To: Fluke Toy Corp.
From: Izzy Dudlyke, Juan Garcia Luengo, Hiba Benjeddou
Subject: Design Challenge 4: Happy Meals!
Date: Friday March 18, 2022

I. Executive Summary

Fluke Toy Corp has tasked our team with designing a happy meal toy that is cost efficient, fun, sustainable and most importantly safe to use. Preliminary research into both current and popular happy meal toys led the team into brainstorming ideas for the toy using a mindmap and "hitchhiking" off these initial ideas to develop new ideas. The team then used a Pugh screening matrix to reach a final design to begin building: a puzzle maze with removable background. The team initially created a CAD sketch and 3D printed the parts to get a proof of concept of our idea, as well as to better be able to visualize what can be improved. We then repeatedly iterated on designs to reach a higher fidelity model, with an improved fit between the top and bottom plate, as well as friction fit of the plate. For the CTF dimensions of the toy, the team completed a tolerance analysis to yield an overall maximum variation in the dimensions of the toy. Some of the notable features of the puzzle maze include the interchangeable background plate with different maze designs that can be traded with friends, the interlocked corner joints, and the maze design with multiple levels of difficulty. Due to the adaptability of the toy, the team believes the target audience is children aged 5 to 13 of all genders and backgrounds. The three plastic parts are made of ABS plastic which is non-toxic and highly recyclable. The total cost of the toy including one removable plate would be $0.38, and we recommend a 3 month manufacturing run using 100 injection molding machines. This will allow each of the 3 designs to have a 6 week toy roll out. Finally, after creating a poster and promo video, the team presented the puzzle maze at the Toy Fair, which was received extremely well, demonstrating the success of the toy.

II. Approach Description

A. Brainstorming

To first get a better understanding of the task at hand, our team did primary research into current happy meal toys, as well as the most popular happy meal toys from the past. This enabled us to gauge an initial idea of what kind of toys do the best and the general size and functions a popular toy would have. This led the team to the first round of brainstorming using a mind map and listing as possible designs as we could. We then conversed about the different ideas and used this conversation to "hitchhike" off these initial ideas to create even more possible design solutions (Figure 1).

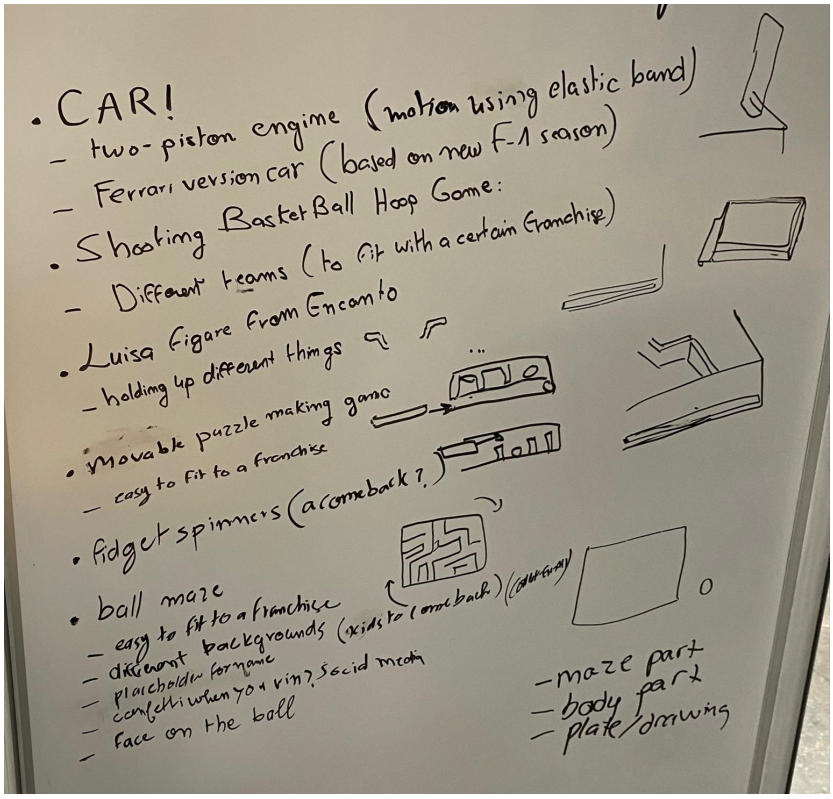

Figure 1: Brainstorming Mind Map

B. Selection Process

After creating possible solution ideas, the team used a Pugh screening matrix to rank the solutions and choose one to start prototyping (Table 1). The team decided to use this decision matrix as it enabled us to quickly compare solution ideas and decide on a final design. Our design criteria included cost, size, safety, and fun.

- Cost: For cost, each individual toy should cost less than $0.40 total.
- Size: The Toy must be able to fit within a 5 cubic inch volume, whilst also leaving sufficient room for food in the happy meal.
- Safety: Any removable parts must be larger than 1.25 inches in width or longer than 2.25 inches in length so as to not be a choking hazard.
- Fun: The toy must be engaging and enjoyable to play with.

The Toy Car option was chosen as the standard solution for this matrix. The solutions were then compared with respect to each design criteria and this chosen standard. By doing this Pugh screening matrix, the team determined that the Ball Maze, with a score of +4, would be the best happy meal toy according to these criteria.

Design Criteria	Toy Car	Encanto Characters	Ball Maze	Basketball Hoop
Cost	0	+1	+1	-1
Size	0	0	+1	-1
Safety	0	+1	+1	-1
Fun	0	0	+1	+1
TOTAL	**0**	**+2**	**+4**	**-2**

Table 1: Pugh Screening Matrix

C. Iterative Prototyping and Testing

The dimensions of the toy were consciously designed to be able to fit into the happy meal, whilst still leaving space for the food. In addition, the slot for the sliding plate was to be 2.5mm wide, therefore we wanted the ball to be a minimum of 5mm wide to ensure it does not fall out. Further, we decided the walls of the maze should be a minimum of 2mm wide to ensure they don't snap when hit by the ball. Each of these constraints, as well as the unit price, helped to guide the dimensions of our toy.

The team began by each creating a rough CAD sketch of the plastic parts on solidworks. After researching maze designs, the team decided to create a design with different levels of difficulty when traveling a different path, to allow individuals of all ages to use our game. This led us to design the maze used in all prototypes (Figure 1).

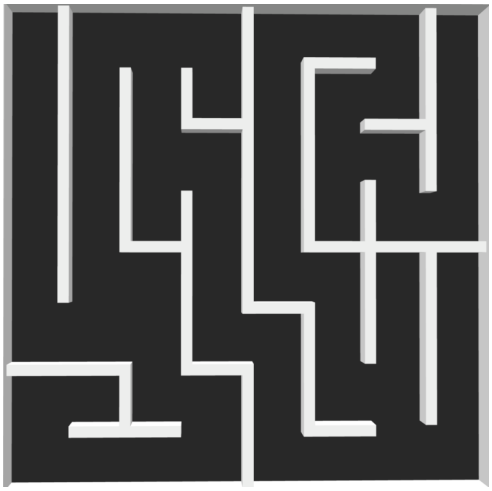

Figure 2: Maze Design with different levels of difficulty based on start and end location

We then printed these parts and constructed the toy as a proof of concept of our idea. The initial design had 4 plastic parts; however, the team quickly discovered that two of the parts could be combined into one, thereby reducing the amount of parts and cost of the toy (Appendix

Figure 1). In addition, we discovered that the removable plate needed more friction so as to not fall out of the designated slot. This led us to our next prototype, which consisted of 3 parts: the maze (top) piece, the base (bottom) piece and the removable plate. This prototype included a narrower slot to increase the friction hold on the plate, and the top and bottom plates had interconnecting corners which snap together (Figure 3). Further iterating on this prototype led the team to the final design of the maze toy (Figure 4a and 4b). In this final design of the plastic parts, all corners were fileted in solidworks, which increases the ease of manufacturability when using plastic injection molding.

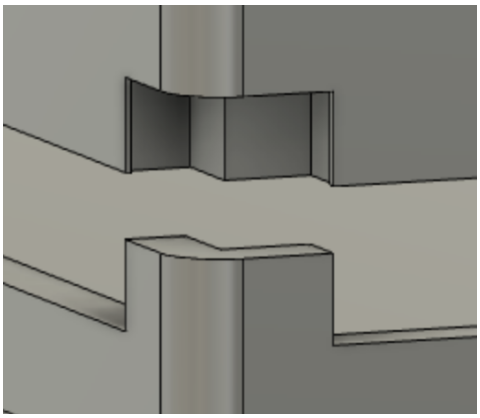

Figure 3: Close up of the interconnecting corners

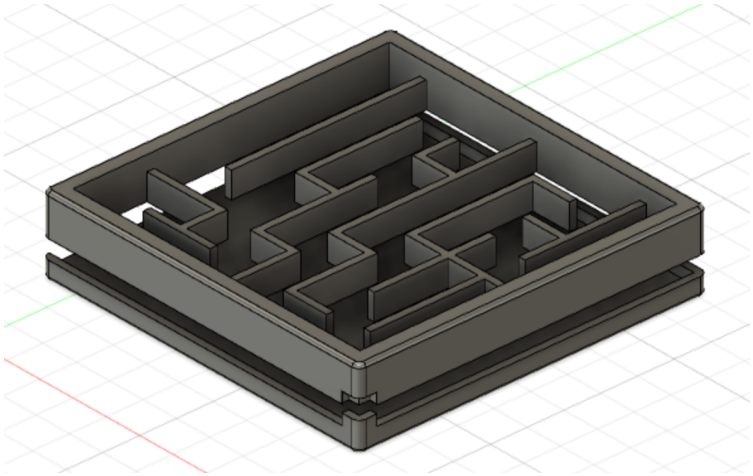

Figure 4a: Final CAD design (top and bottom plate)

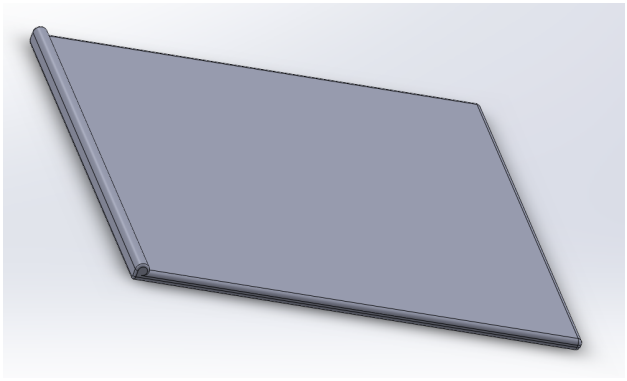

Figure 4b: Final CAD Design (removable plate)

Each team member also designed background images based off of this maze design. The team decided to base the background on movies to ensure that children would want to use the toy. We decided to make 3 base models for our toy: “Cars” (a classic film), “Encanto” (a newly released favorite), and “Lightyear” (a popular film awaiting release). These designs each are unique and specific, incorporating images from the film (Figure 5a, 5b and 5c).

Figure 5a: Lightyear Background (Help Buzz get back to earth!)

Figure 5b: Encanto Background (Explore the Madrigal House with Mirabel!)

Figure 5c: Cars Background (Race to the finish line with Lightning McQueen!)

Once a final prototype - including all plastic parts and completed backgrounds - was made, the team bagan testing using Duke undergraduate students to receive feedback. Overall, this feedback was extremely positive, with most people saying the interchangeable backplate was an original design feature. This feedback also helped to guide further minor improvements to the overall look of the toy.

III. Toy Description and Documentation

A. Key Features

The 3 different models of the final toy are pictured below (Figure). The maze's main feature is the interchangeable backgrounds. The design of the maze casing features a space for a removable plastic plate. The advantage of this feature, along with being unique, is that this allows the toy to remain relevant in time. When a new movie or franchise is released, a new maze background is changed instead of the toy itself. Furthermore, the maze is made of 4 pieces: the top maze part, the bottom part, the removable plate, and the acrylic covering. To aid ease of assembly, the top and bottom pieces are connected by interlocking corners which are glued together. The maze also has fileted corners to increase the ease of manufacture with injection molding. In addition, the maze has purposefully been designed with multiple levels of difficulty in the design: it is easier to travel from the top right corner to left than the inverse. This was to ensure that children of all ages were able to use our toy.

Figure 6: 3 Models of Final Toy Design

B. Design Documentation

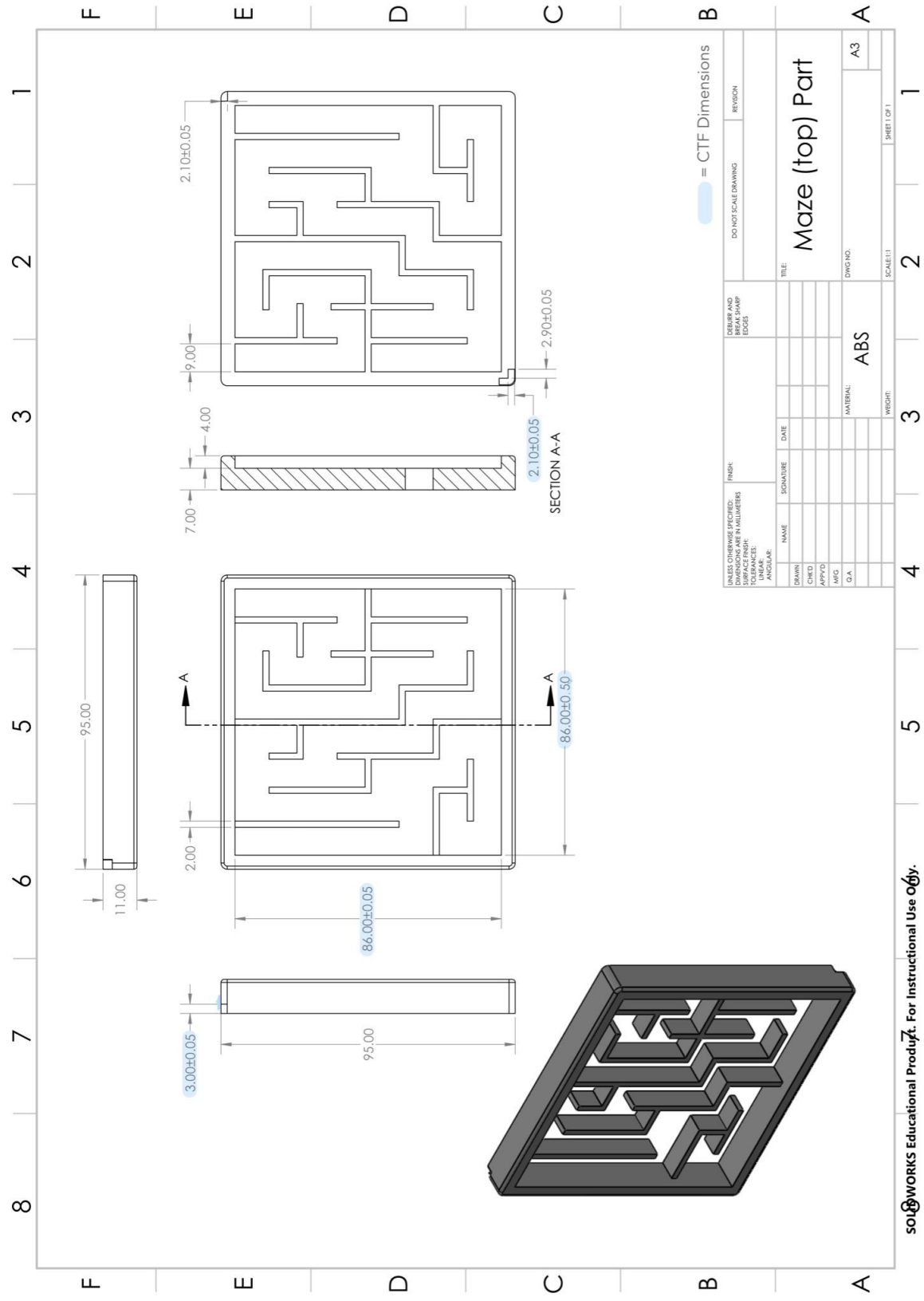

Figure 7a: Dimensioned Drawing of Maze (top) Part with cross section view

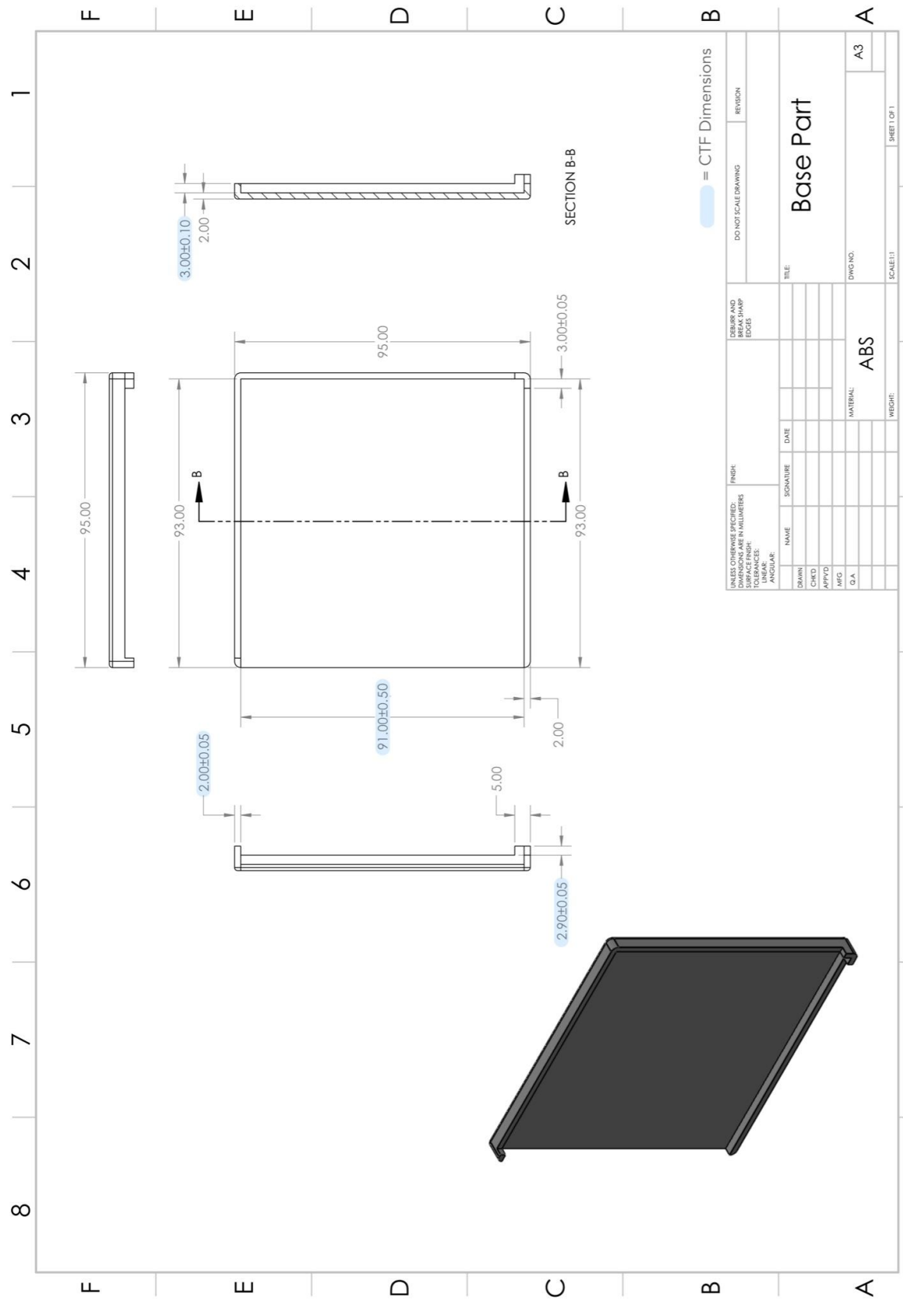

Figure 7b: Dimensioned Drawing of Base Part with cross section view

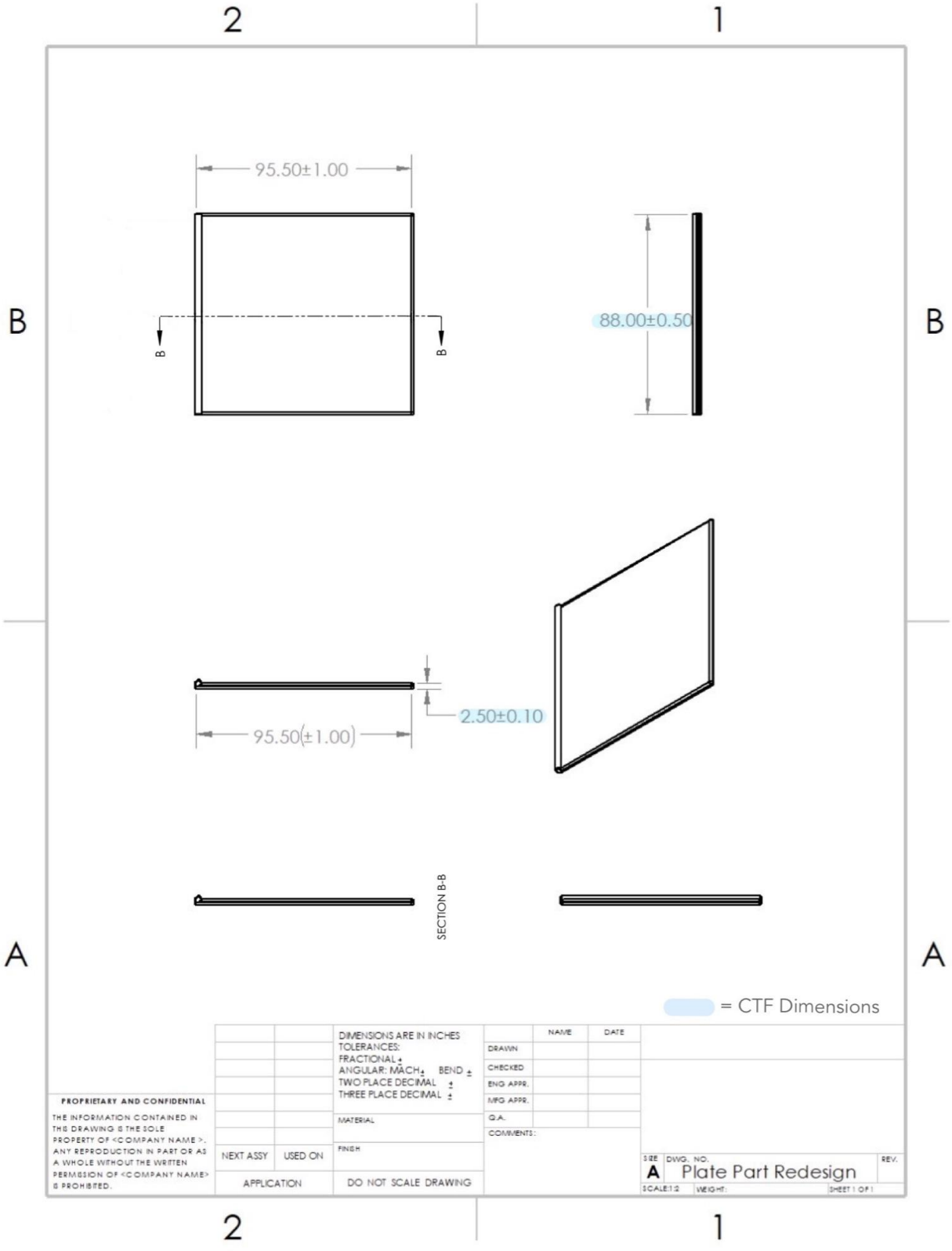

Figure 7c: Dimensioned Drawing of Removable Plate with cross section view

i) CTF Dimensions and Tolerance Analysis

The team found 3 parts of the toy which must meet required dimensions in order for the toy to function, and therefore are CTF dimensions. These areas are the cavity of the joints on the corners of the maze (top) part, the slot for the removable plate, and the cavity for the acrylic screen. If any of these parts were to not fit, the toy would no longer function as intended.

Each of the CTF dimensions were calculated using the dimension and tolerance of the constraining part (for the cavity joint on the maze part, the dimensions of the extrusions on the base part to fit the cavities constrained this dimension). The minimum dimension to avoid interference for the part was calculated by adding the allowance (if any) to the maximum of the constraining dimension (using the above tolerance + dimension). By using the above tolerance of the part, the CTF dimension was then calculated (Table 2).

For each of these CTF dimensions, worst-case tolerance analysis was calculated by summing the individual stackup tolerances to yield an overall maximum variation. The results of these calculations for each CTF dimension can be seen in the table below (Table 2).

Part	**Constraining Dimension** (mm)	**Allowance** (mm)	**Min Dimension to avoid interference** (mm)	**CTF Dimension of Part** (mm)	**Worst Case Tolerance Analysis**
Cavity Joint Width	2.00±0.05	0.00	2.05	2.10±0.05	±0.10 mm
Cavity Joint Height	2.90±0.05	0.00	2.95	3.00±0.05	±0.10 mm
Sliding Compartment Width	88.00±0.50	2.00	90.50	91.0±0.50	±1.00 mm
Sliding Compartment Height	2.5±0.10	0.30	2.90	3.0±0.10	±0.20 mm
Acrylic cavity	85.00±0.50	0.00	85.50	86.0±0.50	±1.00 mm

Table 2: CTF Dimensions and Tolerance Analysis

3D Exploded View

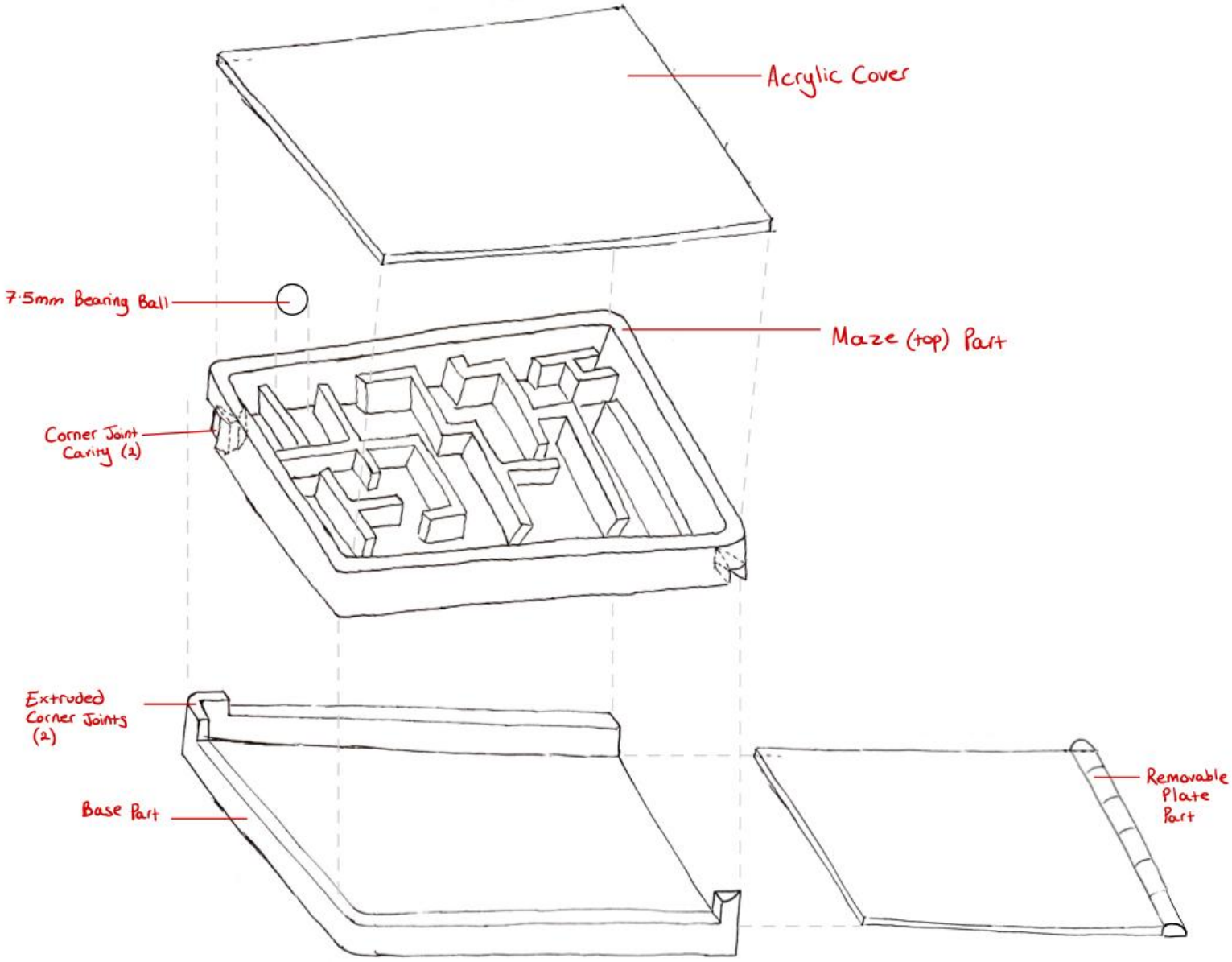

Figure 8: Exploded Drawing of Puzzle Maze Toy

ii) Part Material Specifications

The team has chosen to use ABS plastic for all plastic parts (excluding the acrylic cover), as it is a sturdy material with high rigidity and good impact resistance, therefore will be able to be handled or dropped without breaking. Further, this is a non-toxic material which is often used in children's toys due to these properties. Finally, ABS plastic is cost effective at $1.27 per pound.

C. Design for Manufacturability

The ball maze has been specifically designed to be easy to mass manufacture. Within the maze piece, each wall is connected to an edge so that it is one piece and can be constructed easily. The Maze (top) piece and base piece have consciously been designed as two parts, as although they could be 3D printed as one solid piece, the hollow slot for the removable plate would not be producible with plastic injection molding. Therefore, this decision was made to increase the mass manufacturability of the product with plastic injection molding. Further, we rounded all edges - where it was possible - to reduce the likelihood of faults in the manufacturing process using plastic injection molding, thereby increasing ease of manufacture of the product.

D. Manufacturing Plan

i) Estimated Toy Production Cost

Throughout the design process, the team repeatedly calculated rough cost estimations and used this to guide the design in terms of reducing the cost. Once the design of the 3 plastic parts was finalized, the team was able to accurately calculate the individual cost of each plastic part. By using 16 cavities per tool the base plate total was $0.11 per part, the sliding plate was $0.11 per part and the maze part was $0.10 per part (Appendix Table 1). In addition, an acrylic top piece was $0.037 per part, and the 7.5mm ball bearing was $0.60 per kg which amounted to $0.0012 per ball. Further, purchasing 10,000 2x3” stickers for the background would be $1612, which amounts to $0.016 per item (Table 3).

This item is able to be purchased with either one or two plates per happy meal. One plate background would be sufficient to play the game and would incentivise more purchases of the toy; nevertheless, two plates would enable the child to interchange the backgrounds immediately, without trading. The net cost of the toy including 1 plate or 2 plates would be $0.38 and $0.49 respectively (Table 3). The choice between one or two plates is the prerogative of Fluke Toy Corp.

Part	Cost of Materials	Cost of Molding	Total Part Cost
Maze (top) Part	$0.030	$0.072	$0.102
Base Part	$0.057	$0.057	$0.114
Sliding Plate	$0.057	$0.055	$0.112
Bearing Ball	$0.60/kg [1]	———	$0.0012
Sticker	$1612/10000 stickers [2]	———	$0.016
Acrylic	$1.50/kg [3]	———	$0.037
TOTAL	$0.198	$0.184	**$0.382**

Table 3: Cost Analysis of Ball Maze Toy

ii) Production Volume and Timing

Our team recommends this toy to be distributed worldwide to over 38,000 locations that provide the happy meal. McDonalds reportedly sells over 1 billion happy meals every year[4]. We suggest a 6 week toy roll-out for each of the 3 current designs, which would approximate to the production of 350 million toys. Using a cycle time of 30 seconds, 1920 parts would be made by each machine per hour. Therefore, a 3 month manufacturing run with 100 injection molding machines (with a press size of 1072 tons) would produce sufficient parts to support the 6 week toy roll out for each of the 3 designs.

For the toy rollout phase, we recommend starting with the “Cars” and “Encanto” design: an old favorite and a newly released film. We recommend limiting the production of the more recent films to increase the rarity and therefore the worth. This may incentivize buyers to purchase more happy meals in order to collect the backgrounds. The “Lightyear” model should start to be run in the 2 weeks prior to the release of the film on June 17th 2022 to create a *buzz*. Then, it should continue to run for the 4 weeks post release to capitalize on the film's popularity.

iii) Post-Injection Molding Processes

Once the parts are made using the injection molding machines, the base part and maze (top) part have to be adhesed using cyanoacrylate glue. The assembly of the parts has been made

[1]Bearing Ball Bulk Buy, https://www.alibaba.com/product-detail/Steel-Balls-Ball-Bearing-AISI52100-Highly_1600386087471.html?spm=a2700.7724857.normal_offer.d_title.4fded75cHEEFMA&s=p

[2] Background Sticker Bulk Buy, https://www.stickermule.com/uses/bulk-stickers

[3]Clear Acrylic Sheet 3mm Bulk Buy, https://www.alibaba.com/product-detail/JINBAO-3mm-5mm-6mm-10mm-12mm_60165618669.html?fromMSite=true

[4] Annual Happy Meal Sales, https://www.forbes.com/sites/aliciakelso/2021/09/21/mcdonalds-happy-meal-toys-are-getting-a-major-sustainability-makeover/?sh=3560fa7705e5

simple using the easy snap joints on the corners of each part. This also ensures that the maze is positioned the correct way on the base plate. The sticker must also be applied to the removable plate. Then the toy is complete and ready to be sold.

E. Sustainability Discussion

The team decided to use ABS plastic for each of the 3 injection molded parts. We chose to use this material as it is relatively cheap but most importantly non-toxic as well as highly recyclable[5]. With further development of the toy, the team will conduct research into suitable biodegradable materials which would further help to increase the sustainability of the product.

IV. Marketing Analysis

i) Target Customer Demographics and Parent friendly features

Our team believes the target audience of our ball maze would be children of any gender between the ages of 5 and 13. As this ball maze has interchangeable background designs from different genres of children's films, this product is adaptable for children with different interests. The current model includes the movies “Cars”, “Lightyear” and “Encanto”. However, when a new more popular film is in cinema, the maze can be easily reproduced using the same molds, with a new design sticker for the removable plate. This ball maze is not only extremely engaging and fun, it is also very intellectually stimulating and may help to increase dexterity and hand-eye coordination within children. This is a large draw for the parents of the users of the ball maze: a way to occupy the children in a fun but mentally stimulating way.

ii) Marketing Materials

To promote the toy at the toy fair, the team created a poster (Appendix Figure 4) and also a promo video. In this video, the concept and draw of the toy was displayed, as well as users playing with and enjoying the toy. The idea for the promo video was sparked during the testing with Duke students, as while the students were playing with the maze, they pulled out their inner child. This promo video is linked here, and can be used to further promote the toy. The team has also created a marketing sheet which conveys the important information for the toy in a digestible way (Figure 9).

[5] ABS Material Information, https://www.plasticcollectors.com/blog/what-is-abs-plastic/

the amazeing puzzles

Explore a multitude of worlds by playing with the amazeing puzzles! Tilt the game to guide the ball from start to finish line and help the character reach their goal. Collect our interchangeable backgrounds and trade them for a unique playing experience.

- Contents of each Amazeing puzzle Happy Meal toy:
  - One square-shaped maze:
    includes various start and finish lines
  - Two interchangeable plates:
    offers two backgrounds to interchange

- Target market: 5-13 year olds internationally

Key Features:

- Interchangeable plate backgrounds
- Fun and engaging for children
- Intellectually stimulating (dexterity and hand-eye coordination)
- Collectible (encourages coming back to collect new designs)
- Easily franchisable
- Tradeable (can trade plates with other children)

Product placement: included in Happy Meal internationally in over 38,000 locations worldwide

- $0.38 per puzzle (1 plate) or $0.49 per puzzle (2 plates)
- 3 month manufacturing run with 100 injection molding machines
- 6 week rollout per design (3 currently)
- Does not pose a choking hazard

Part	Cost of Materials	Cost of Molding	Total Part Cost
Maze (top) Part	$0.030	$0.072	$0.102
Base Part	$0.057	$0.057	$0.114
Sliding Plate	$0.057	$0.055	$0.112
Bearing Ball	$0.60/kg [1]	———	$0.0012
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Acrylic	$1.50/kg [3]	———	$0.037
TOTAL	$0.198	$0.184	**$0.382**

Figure 9: Marketing Sheet

V. Conclusion

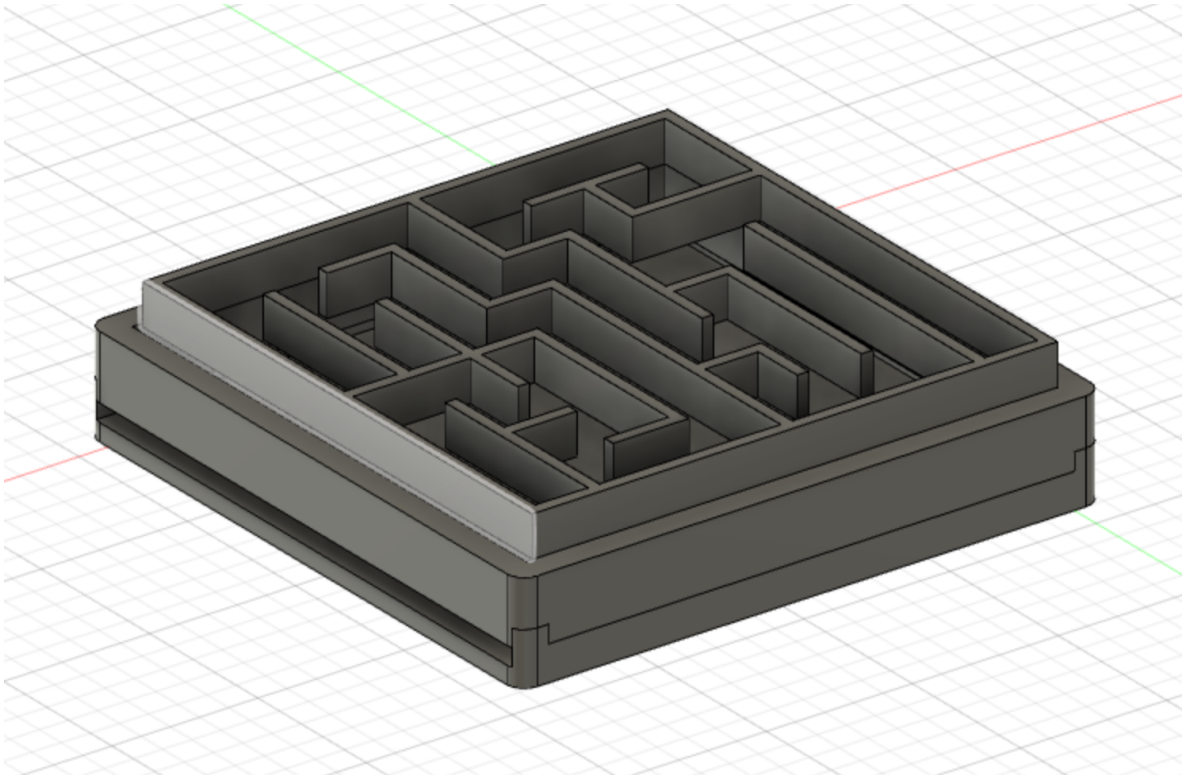
In conclusion, the team used multiple brainstorming and decision making techniques to arrive at a design for the toy. The team then used iterative prototyping to first create a proof of concept and reach a final product that was fully functional and fit together well. After creating this working prototype, the team tested it against Duke undergraduates to receive feedback to guide further improvements.The final design of the puzzle maze was unique with a removable plate with different maze backgrounds to allow children of all interests to be engaged with our toy.

Once the final design was reached, the team then conducted tolerance analysis of CTF dimensions on the toy, as well as calculating the estimated cost of each toy using the plastic part cost estimator spreadsheet. Then the team conducted research into happy meal sales to recommend a production volume of approximately 350 million toys, for a 6 week toy rollout of each of the three designs.

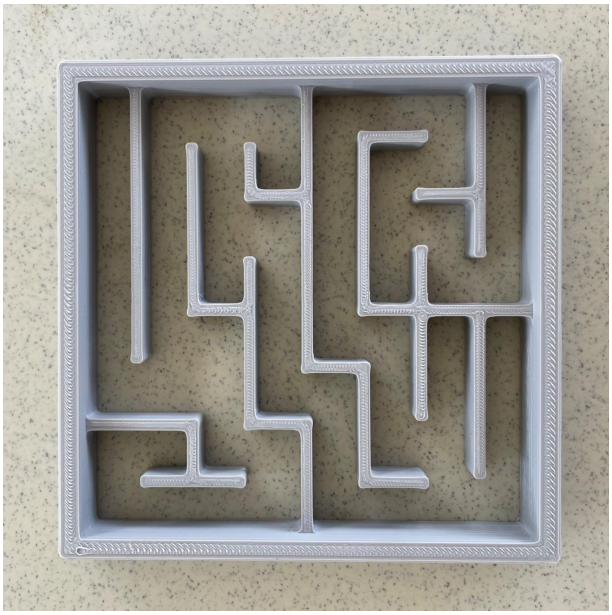
Finally, the team created a range of materials for the marketing of the puzzle maze, including a poster as well as a promo video. The video proved to be very useful during the presentation, as it actively demonstrated the toy's main selling points in one minute in a fun and creative way.

The presentation was received very well. Each group member was dressed as the maze background they designed. Two functional mazes were present, which became very useful towards the end of the lab time where people bagan racing against each other in completing the maze. The engagement of users with our puzzle maze emphasizes the success of our puzzle maze toy.

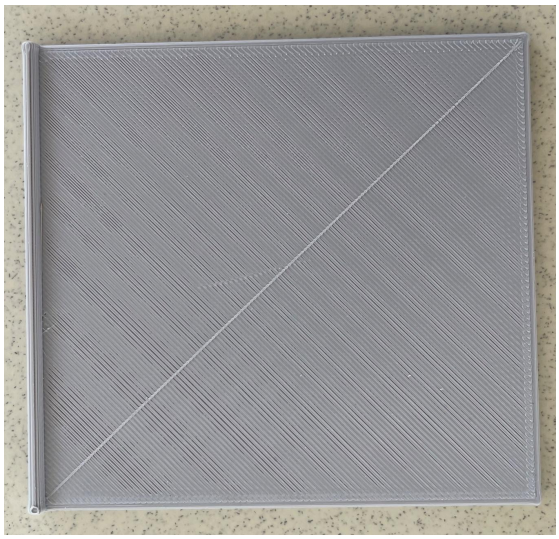
VI. Appendix



Appendix Figure 1: Initial design with 4 plastic parts (3 plastic body parts with removable maze piece pictured - removable plate part not pictured)



Appendix Figure 2: Maze (top) Part



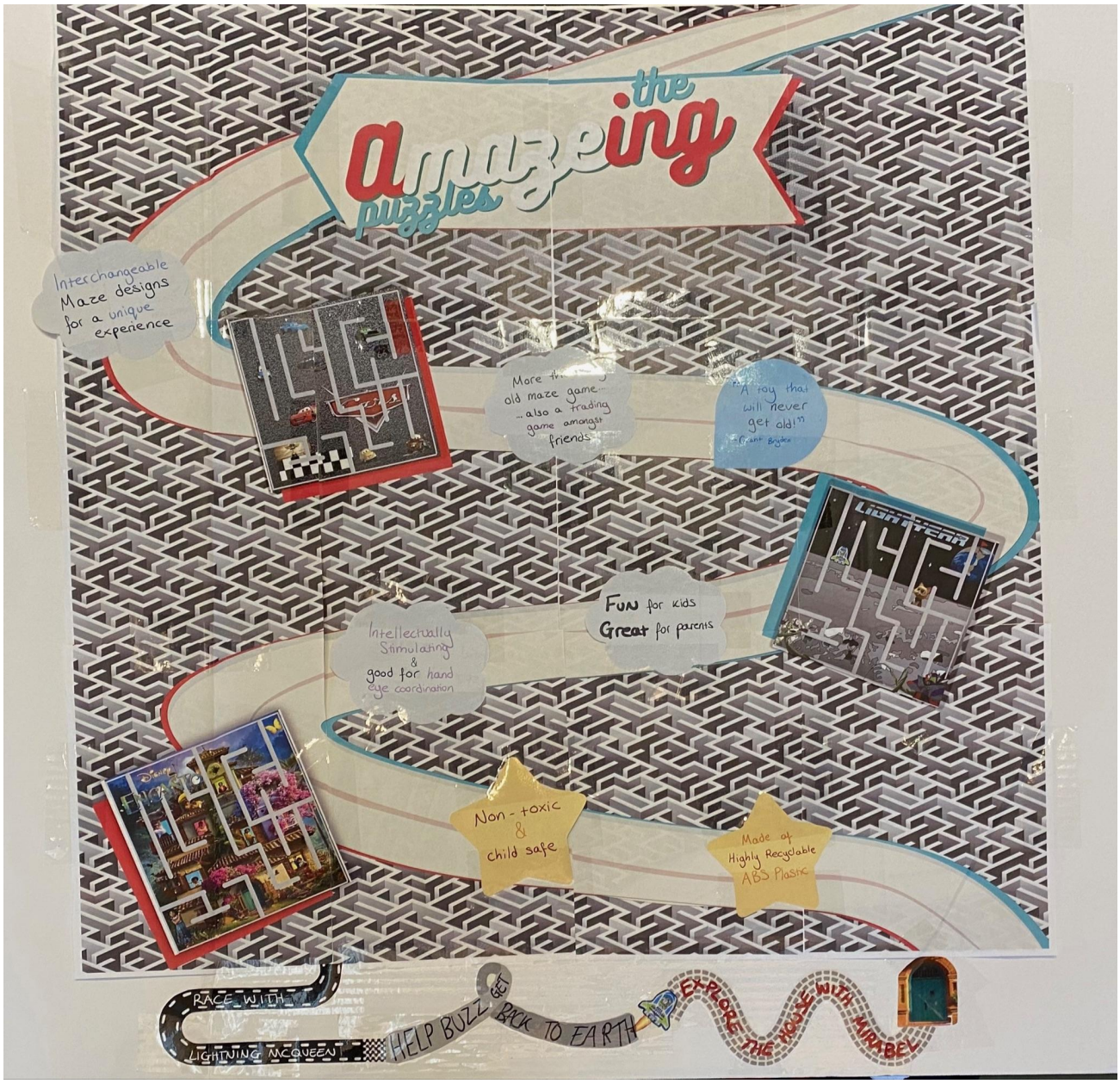
Appendix Figure 3: Removable Plate Piece (without background design)

Plastic Part Cost Estimator

Ver 2/19/20

	Part Name	Projected Area	Cavities per Tool	Injection Pressure	Press Size	Attended?	Press Cost	Cycle Time	Yield Rate	Parts / Hour	Molding Cost	Material	Specific Gravity	Part Volume	Part Volume	Part Weight	Raw Material Cost	Part Material Cost	Total Part Cost †
		in2	#	tons	tons		$/hr	sec	%	#	$	#		cc	in3	lbs	$/lb	$	$
1	Base Plate	13.4	16	5	1072	No	110	30	99.999	1920	$0.057	ABS	1.06	19.70	1.20	0.046	$1.24	$0.057	**$0.11**
2	Maze Part	4.1	16	5	325	No	58	30	99.999	1920	$0.030	ABS	1.06	24.90	1.52	0.058	$1.24	$0.072	**$0.10**
3	Sliding Plate	13.4	16	5	1072	No	110	30	99.999	1920	$0.057	ABS	1.06	19.05	1.16	0.045	$1.24	$0.055	**$0.11**
																		Total:	**$0.33**

Appendix Table 1: Plastic Part Cost Estimator Spreadsheet



Appendix Figure 4: Poster for Toy Presentation