K).

In terms of the next steps in product development, many optimizations could be made to the design of the game body, such as improved accessibility to the battery, better tolerances on the playing field for holding the tiles, and improved covers for the internal electronics compartment and the main control board. Additionally, the CPX cover is currently opaque rather than transparent. This was a communication issue, and next time, we will need to ensure that a resin printer is used. The body for our game also

does not quite match our design. Again, this was a communication issue, and some details got lost in translation. Ultimately, the product would need significant iterations before it is ready to launch, but there is a solid argument in favor of the continuation of development efforts.

References

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Appendices

Appendix A: Benchmarking Table

Product Name	**Manufacturer**	**Details**
The Oregon Trail	Minnesota Educational Computing Consortium	*Oregon Trail can help students develop critical thinking and problem-solving skills as they make decisions that affect the survival of their virtual family.[1]*
Catan	Catan Studio™	*Multiplayer strategy game where players build their settlements and compete against one another. Includes a board, cards, and pieces.[2]*
Cluedo	Hasbro	Multiplayer mystery game where players assume the identity of murder suspects and gather clues to find the culprit. Includes game board, player tokens, and cards detailing person, place, and weapon. [5]
Ticket to Ride	Days of Wonder	*Multiplayer strategy game where players collect train cards to claim railway lines connecting cities throughout the U.S. Includes a board, cards, dice, and train pieces.[4]*
Risk: Continental Game	*Hasbro*	*No attempt has been made to teach strategy, as each player will develop his own as he becomes familiar with the game.[7]*
Qwirkle	*Mindware*	*A scrabble/domino type multiplayer game where players must place tiles in a specific order, forcing you to think ahead and use your tiles in the most effective way possible.* [3]

Appendix B: User-Centered Research Summary

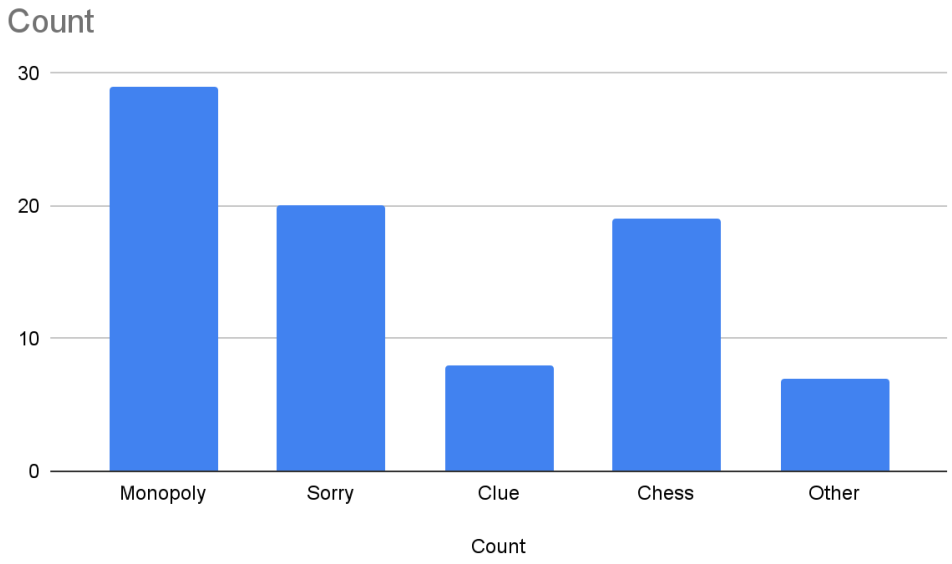
Survey Summary:

Q1: Did you play board games when you were between the ages of 2-12 years old?

Answer	# of Responses
Yes	31
No	1

Q2: What board games did you usually play?

Answer	# of Responses
Monopoly	26
Chess	25
Clue	18
Sorry	16
Candyland	7
Other	7

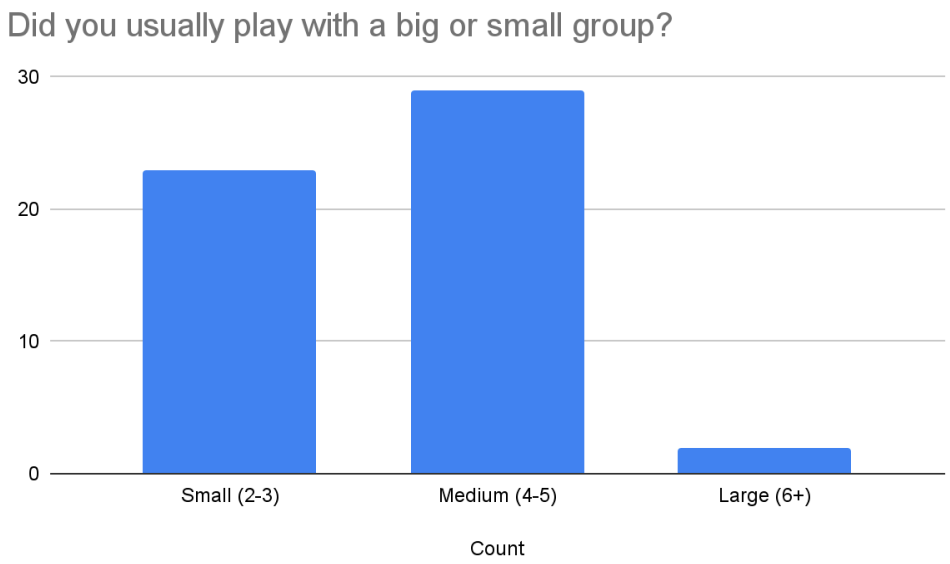


Q3: Mentioned the games being luck-based, rules were set/ rigid

- Yes: 25
    - 7 mentioned Monopoly
    - 6 mentioned chess
    - 1 mentioned Clue
    - 14 mentioned strategy
- Not sure: 2

Q4: Did you usually play with a big or small group?

Group Size	# of Responses
Small (2-3)	22
Medium (4-5)	26
Large (6+)	2



Q5: On a scale of 0-10, how often do you play board games today?

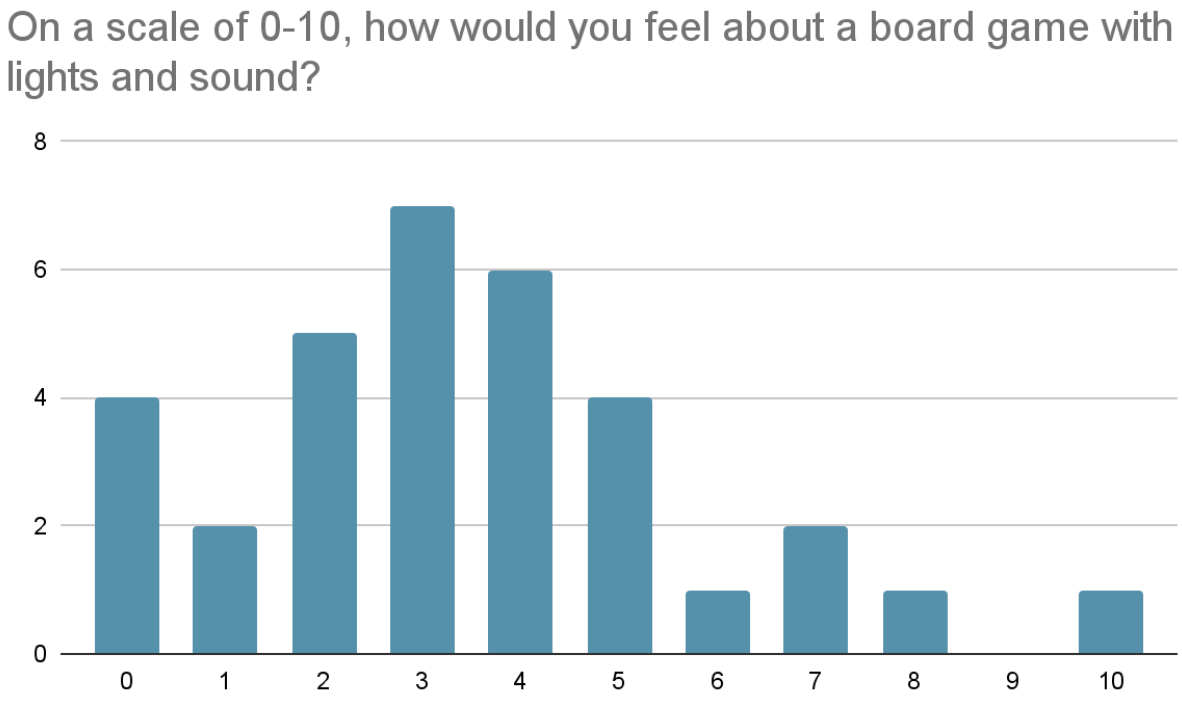
Response	# of Responses
0	4
1	2
2	5
3	7

4	6
5	4
6	1
7	2
8	1
9	0
10	1

Q6: On a scale of 0-10, how would you feel about a board game with lights and sound?

Respons e	# of Responses
0	4
1	2
2	5
3	7
4	6
5	4

6	1
7	2
8	1
9	0
10	1

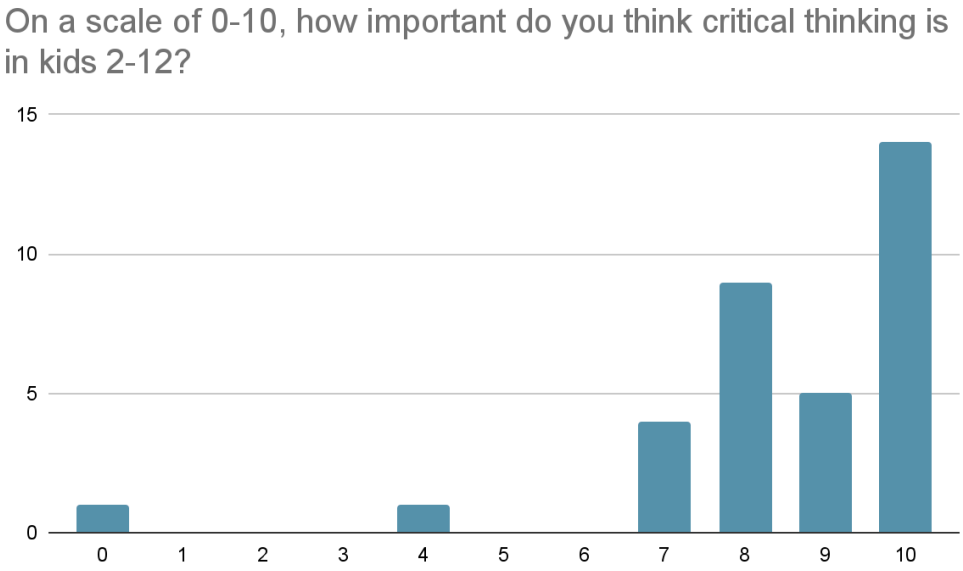


Q7: On a scale of 0-10, how important do you think critical thinking is in kids 2-12?

- Average of 9 on importance:

Response	# of Responses
0	1
1	0
2	0
3	0
4	1

5	0
6	0
7	4
8	9
9	5
10	14



Q8:

- Reasons for why critical thinking is important:
  - “Will continue to think critically further into their life” - mentioned in 10 responses
  - “Critical thinking skills are crucial for brain development” - mentioned in 4 responses
  - “Useful for future success, career, and education” - mentioned in 5 responses
- Reasons for why critical thinking isn’t important:
  - “Most kids don’t want to do a lot of thinking to do a board game”
  - “Should have a good childhood instead of thinking too much”

Appendix C: Target Value Justification

The target values of our wants were based on our user-centered research (Appendix B) as well as our benchmarking (Appendix A). 28 out of 34 respondents to our survey

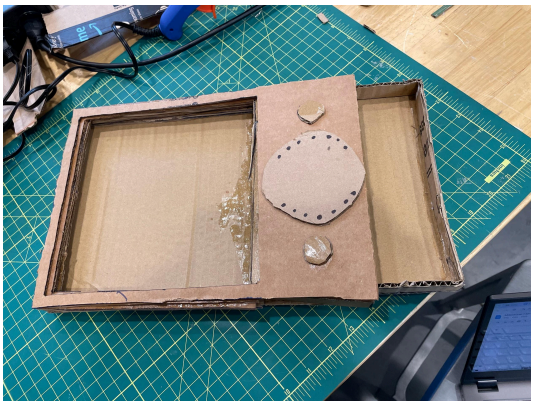
ranked critical thinking skills as eight and above on a 1 to 10 scale, 10 being the most important. Thus, we deemed it important to aim to promote a 60% increase in these skills. For the rest of our values, we based them on previously existing games that fit our project criteria. For example, Clue on Amazon costs $22, weighs 2.11 lbs, and has a volume of 1.61 x 15.75 x 10.51 inches or 4.09 cm x 40.00 cm x 26.70 cm [10]. Thus, we aimed for values similar to these but slightly bigger to account for different methods of manufacturing and the nature of our game: <$25, <3 lbs by weight, and <3125 cm^3 by volume. For our constraints, target values were taken from the semester project prompt.

Appendix D: Decision Matrix

Weight (%)	Metrics	Concept 1	Concept 2	Concept 3
35	Improves Critical Thinking	3	1	2
10	Affordable	3	2	1
15	Portable	3	2	1
10	Quick Gameplay	3	1	2
10	Visually Appealing	1	2	3
20	Easy to learn	3	2	1
Score		0.5	0.26	0.28
Rank		#1	#3	#2

Appendix E: 3D Sketches

Initial:



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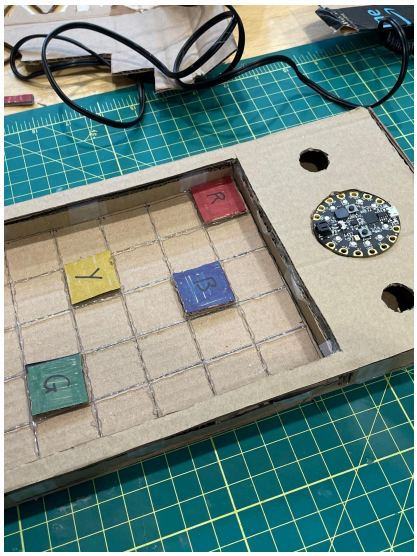
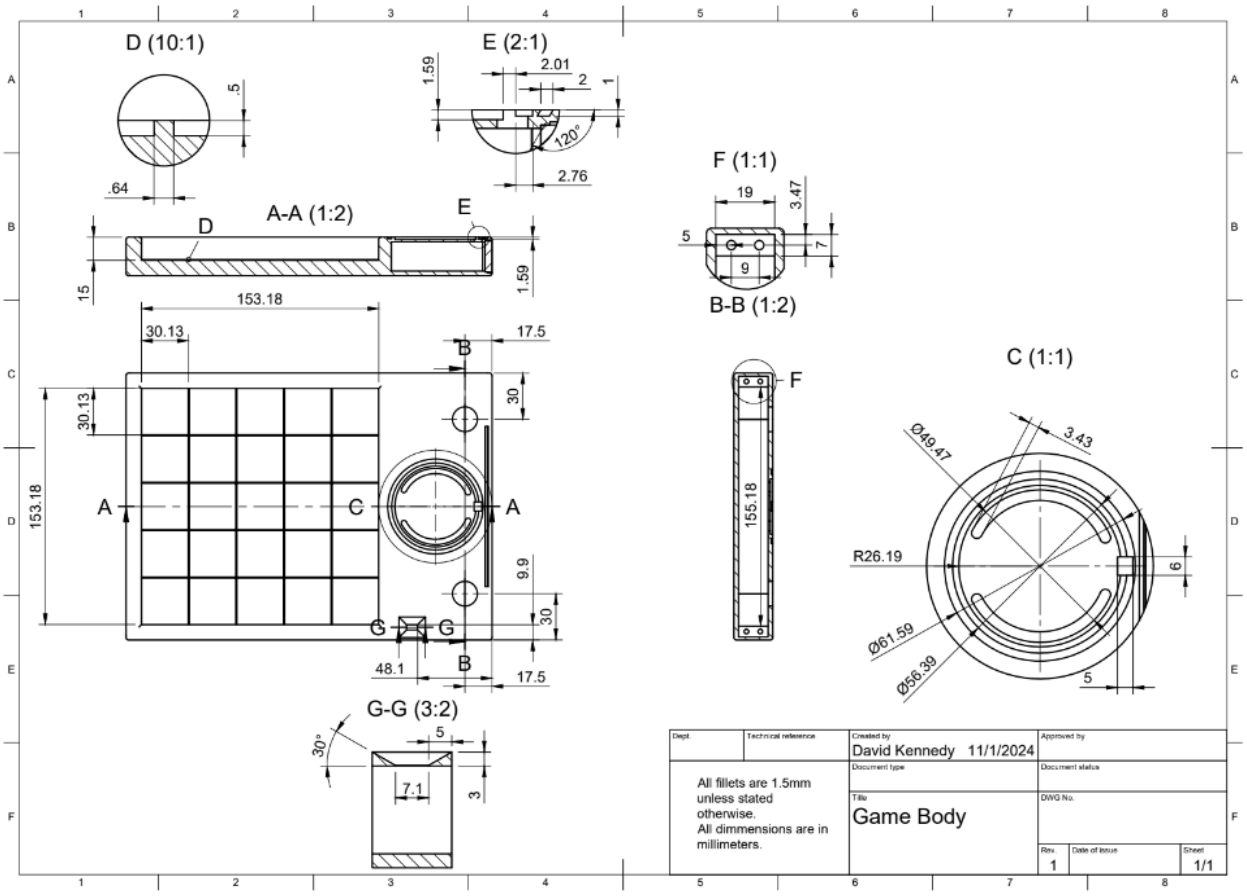
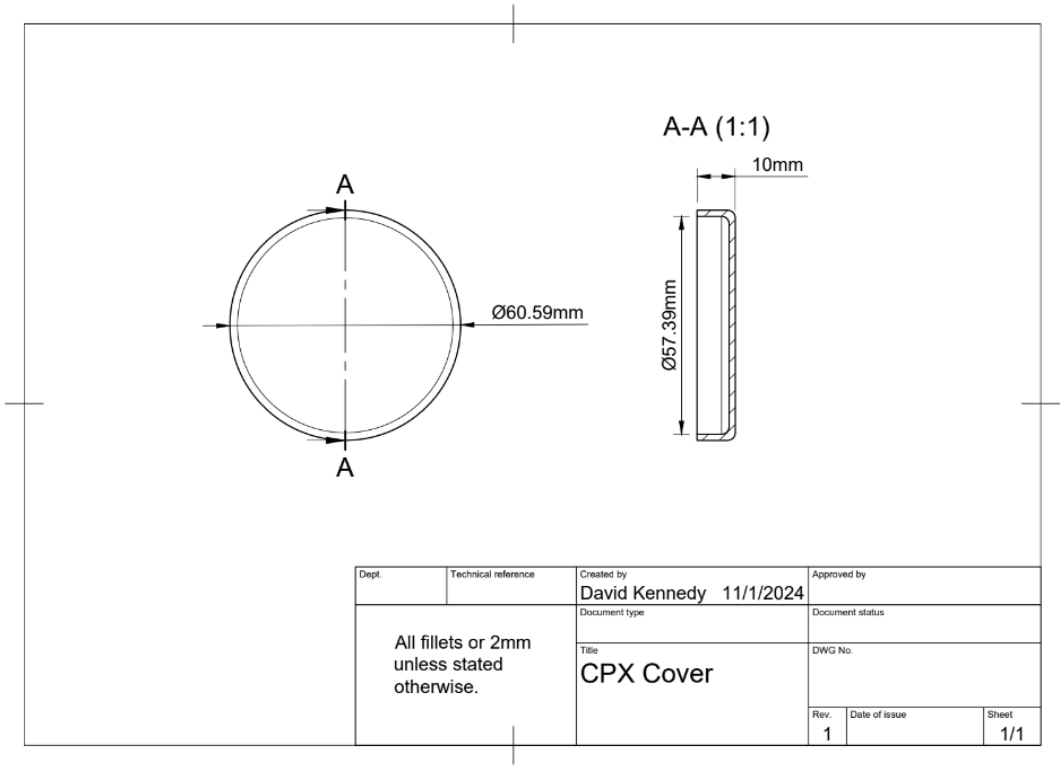


Appendix F: Final Engineering Design Packet

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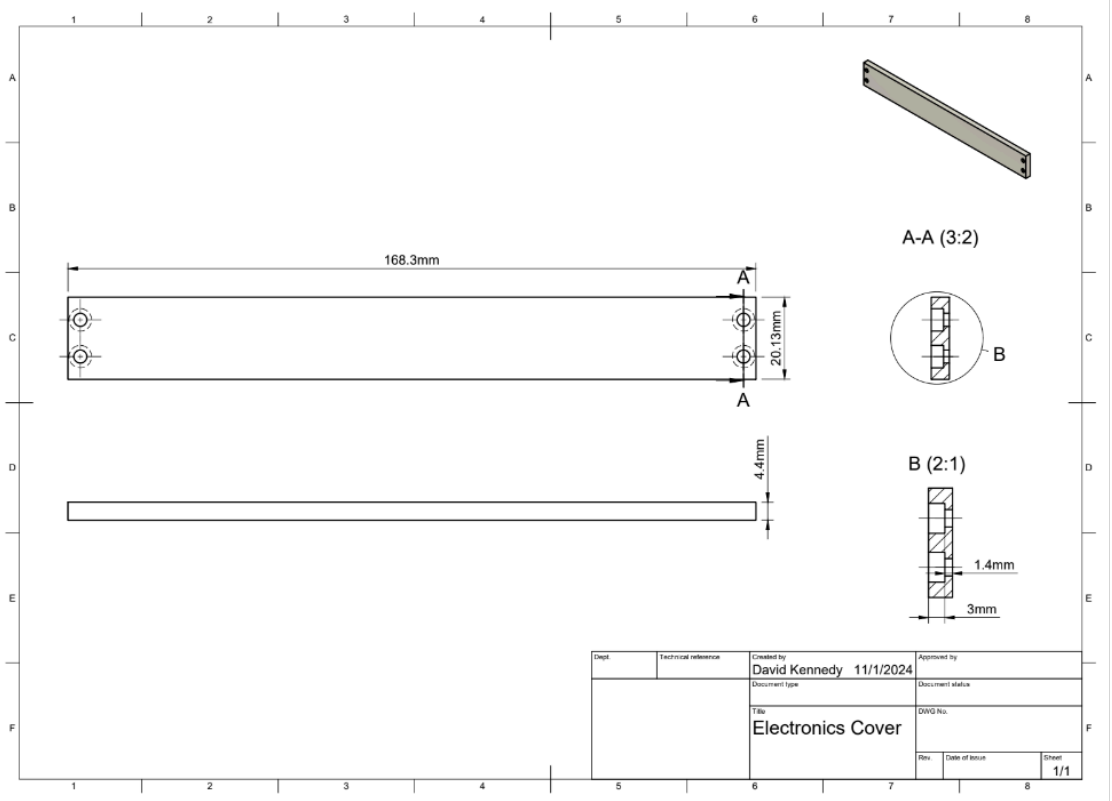
A
Ø60.59mm
Ø57.39mm
A
Dept.
Technical reference
Created by
David Kennedy 11/1/2024
Approved by
Document type
Document status
All fillets or 2mm unless stated otherwise.
Title
CPX Cover
DWG No.
Rev.
1
Date of issue
Sheet
1/1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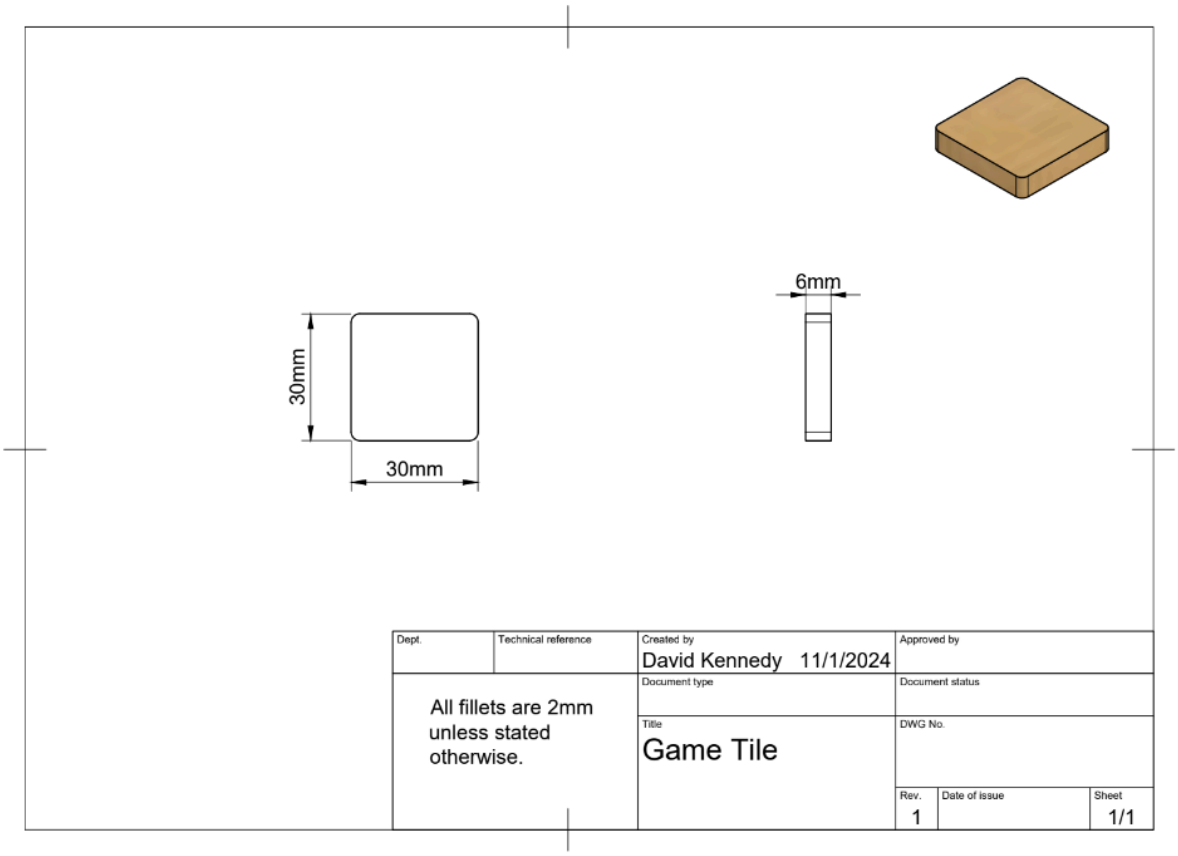
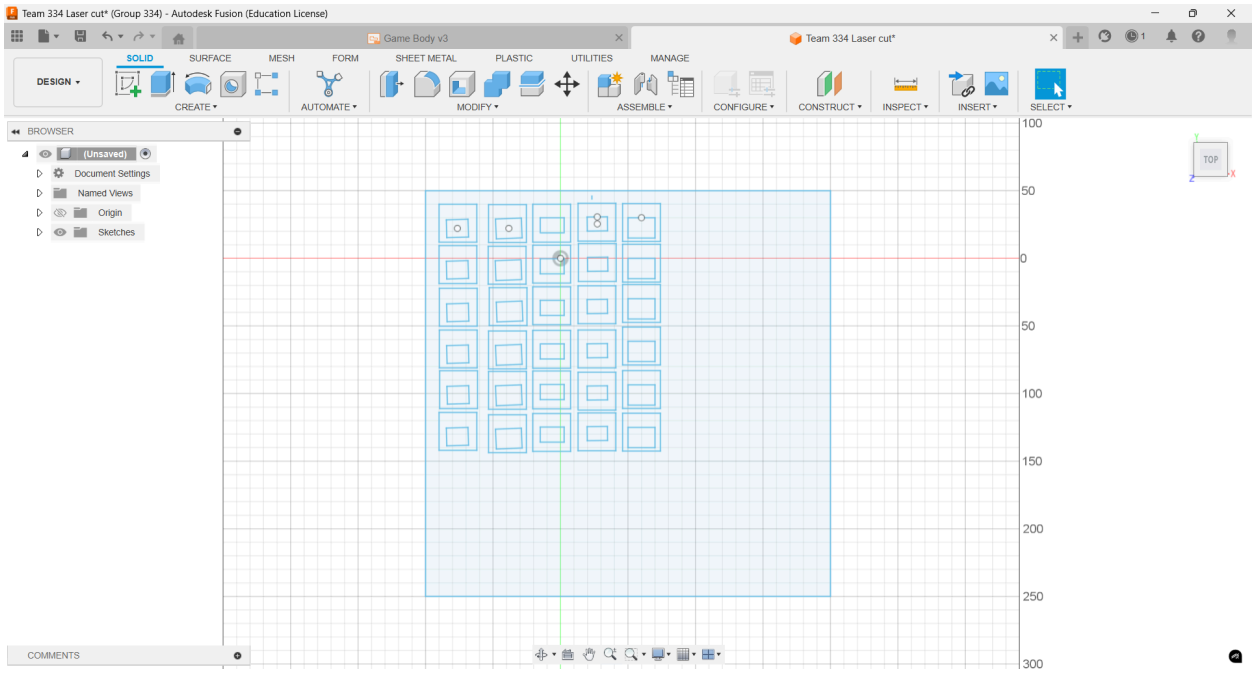
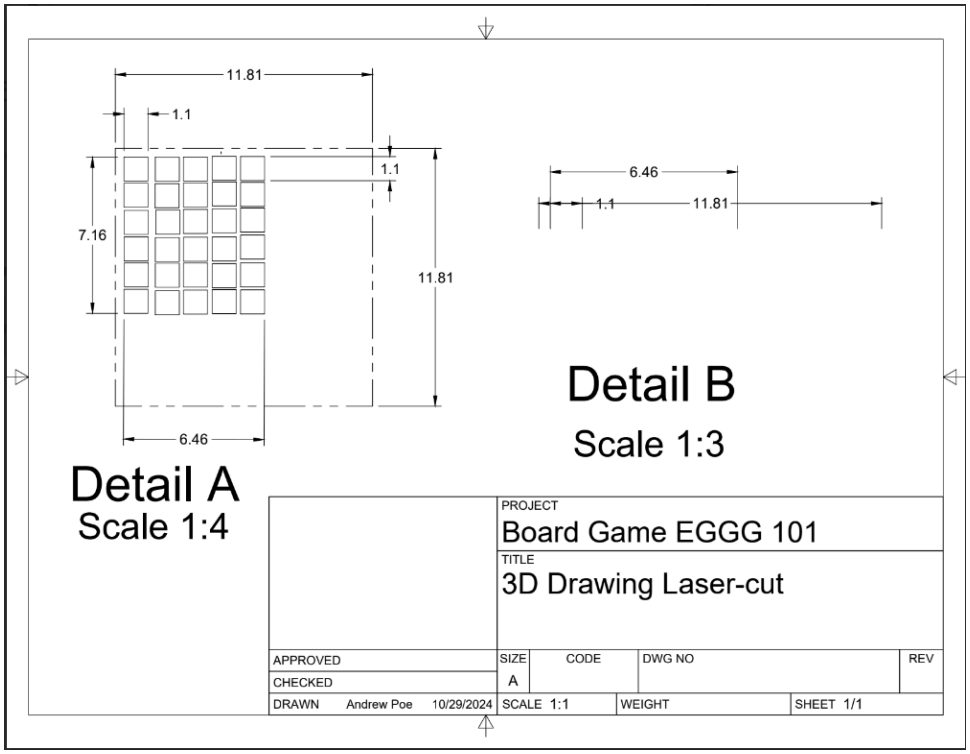
A
20.13mm
A
4.4mm
A-A (3:2)
B
B (2:1)
1.4mm
3mm
Dept.
Technical reference
Created by
David Kennedy 11/1/2024
Approved by
Document type
Document status
Title
Electronics Cover
DWG No.
Rev.
Date of issue
Sheet
1/1


6mm
30mm
30mm
Dept.
Technical reference
Created by
David Kennedy 11/1/2024
Approved by
All fillets are 2mm unless stated otherwise.
Document type
Document status
Title
Game Tile
DWG No.
Rev.
1
Date of issue
Sheet
1/1


Team 334 Laser cut* (Group 334) - Autodesk Fusion (Education License)
Game Body v3
Team 334 Laser cut*
DESIGN
SOLID
SURFACE
MESH
FORM
SHEET METAL
PLASTIC
UTILITIES
MANAGE
CREATE
AUTOMATE
MODIFY
ASSEMBLE
CONFIGURE
CONSTRUCT
INSPECT
INSERT
SELECT
BROWSER
(Unsaved)
Document Settings
Named Views
Origin
Sketches
COMMENTS
TOP



Appendix G: Relevant Calculations

- Area of Game Body Base = 266.35 mm * 173.18 mm = 46,126 mm^2
- Volume of 3D Printed Material = 490.670 cm^3
    - This was calculated using built-in features of Fusion360
- AreaTile = 28 mm * 28 mm = 784 mm^2
- Area of Laser-Cut Material = $Area_{Tile}$ * 30 tiles = 23,520 mm^2

Appendix H: Cost of Goods Estimate

COST OF GOODS (1 unit)	$163.64						
Instructions: Input values in orange cells only. Cost of Goods total for 1 unit is shown in green)							
Laser Cutting			**3D Printing**			**Electronics**	
Inputs			**Inputs**			**Inputs**	
Cut Envelope (mm^2)	90000		Volume of 3DP Parts (mm^3)	490670.00		No. of Test Leads Used	0
Cut Path (mm)	3360		Estimated Print Time (hour)	24.00		Cost of custom components (US$)	$0.00
						No. of CPX Base Kits Used	1
Constants			**Constants**			**Constants**	
3 mm or 6 mm Baltic Birch, Unit Cost (US$/in^2)	$0.02		PLA filament, Unit Cost (US$/g)	$0.02		CPX Base Kit Cost of Goods (US$)	$11.98
3 mm or 6 mm Baltic Birch, Unit Cost (US$/mm^2)	$0.0000310		Infill Density (%)	20%		Test Leads Cost of Goods (US$/unit)	$0.13
Laser Cutter Linear Speed (mm/sec)	9		Density of PLA (g/mm^3)	0.00124			
Laser Cutter Usage Rate (US$/min)	$0.26		3D Printer Usage Rate (US$/hour)	$0.21			
Operator Time (% Laser Cut Time)	85%		Operator Time (% 3D Print Time)	25%			
Operator Pay Rate (US$/hr)	$22.50		Operator Pay Rate (US$/hr)	$22.50			
Calculations			**Calculations**			**Calculations**	
Birch Wood - Raw Material (US$)	$2.79		Estimated weight of 3DP Parts (g)	121.69		Cost of test leads (US$)	$0.00
Laser Cut Time (min)	6.22		Cost of PLA (US$)	$2.43		Cost of CPX (US$)	$11.98
Laser Cutter Usage Fees (US$)	$1.62		3D Printer Usage Fees (US$)	$5.04		Cost of Custom Components (US$)	$0.00
Operator Fees (US$)	$1.98		Operator Fees	$135.00			
Subtotal - Laser Cutting	**$6.39**		**Subtotal - 3D Printing**	**$142.47**		**Subtotal - Electronics**	**$11.98**

Other Custom Items

Item	Unit Price	Per	Description	Quantity Used	Cost of Item
Buttons	$1.10	1	Buttons	2	$2.20
Cardstock	$0.06	1	Cardstock	10	$0.60
				Subtotal - Custom Items	**$2.80**

Appendix I: Life Cycle Inventory Estimate

Material	Amount per Unit	LCI Unit	Conversion Factor	LCI Units per 10,000
Plywood (mm^3)	270,000	1 kg	7E-07 kg/ mm^3	1890
PLA (g)	121.69	1 kg	0.001 kg/ g	1216.9
Electronics (USD)*	26.16	1 USD	N/A	261600
Paper (lbs)	1.1	907.2 kg	(0.4536 kg/ lbs)/ 907.2 kg	5.50
Manufacturing (hrs)	24.1	1 kWh	For 3DP: hrs * 0.2 kW For Laser-Cut: hrs * 0.05 kW	48050000
*Includes the CPX and buttons provided by the team				

INPUTS								
	Water (kg/ LCI Unit)	For 10, 000 Units	Electricity (kWh/ LCI Unit)	For 10, 000 Units	Natural Gas (m^3/ Unit)	For 10, 000 Units	Other Energy (MJ/ LCI Unit)	For 10, 000 Units
Plywood	0	0	4.81E-02	9.09E+01	0	0	0	0
PLA	47.713	58061.9497	1.63E+00	1.98E+03	0.37799	459.976031	1.12E+00	1.36E+03
Electronics	0.0943258702	24675.64764	0	0	0	0	6.75E-07	1.76E-01
Paper	72740	400070	420.5948	2313.2714	0	0	1.36E+04	7.46E+04
Manufacturing	0	0	0	0	2.98E-01	1.43E+07	0	0
TOTAL		482807.5973 kg		4.38E+03 kWh		14333774.98 m^3		75957.04896 MJ

OUTPUTS (GREENHOUSE GASES)								
	Carbon Dioxide (kg/ LCI Unit)	For 10, 000 Units	Methane (kg/ LCI Unit)	For 10, 000 Units	Nitrous Oxides (kg/ LCI Unit)	For 10, 000 Units	HFCs (kg/ LCI Unit)	For 10, 000 Units
Plywood	0	0	0	0	0	0	0	0
PLA	2.65E-01	3.22E+02	1.30E-03	1.58E+00	3.71E-04	4.51E-01	0	0
Electronics	5.67E-03	1.48E+03	1.11E-07	2.90E-02	0	0	4.04E-07	1.06E-01
Paper	48.5	266.75	0	0	0	0	0	0
Manufacturing	5.85E-01	2.81E+07	1.07E-05	5.16E+02	1.07E-05	5.16E+02	0	0
TOTAL		28096906.45		517.6704414		516.5080927		0.1056395736
GWP		1		30		270		3000
TOTAL (as CO2e)		28096906.45 kg		15530.11324 kg		139457.185 kg		316.9187208 kg

OUTPUTS (OTHER)					
	VOC (kg/ LCI Unit)	For 10, 000 units	Manganese (kg/ LCI Unit)	For 10, 000 Units	
Plywood	1.82E-09	3.43E-06	0	0	
PLA	0	0	0	0	
Electronics	0	0	0	0	
Paper	0	0	1.04E-01	5.74E-01	
Manufacturing	2.64E-05	1.27E+03	1.82E-09	8.73E-02	
TOTAL		1.27E+03	kg	0.6608538	kg

Total	per 10, 000	units
INPUTS		
Water	4.83E+05	kg
Natural Gas	1.43E+07	m^3
Energy	7.60E+04	MJ
Electricity	4.38E+03	kWh
OUTPUTS		
CO2e	2.83E+07	kg
Volatile Organic Compounds	1.27E+03	kg
Manganese	6.61E-01	kg

Appendix J: Design Validation Calculations and Experiment Documentation

Want	Metric	Target Value	Achieved Value	Metric Met?
Improves critical thinking skills	Knowledge test	60% increase in score on a critical thinking assessment after playing the game.	Using a proxy group yielded a 20% increase in critical thinking capabilities.	The metric was not met. This can be attributed to the proxy group already being very capable of critical thinking
Portable	Mass and volume	< 3lbs and < 3125 cm^3	49067.0467 cm^3 1.93 lbs	Metric was met
Relatively quick gameplay	Time spent per game	20-25 mins	~8 mins	We ended up under our metric, but our test subjects are much older than our target demographic.
Visually appealing	User survey	>70% of people would buy the game based on appearance alone	75% of those surveyed said they were “likely” to buy the game	Metric was met

			based on appearance	

Constraints	Metric	Target Value	Achieved Value	Metric Met?
Uses 3D printed material	Volume	< 33 x 24 x 4cm	490.670 cm^3	Yes.
Uses laser-cut material	Size	< 300 mm x 300 mm	23, 520 mm^2	Yes.
Use Circuit Playground	Present	True	True	Yes.
Limit the minimum size of parts	Volume	5mm^3	>5mm^3 / part	Yes.

Data from Walk-A-Mile Immersion Testing:

Observation	Interpretation
Subject: 2 college-aged individuals (relative beginners) Some technical errors with the buttons and CPX occurred, but it did not detract from the game itself. Playtime: player 1: ~5 mins; player 2: ~8 mins. There was a clear winner.	The game seems to be enjoyable for both players. It encourages concentration. The technical errors caused some confusion but did not overall ruin the experience.
Subject: 1 college-aged individual (beginner) Still some technical errors with the buttons and CPX. Playtime: ~ 4 mins 30secs.	Again, the game seems to be enjoyable for the player. Playing solo was about the same experience as playing with two people but without the competition.

Appendix K: End-user Instructions

Objective:
Players take turns moving colored tiles on a board to solve a puzzle. Each color has a unique movement rule. The objective is to solve the puzzle in fewer turns than the other player. After both players complete the puzzle, the winning player is displayed in blue lights for player one and red lights for player two.

Components:

- **Card Pile**: Cards that describe the ending position of tiles.
- **Game Board**: A grid of squares (e.g., 5x5) where tiles are placed.
- **Tiles**: Colored tiles (Red, Blue, Purple, Green, Yellow) with 5 of each color
- **Yellow Button**: A button that must be pressed after each tile move.
- **Green Button**: A button that switches turns between players and shows the winner at the end.

Setup:

1. Select a game card at random or by choice.
2. Place tiles randomly on the game board, with the number of each tile color matching the prescribed amount on the game card.

How to Play a Round:

1. **Player 1's Turn**:
    - Player 1 begins by moving one tile at a time based on the color movement rules:
        - **Red Tile**: Moves diagonally any number of spaces.
        - **Blue Tile**: Jumps over a tile next to it.
        - **PRUPLE Tile**: Moves only horizontally or vertically any number of spaces.
        - **Green Tile**: Switches positions with any other tile.
        - **Yellow Tile**: Moves one tile in any direction.
    - After every move, Player 1 must press the **Yellow Button** to note the move.
    - Player 1 continues making moves until the puzzle is solved.
2. **Switch Turns**: After solving the puzzle, Player 1 presses the **Green Button**. Now, it's Player 2's turn to solve the puzzle.
3. **Player 2's Turn**:
    - Randomly shuffle the tiles around the playing surface.
    - Player 2 follows the same rules as Player 1 and moves tiles to complete the puzzle.
    - Player 2 also presses the **Yellow Button** after each move and the **Green Button** after completing the puzzle.
4. **Determine the Winner**:
    - Once Player 2 finishes, the **Green Button** is pressed, and the winning player's color will be displayed on the CPX device.
        - If Player 1 wins, the CPX will display red lights.
        - If Player 2 wins, the CPX will display blue lights.
        - If there is a tie, the CPX will display alternating red and blue lights.
5. **Repeat Setup Steps for the Next Round**