Final Report
Travel-Compatible Toddler Toy

ME 450 WN23

Team 7:
Angela Peterson
Cayla Kadets
Sam Weller
Sedona Giambalvo
Section Instructor: Sita Syal
Sponsor: Sarah Kreitman, UM Ross Masters Student
4/24/23

Revised Abstract

Currently, parents do not have a reliable source of entertainment for children in a travel setting outside of screen entertainment from phones and tablets. The toys on the market either have too many pieces, are not portable, are not equipped for use in a travel setting, or are too distracting to parents and bystanders. Therefore, our goal is to create a travel compatible, safe, interactive squid toy for toddlers, 2 to 3 years of age, that provides an alternative to current screen entertainment. At the end of this project, we have created a working, high fidelity prototype.

EXECUTIVE SUMMARY

Currently, parents do not have a reliable source of entertainment for children in a travel setting outside of screen entertainment from phones and tablets. The toys on the market either have too many pieces, are too cumbersome to be portable, are not equipped for use in a travel setting, or are too distracting to parents and bystanders. Therefore, our goal is to create a travel compatible, safe toy for toddlers, 2 to 3 years of age, that provides an alternative to current screen entertainment.

Our requirements are based on our stakeholders' needs. Some of our major stakeholders include parents, children, and toy manufacturers. Based on the stakeholders' needs, the toy must be portable for both the guardian who must transport the toy (33x33x33cm) and for the toddler using the toy (toy weighs ≤ 2 lbs). It must also be safe for children, which includes that the materials that the toys are made of are not harmful to children and that the toy has no parts that are small enough to be choked on by a toddler. To ensure our safety requirements are met, testing based on the ASTM F963-17 standards has been performed. Some other requirements (and specifications) include: no screens, not distracting to surrounding people (≤ 50 dB), and is not easily displaced (≤ 5 pieces, plus a mechanism to allow retrieval of the toy, by a kid, if it is dropped).

We have performed both individual and team concept generation, including mind-mapping and screening, to come up with toy designs that satisfy our requirements. To select our final design, we used a pugh chart, which ranked various categories, including many of our requirements, for each of our top five chosen toys. The pugh chart led us to our chosen design: a squid toy that is around 10 inches tall and 3 inches in diameter. If you pull the longer arms of the squid, you can blink the squid's eyes and move its tongue. The body of the squid is made out of fabric, the head is made out of a two-toned fabric that a kid can draw on using only their hands, with a ring at the top to attach a device that will prevent displacement of the toy.

In order to meet all standards, we have done a multitude of testing on our product, which involves various testing methods. We have performed force tests on multiple parts of the toy, including the elastic arms, the 3D printed plastic head and all the 3D printed inner mechanism pieces. All have passed their force tests. We originally had a plan to do a drop test on the toy, but our sponsor has requested that we not take the chance of destroying the toy. In terms of safety, we have performed research on the materials we are using for our toy (ABS plastic, silicon, various fabrics, etc.) and have ensured that all materials are safe for kids to interact with. In addition, we have observed our sponsor's niece interacting with the toy, which has helped us understand that the toy is entertaining and, so far, safe and durable. Also, we have sent out two surveys to parents with young children to get a better idea of if this toy would be bought, if they think it is portable, if they think their kid would be entertained by the toy and if there are any other concerns they might have with the toy. Overall, we have performed a majority of our prototyping and testing in the X50 Design Space. In the end, we have created a high fidelity, full sized prototype of our squid toy. It uses manufacturing processes such as injection molding, additive manufacturing (SLA 3D printing) and sewing/assembly of parts. The toy is less cohesive (in terms of the attachment of all the different materials/parts together) than we would have liked, but it gives a good, functioning idea of how the toy would work and the different sensory elements on the toy.

INTRODUCTION

Problem Statement

Currently, parents do not have a reliable source of entertainment for children in a travel setting outside of screen entertainment from phones and tablets. The toys on the market either:

- Have too many pieces
- Are too cumbersome to be portable
- Are not equipped for use in a travel setting, or
- Are too distracting to parents and bystanders.

Therefore, our goal is to create a travel compatible, safe toy for toddlers, 2 to 3 years of age, that provides an alternative to current screen entertainment.

Justification of Problem

Our sponsor, Sarah Kreitman, has voiced that she has a two year old niece who loves playing with toys; however, she noticed that there are not many options out there in terms of a toy made specifically for travel or more specifically a toy that has the ability to be conveniently played with during car travel. Most toys are either too large, have too many components, or are too noisy and would be distracting to those around them. Many parents, in the instances where they are traveling and they need to entertain their children for long periods of time, are resorting to giving their kid a smartphone or tablet in order to entertain them. Giving children screen entertainment for long periods of time at young ages can be detrimental to their development, so the need for an alternative travel compatible toy exists. Portability, alongside safety, are the two main concerns of our team in designing a toy to meet the needs of our sponsor, and parents and kids alike.

BACKGROUND

The Problem with Screens

Many parents do not want to hand their children tablets or phones in order to occupy them, even though many do. Is there science to back the parents' dislike for their kids constantly being on screens? Yes, there is. Having an addiction to screens is a real thing; screen addiction activates the same parts of the brain as drugs, alcohol and gambling [1]. For young kids, this high use of screens is resulting in numerous negative effects, some of which include: a slowdown in cognitive development, a decrease in focus, a worsening of social skills and a worsening of health overall. The worsening of social skills and health are mainly due to kids spending large amounts of time on screens rather than playing outside and hanging out with other kids [2]. Not only that, but researchers have noticed that the more often kids use screens, the more behavioral problems and violence they have [3]. If screen time is causing so many negative effects, what is an appropriate amount of time that kids should be spending on screens? The *American Academy of Pediatrics* recommends that screen time is discouraged for children under two years of age, and for children two to five years, screen time should be limited to one hour per day and should be high-quality programming along with being monitored by an adult [4].

Average Attention Span of a Toddler

Generally, a 2 to 3 year old toddler is believed to have an attention span of 4 to 8 minutes [5], with the upper limit of this time range being 5 minutes per year of the child [6]. For most travel situations, even those as short as a car ride, this attention span would be a problem, as it wouldn't take long for a toddler to become bored. A bored child could then become an annoyance to their caregiver or others around them. Fortunately, a toddler's attention span can be affected by the stimuli they are focusing on. In cases where toddlers are focusing on something creative or that uses their imagination, their attention span can greatly increase beyond the upper limit mentioned above. In contrast, an activity that a child finds boring or frustrating, such as working on school work or doing chores, will greatly reduce the attention span of the child for that task. Creative stimuli would be activities like building blocks, puzzles or similar problem solving toys, playing pretend, such as using a doll house and dressing up, or using open ended, creative tools, like painting, drawing, making music, sculpting with clay, and doing crafts [7]. Obviously, some of these activities are not fit for a travel setting, but they do provide a better understanding of how a child's attention span could be increased with a toy for use in travel settings if it provided an outlet for imagination.

Toy Safety and Choking Hazards

One of our team's largest concerns is that we would like to ensure, while we are coming up with a solution that is entertaining and not screen forward, that we are placing safety as one of our highest priorities. Toddlers can be unpredictable, and we want to make sure that the toy we create is not one that requires use only under constant supervision. Choking is the leading cause of child mortality [8]; hence, we need to follow strict guidelines to ensure that our toys are not choking hazards. The best way to identify whether or not something will be a choking hazard for children is to utilize a Small Parts Test Figure, SPTF. A Small Parts Test Figure is a truncated cylinder with a diameter of 3.17 centimeters / 1.25 inches simulating the mouth of and a depth of 2.54 - 5.71 centimeters or 1 - 2.25 inches simulating the pharynx of a small child. Oftentimes, an empty toilet paper roll is used to model a SPTF where unavailable, as depicted in Figure 1 below. If a toy, or any pieces or attachments of the toy can fit through the center of an empty toilet paper roll, then it is deemed a choking hazard for children [9]. Thus, as our team trudges forward with the design process, it will be important for us to keep the toilet paper roll test in mind.

[10]

Figure 1. Identifies the toilet paper roll dimensions discussed to model a Small Parts Test Figure used to determine whether or not a toy, or a piece of a toy would be a choking hazard for the average child.

Standards and Testing for Children's Toys

Given the range of concepts employed in toy manufacturing and design, no single standard can be used to ensure safety across all toys. In order to amass the standards necessary for crafting a toddler toy, we needed to do some background research into the standards for material property testing of a toy, abuse testing, and sharpness tests, as well as determine standards for safety labels on toys. We first found ASTM F963-17 "Standard Consumer Safety Specifications for Toy Safety," in which there were several standards we found would be generally helpful for the safety of our toys: 4.2 (Flammability), 4.3 (Toxicology), 4.7 (Accessible Edges), 5 (Labeling Requirements), 8.6-8.10 (Abuse Testing), and Annex A5 (Flammability Testing) [11]. Using this set of standards, we were first able to determine the procedure with which to test if our toy was flammable using a burn test. In a burn test, four final products of the toy are ignited from one point using a candle, and allowed to burn for 60 seconds, at which point they are extinguished using a fire extinguisher. The distance along the major axis (the longest straight line through the toy) that the toy burned is measured, and as long as all 4 toys produced a burn rate less than 0.1 in/s each, the toy is accepted. We also learned the process that a material is determined to be nontoxic, though this is not something we would have to test for unless we produced a new material for our toy that needed such testing. As such, we will be able to find materials later on that have already been deemed non toxic for our toy design. Accessible edges was another test we found in our research, in which a potentially sharp edge has a piece of polytetrafluoroethylene tape dragged over it and, so long as any cuts in the tape are less than ½ inches, the edge is accepted as not sharp. Finally, we found standards for warning labels to be placed on packaging for our toy, such as toys with marbles, small parts, aquatic toys, or crib and playpen toys. Since we don't have a toy concept generated yet, this will primarily be used for future reference when we need to label our toy with proper warnings.

Car Safety

Due to the fact that one of our target locations for use of our product is within a car, we found it important to do background research on common safe car practices. Since safety is one of our main priorities when developing our solution to our defined problem, it is important for us to consider safety measures already in place in the areas in which we intend for our product to be used. Children typically sit in a forward facing car seat from ages 2-5 or until their height and weight exceeds the recommended [12]. Thus, as we begin to think about the size and shape of our design we must do so with keeping in mind that our space may be limited by the car seats or the location of airbags in vehicles. We do not want our product to cause more harm than good in a travel setting, which brings up another car safety issue that we would like to consider. Noisy toys can be distracting to drivers. It has been proven that noise distractions of drivers in cars can cause mental strain, and that music itself can be a distracting auditory stimulus while driving [13]. Drivers can still perform at high levels and drive safely with noise distractions, but the mental cost will be higher and the driver will feel more drained after the fact. Our product is supposed to have more benefits that outweigh any costs in a travel setting, so we have to be mindful of the size and sound level, for portability and safety reasons.

Current Toy Market Research

In order to validate the need for the travel-compatible toddler toy project, it was important for our team to investigate the toys for children that are currently available and popular in today's market. Searching the websites of toy companies and manufactures that are presently the most popular with parents and children, we were able to find common characteristics of toys within certain price ranges, which are listed in Table 1 on page 6.

Table 1. Through extensive research, it was found that popular toys currently on the market for children below the age of 5 have common traits at certain selling price points. Toys with more electrical components, made out of plastics, or target the older end of the age range tend to fall into more expensive categories.

$0 - $25	**$25 - $50**	**$50 - $100**	**$100+**
Soft fabrics	Soft wood	Rideable	Rideable
Plush toys / stuffed animals	Noise element	Noise element	Motorized
Toys made up of many small pieces	Requires large amounts of space to play or store	Requires large amounts of space to play or store	Large playhouse/kitchen set-ups

The common characteristics in Table 1 above were determined after looking at what various children toy companies and manufacturers are selling to parents or caretakers today. Leading toddler toy companies include, but are not limited to, Mattel, Hasbro, Fisher-Price, Baby Einstein, and LeapFrog. The overwhelming majority of toys that are being sold are made entirely out of plastics, or contain multiple plastic parts. Toys within a lower price range, less than $25, include many stuffed animals, plush toys, and infant toys composed of many parts. If a toy included noise or lighting elements, it most likely was found to have a selling price greater than $25. Many toys that require large amounts of space to set up, such as playmats or *Jumperoos* (seen in Figure 2 below), fell into the greater than or equal to $50 category. Finally, the most expensive toys, which cost a minimum of $100, notably included toys that children could ride or were fully immersive, such as motorized sidewalk vehicles, playhouses, or model kitchens. Considering the cost information that we found, and since we plan to bypass the use of screens, limit noise elements, and ensure the size is small enough to be played in a travel setting, we estimate that our toy will sell at no more than $50.

[14][15]

Figure 2. Many toys that fall within the price range of $50 - $100 are activity playmats (left) or *Jumperoos* (right). These toys are designed for the younger end of the toddler age range, and allow the child to lay on or sit in the toy as they interact with the various parts.

Due to the fact that we have size, screen, and noise constraints for our project, we can narrow our view of the current toy market. Looking at the portion of toys made for toddlers that are assumed to be portable, it is evident that companies and parents have defined what portable means in their own unique ways. Travel compatibility seems to be defined in three ways: easy to pack or store, easy to transport, and easy to play with during travel. Our team found that usually when a company declared a toy portable it fit the first two criteria. Despite being easy to handle, the toys can be too messy to play with during travel, like *Play-Doh*, or contain too many pieces to be easily played in a car, like *Mega Bloks*. Toys that fit all three descriptions of portable can be found, such as the *VTech Busy Learners Activity Cube* or the *LeapFrog LeapTop Touch*, although nearly all of the toys we could find included some noise or screen element. Therefore it is evident that what the market is currently providing for non-screen, travel-compatible toddler toys is not sufficient, and there is an opening in the market that our new toddler toy design can fill.

DESIGN CONTEXT

Stakeholders

Many people, companies, and organizations can influence the design of our toddler toy product, or be influenced by our end result. Each of these stakeholders holds a different amount of influence, which we defined in three distinct categories: primary, secondary, and tertiary. Primary stakeholders are directly impacted by the creation of our product. Secondary stakeholders are still affected by our problem, defined earlier in the problem statement, but are indirectly impacted. Tertiary stakeholders do not have a direct connection to the problem themselves, but can influence whether the product we come up with will be a success. Considering the short duration of time in which we are allotted to work on this project, our primary stakeholders are our sponsor, parents who will eventually be purchasing our product, and children aged two to three years old, who are the intended audience for our product. These three stakeholders are uniquely impacted by the problem statement and will be most directly affected by the solution. Figure 3 below shows some of the other relevant stakeholders that we are considering as we begin to make design decisions.

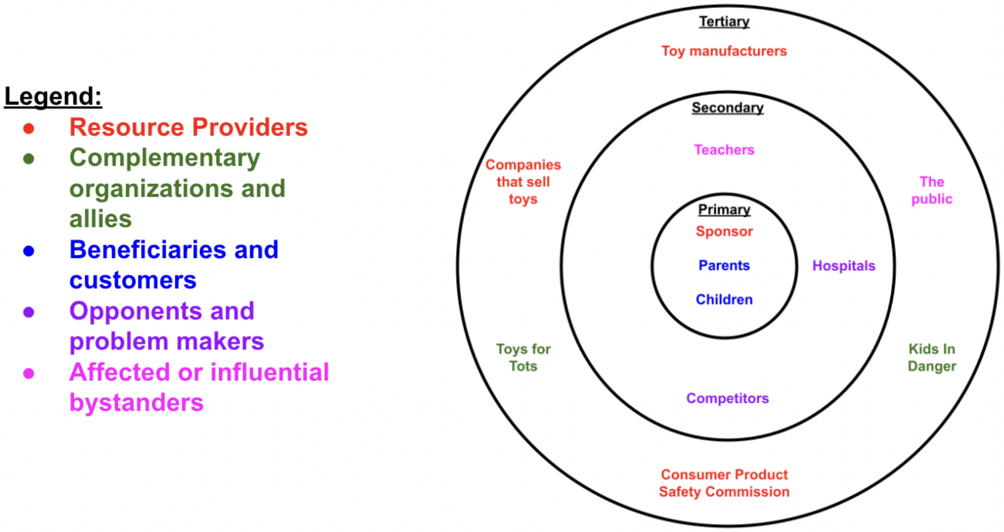


Figure 3. Shows a bullseye diagram Stakeholder Map. Moving outwards, the stakeholders are presented from those most directly impacted by the problem to those who are not directly affected but could still have an effect on whether or not the solution is approved. Each stakeholder is grouped into one of six categories, identified by the legend.

All of the stakeholders that are listed in Figure 3 above are not only sorted into three priority groups, but are sorted into one of six categories, describing the relationship they have to the problem. The stakeholders can fit the descriptions of more than one category, but our team has sorted them into which category they exemplify best.

Resource Providers. Stakeholders that contribute expertise or resources, whether they be physical or financial, can be labeled as Resource Providers. For our toddler toy project, we consider companies that sell toys, toy manufacturers, the Consumer Safety Product Commission, and our sponsor the Resource Providers. If our toy design follows a path that leads to mass production, it will become necessary to have connections with a toy manufacturer that will be able to provide us with the physical resources we will need to create the toys. The companies that sell toys can provide us a space to introduce our toys to our ideal market and make a profit. The Consumer Safety Product Commission will be able to provide our team with the necessary expertise and safety information if we plan to release the toy into the market. All of these stakeholders have important roles to play in the future of the toddler toy design, although when considering our condensed timeline, their roles are not immediately needed. Therefore, we have categorized them currently as tertiary stakeholders. Our sponsor is also a Resource Provider, as she brought the problem to our attention and provides feedback to our team weekly. She has experienced the problem described in the problem statement firsthand, so she is very invested in a solution being made. The creation of our toy will directly impact her, so we have classified her as a primary stakeholder.

Complementary Organizations and Allies. There are many organizations that support our toddler toy project and also seek to find a solution to our problem. We label these organizations, such as Toys for Tots and Kids in Danger, as Complementary Organizations and Allies. Toys for Tots is a program that strives to make sure all children, regardless of their families financial situation, have the opportunity to unwrap a gift during the holiday season. They accomplish this by raising funds and collecting toy donations throughout the year. Almost all donations that they collect are used directly to buy the toys. If our team creates our toddler toy and is able to sell it at an affordable price, Toys for Tots will be able to purchase toys for more families. Kids in Danger benefits as well, but in a different way. They are a non-profit whose goal is to protect children by bringing attention to product safety. Organizations like Kids in Danger will most likely be supportive of our toddler toy solution as long as they know that one of our top priorities for the toy is safety. Having the support from organizations such as Toys for Tots and Kids in Danger is favorable, but neither are directly connected to the issue of travel-compatibility. Therefore, our team has classified them both as tertiary stakeholders.

Beneficiaries and Customers. Stakeholders who most directly benefit from the development of our toddler toy are categorized as Beneficiaries and Customers. As stated previously, both parents, who will eventually be purchasing our product, and children, between the ages two to three years old, are those who receive the direct benefit of our solution. Specifically, we choose to include parents over a caretaker or nanny, because in most cases a parent of the child is buying and providing the toy, whereas a caretaker is using what is already available to the family to entertain the kid. We also are focusing on making the toy priced appropriately in terms of other toys on the market to reduce the financial burden on our intended users. Due to both parents and children being the product's intended audience, we have classified them as the primary stakeholders. If a parent decides the toy is too distracting or too expensive, they will not purchase the product for their child. If a toddler finds the toy frustrating or too boring, they will not want to play with the toy. Without either of their approval, the product will not be bought. Hence, the toy has failed to be a solution to the original problem. This phenomenon is why our team has decided to give them top priority.

Opponents and Problem Makers. Not only do some companies and organizations object to the production of our team's toy solution because it benefits from the status quo, but some are actively harmed by our product. Competing toy companies and hospitals are both examples of these Opponents and Problem Makers. It is evident why competing toy companies would try to undermine our solution, or prevent its societal impacts. If our toy succeeds, and our sales go up, their sales go down. If a parent chooses to buy our toy for their toddler, they are less likely to buy from competitors. Hospitals have the potential to be for and against our toy solution. They are for our solution, because if we create a safer toy, there will be less hospital visits by children with toy related injuries and emergencies, which would lighten the load for the already overcrowded emergency rooms. On the other hand, if less children are being injured as a result of our toy, this would decrease the profit that a hospital is making; thus, the hospital would be against our toy. Both of these stakeholders are affected by our problem statement, but are only indirectly affected by the creation of our toy. Therefore, both were classified as secondary stakeholders.

Affected or Influential Bystanders. The last category that our stakeholders can be divided into is Affected or Influential Bystanders. These stakeholders are not directly impacted now, but have the potential to be in the future. Included in our stakeholder map are teachers and the general public. One of the main goals of our toddler toy solution is for it to be portable. As a result of it being portable, many members of the public will be subjected to the product. If a bystander finds the toy annoying or distracting in any way, they are likely to not purchase one of their own, or recommend the product to others. Despite that, they are not immediately influential to our design, as we are trying to cater to the wants of the parents and kids who will buy and use the toys. Accordingly, we have categorized the public as tertiary stakeholders. Teachers are also impacted by the toy, because eventually if our toy gains enough popularity then it could be integrated into a classroom setting.

Global Context

One of the biggest things that we must consider when framing the scope of our product is that China makes 70% of the world's toys [16]. As the "world's factory," China has been working overtime to meet the ever growing demand for consumer goods. To maintain that our toy is ethically sourced, we have to make sure that if our toy were to become mass produced that the labor used does not come from sweatshops, "dormitory labor" systems, or anything of that sort [17].

Cultural and Social Context

As we work to create a product for children to use, the social context in which our product lies is very important to our design process. We must remember to consider that screen entertainment can have a negative impact on the development of children, but also that children have short attention spans to begin with. It is hard to entertain them for long periods of time, which is why many parents have resorted to giving their children a phone or table, creating a culture of "iPad kids"; screen entertainment is addictive and can keep a child occupied for a lengthy period of time, especially in a travel setting. Thus, this problem indicates that there is a gap in the toy industry that we are attempting to fill.

Environmental Context

Most children's toys are made from plastic, so that is something that we must take into consideration when we are constructing our toy. Many toys only have a lifetime of a couple of years before they are discarded and end in landfills, so the end-of-life of the material could impact whether or not we select it for use. In creating our product, we are trying to solve a social problem, but we do not want to create any additional problems environmentally or otherwise.

Ethical Issues

When working with children, there are many ethical issues that stem simply from dealing with kids, their safety, and the appropriateness of the entertainment that they are to consume. We want to make sure that our toy isn't solving the major addiction of screen entertainment in children by perpetuating or endorsing another (i.e. child obesity through the inclusion of food in our toy). Safety is one of our largest priorities, so we want the end users of our product to have an enjoyable experience without worrying about any present or future consequences related to the consumption of our entertainment. Lastly, we also seek balance between creating a toy that benefits our key stakeholders, but that also benefits us in the long run as being profitable.

Inclusivity and Power Dynamics

Again, with there being such a distinct gap in the toy industry where our product domain lies, we want to make sure that our toy attracts the largest audience possible. We want our product to be universally interesting, something that boys and girls alike will enjoy using. All children are different and have different interests, so this may be a struggle for us to meet every distinct group of children's respective desires. Additionally, we want to make sure that we create a product that is universally accessible; we want children with disabilities to be able to enjoy our toy as well.

DESIGN PROCESS

Design Process

In order to create an effective solution to the complex problem presented to us by our sponsor, we will be utilizing a structured, solution based approach to the design process. Our need has been identified by our sponsor, with which we will effectively define the problem, generate and explore concepts, and develop and verify a solution. These steps are not linear, but rather, they are a cyclical process, with each step having multiple iterations before arriving at a fully developed solution. Our process is outlined in Figure 4 below, where you can see the feedback style loop that we have outlined for our design process.

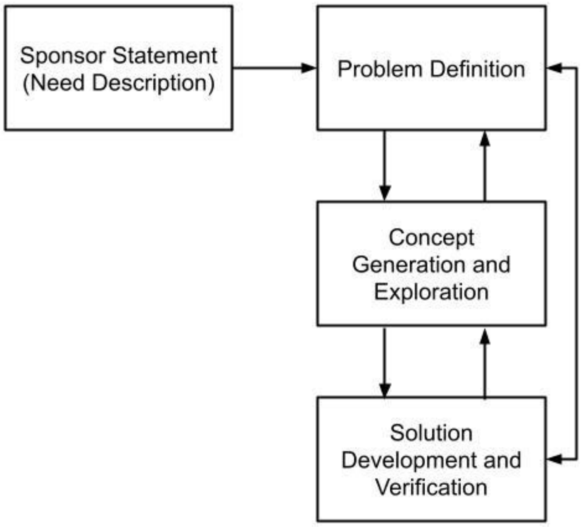


Figure 4. Shows the iterative design process that our project will undergo throughout the course of the semester.

It is important to note that the final step for our design process is Solution Development and Verification rather than Realization because that step is out of the scope for ME 450. One of our biggest limitations to the design process is time, since we are only allotted the few months we have in the semester to move from start to finish with our project.

Stakeholder Requirements and Engineering Specifications

In order to begin concept generation, our team needed to better define our problem and decide what elements our potential solutions would need to conform to. After speaking amongst ourselves, speaking to our project sponsor, and extensive background research, we created a list of requirements and their specifications that reflect what we wish to accomplish with our toddler toy. Table 2 on page 11 below lists, in order of importance, those requirements that we deemed necessary and the specifications needed to measure their success.

Table 2. A list of the requirements and specifications needed to ensure our team's toddler toy is accomplishing the goals of our problem statement. The order in which they appear in the table indicate our priority, with what we perceive as most important near the top of the table.

Requirements	Specifications
Portable: Adequate size for toddler to play in a car	- Weight: ≤ 2 pounds
Portable: Easy for caretaker to pack and transport to various locations	- Able to fit on toddlers lap (33x33x33cm / 13x13x13in)
Safe: Materials toys are comprised of are not harmful to children	- Toy has a burn rate averaged over 4 tests is less than 0.1 in/s [11] - Material used in toy production is previously found to be nontoxic [11] - Toy edges should not produce a cut in polytetrafluoroethylene tape longer than ½ inch, as per a sharp edge test [18] - Proper "Warning" and "Caution" labels on the toy that identifies potential hazards [11]
Safe: No toy parts are small enough to be a choking hazard	- Small parts test figure (SPTF) — a truncated cylinder with diameter of 3.17 cm/1.25 inch simulating the mouth and a depth of 2.54-5.71 cm/1-2.25 inch simulating the pharynx [9] - Proper "Warning" and "Caution" labels on the toy that identifies potential hazards [11] - When pulled with 5 lbs force, maximum appendage length <12" - If multiple elastics, cannot be easily tangled to form a loop, in which a child's head can fit through
No screens	- Zero screens on toy
Child will not be able to permanently deform toy while playing with it	- Uses: 360 times, 20 min duration each play -Toy can be dropped 4 times from a height of 3 ft ± 0.5 in without breaking [11] - Toy can withstand an applied torque of 3 ± 0.2 in-lbf clockwise and counterclockwise without breaking [11] - Toy (non-elastic) can withstand 15 ± 0.5 lbf applied in tension parallel and perpendicular to major axis without breaking [11] - Toy can withstand 25 ± 0.5 lbf in compression without breaking [11]
Cannot be easily displaced by child	- ≤ 5 pieces - Toy has a mechanism that attaches it to the front seat or grab handle in the car so that it can be retrieved by the child if dropped
Keeps a child occupied for duration of travel	- Child is occupied for ≥ 20 min
Competitive Pricing in relation to similar toys on the market	- Sells for ≤ $35 per toy
Non-distracting to surrounding people	- ≤ 50 dB - On/off function for sounds

Justification for Requirements and Specifications

Extensive background research on current toys, safety, and standards was conducted in order to construct both the requirements and specifications listed in Table 2 above on page 11. Requirements and specifications are listed in order of priority, with our highest priorities being portability and safety.

(1) Portable: Adequate size for a toddler to play in a car. The main reason we were brought and are pursuing this toddler toy project is because there is a lack of toys on the market that can be used in a travel setting. Therefore, the ability for our toy to be portable is a high priority for our team. Specifically, we want to make sure that a child will be able to play with the toy we create within a travel setting, such as a car. In those settings, the child will most likely have to hold the toy on their lap in order to play with it. We do not want to injure the child or cause them any extra strain, so we researched acceptable age ranges for what a toddler can hold for prolonged periods of time. Our team found that a child can carry approximately 10% of their body weight comfortably in a backpack [19], which for most children that are 2 to 3 years old, is 20 pounds [20]. That is how we ultimately determined our specification of the item weighing less than or equal to 2 pounds.

(2) Portable: Easy for caretaker to pack and transport to various locations. Not only do we want a child to be able to play with our toy in a travel setting, but our team wants to ensure that the toy is easy for parents to handle as well. Parents are less likely to bring along a toy when they travel if it is difficult to pack, heavy, or unreasonably large. Since we intend for the toy to be playable in a car, it must be able to be held on a child's lap. Research shows that the average shoulder width of a 2 to 3 year old toddler is 13 inches. Therefore, we have created a size specification for our toy, limiting its size to less than or equal to the dimensions 13” x 13” x 13” (33 x 33 x 33 cm).

(3) Safe: Materials that toys are composed of are not harmful to children. The project's primary user is intended to be children, therefore our team has placed a large emphasis on safety. If a 2 to 3 year old is going to be spending long amounts of time playing with this toy, at times unsupervised, the material from which the toy is made should not have any potential to harm the child. Many toys in the current market are made of various types of plastics, and because some plastics may be a health hazard, we need to ensure the toy be made out of safe materials that meet the 16 CFR 1500.49 [18] and ASTM F963-17 standards for flammability, toxicology, accessible edges, and more [11].

(4) Safe: No toy parts are small enough to be a choking hazard. Young children, especially those in the toddler age range we intend to focus on (2 to 3 years old) have a tendency to put foreign objects in their mouths. If an object is too small, it can become a choking hazard for children. Often, parents are able to give their child a high amount of their attention during playtime in order to minimize this choking risk, but in most travel situations, a parent can only designate a small amount of attention before they become too distracted and endanger themselves. Thus our team will comply with the ASTM F963-17 [11] and SPTF [9] size and labeling standards and test.

(5) No Screens. As we discussed in our background research, screen entertainment results in a plethora of developmental and health problems, such as a slowing of cognitive development and impediment of social skills. These health risks therefore should be avoided, which is why we have created a specification that the toy should not have any screens.

(6) Child will not be able to permanently deform a toy while playing with it. Beyond the lifetime of the toy in comparison to a toddler, we also wanted to make sure that the toy didn’t run the risk of being broken by the child during its expected lifespan. Given that our age range is a year, and we anticipate that the toy would be used more than once on days it’s used, we’ve defined that the toy should be able to survive 360, 20 minute uses. We specifically said 360 uses as opposed to 720 uses or more because we found it was more likely the toy would be used every other day than every day, but on the days it’s used, it would be used for multiple trips. We also wanted a toy to be used for 20 minutes because our hope was that the toy could entertain a child longer than the expected upper limit for their attention span, otherwise the toy wouldn't be fulfilling its goal. In addition to the lifespan of the toy, we also provided abuse tests in order to determine if the toy would deform under regular use, which were standards given in ASTM F963-17 for abuse testing of toys [11].

(7) Toy cannot be easily displaced by a child. A major problem for most toys already on the market is that they have too many pieces to be effectively transported or used in public. If a parent has to pack up a bag of 8 toy cars or unroll a mat for the cars to be used, they likely won't pick that toy to entertain their child in the car. Likewise, a toy with many individual pieces runs the risk of having pieces lost or forgotten by the child by them throwing or dropping them, and then being left behind by the unknowing parent. Depending on the pieces lost or the toy in general, this can ruin the usability of the toy. These concerns have led our group to specify that our toy should have no more than 5 distinct pieces to it, with a hope that pieces can be attached to the main body of the toy so that the risk of losing these parts is reduced. Additionally, we have specified that our toy should have a mechanism that attaches it to the front seat or grab handle in the car so that it can be retrieved by the child if dropped. In order to ensure that the child can use the toy to its full potential even in the event that the kid throws or accidentally loses control of the toy. The inclusion of a mechanism that attaches the toy to either the grab handle or the backseat of the car would allow the child to pick the toy back up by the mechanism if it were to be accidentally or intentionally dropped.

(8) Keeps a child occupied for the duration of travel. While there is no standard length of time for the duration of travel, car rides can vary from a 15 minute trip to the store to an hour or more road trip. We were forced to discuss with our sponsor what we believed to be an adequate time frame. We ultimately decided to define the travel time a toy must entertain a child to be at least 20 minutes. Our reasoning for this time is to play into the idea that the toy will mostly be used during quick car rides as opposed to longer trips, and this allows us to cover most short ranged trips. We also didn't set the time lower, because, as the time to entertain the child is reduced, it gets easier to find a way to entertain a child without a toy, given that the upper attention span of a 3 year old is 15 minutes. While 20 minutes is still short relative to a road trip, we felt it was an attainable amount of time that would require our solution. As a difference from our prior Design Review, this requirement moved up to mid priority as a recommendation from our sponsor.

(9) Competitive pricing in relation to similar toys on the market. Based on the benchmarking research we have already conducted, children play with a wide range of toys from 18 months to 5 years, and especially at our narrower age range of 2 to 3 years, our toy should not be a major financial investment on the part of the parent. While much of the cost and pricing would come down to how we could produce the toy, we want to try to keep the cost of the toy down so that the toy is on par with other toys produced made of the same material for the same age range. If our toy cost $100 but only had an expected usage time of a year, that wouldn't be appealing for the parents. Given the prices and age ranges for toys already on the market, we would like our toy to cost no more than $35. Once we finalize the selection of materials for our toy, we will refer back to the benchmarking research we conducted in order to ensure similarity in pricing of our toy to that of toys already on the market.

(10) Non-distracting to surrounding people. The highest level of noise a person can experience before they begin to have hearing damage over long exposure periods is 70 dB, which is comparable to a car on a freeway or music that fills a room [21]. Since there isn't a definitive answer as to what volume level would be considered distracting, we have decided that any toy we design, if it makes noise, should be no louder than 50 dB, which is about as loud as a conversation in a private living space. At this volume, a toy should not run the risk of hearing damage to anyone nearby, and should not be a major annoyance in a louder public space. Our group also decided that, in the event the toy is being used somewhere quieter or it does become a disturbance to nearby people, the toy should also have a mute function that the parent can use to turn off any sound making capabilities.

CONCEPT GENERATION METHODS

Our concept generation process (shown in Figure 5 below) did not follow a very linear process. Generally, we started with our first round of individual concept generation, then met as a group to perform various mind mapping. After mind mapping, we went back for a second round of individual concept generation. From there, we moved into multiple team concept generation methods, following the order of two different rounds of screening and then a final round of mind mapping. After that, we did one final round of individual concept generation, which led into our concept selection process.

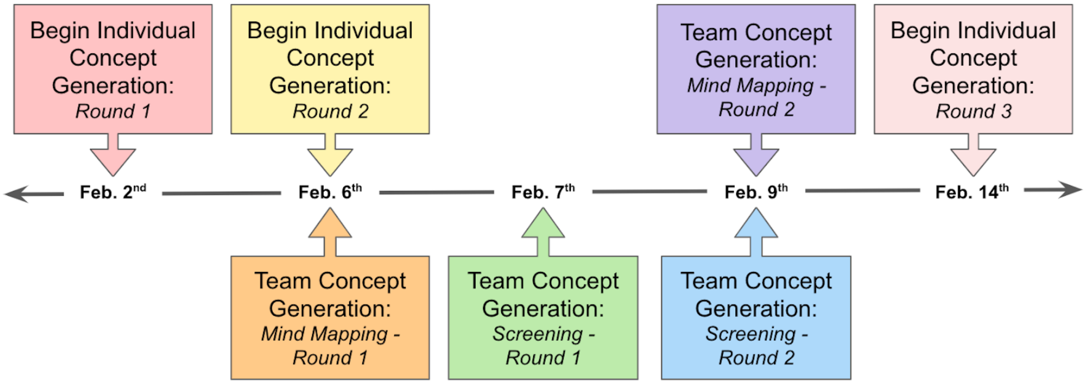


Figure 5. Start to finish timeline of concept generation process. Includes three rounds of individual concept generation, two rounds of mind mapping and two rounds of screening (not in that order).

Individual Concept Generation - Round 1

Before meeting as a team, we all took time on our own to come up with twenty possible concepts for a travel compatible toddler toy, giving us a total of eighty concepts to start with. To see some of the ideas that each member came up with, see Appendix B, Figures B1-B4. These concepts ranged from very simple toy ideas, such as a ball on a string, to far more complex/detailed ideas, such as a mirror that can project makeup onto the toddlers face as they look into it. The ideas drastically varied in size, themes, complexity, etc.; however, there were also some consistencies between different team members' concepts, with many team members coming up with doll toys and fidget board ideas.

Team Concept Generation: Mind Mapping - Round 1

Our first time meeting as a team was after we all brainstormed twenty individual concepts. After sharing our twenty concepts with each other, we noticed that there were certain requirements and topics that needed to be expanded in the toy ideation space. This led to the creation of four different mind maps: Things to Attach to, Portable / Attachment Style, Interests of a 2-3 year old, and Materials (see Appendix A, Figures A1 - A4).

Mind Map 1: Things to Attach to. The “Things to Attach to” mind map’s goal was to come up with attachment locations so that the toy cannot be easily displaced by the toddler, which is one of our requirements. Since the toddler will ideally be using the toy during car travel, the locations we came up with are all possibilities of places where a toy could be tethered to inside a car. This includes attachments placed inside the car itself, on the car seat that the child sits in and on the child. See Appendix A, Figure A1 for the actual mind map.

Mind Map 2: Portable / Attachment Style. The "Portable / Attachment Style" mind map, depicted in Appendix A, Figure A2, included methods that would allow the toy to be attached to the locations listed in the "Things to Attach to" mind map. We also discussed ways in which the toy could be made easily portable, which is another one of our requirements. Some attachment styles listed included hooks, straps, glue and making the toy foldable.

Mind Map 3: Interests of a 2-3 year old. The "Interests of a 2-3 year old" mind map, depicted in Appendix A, Figure A3*,* was one of the more helpful mind maps, because it helped us realize the extent of a two to three year olds knowledge. We learned that around the ages of two to three, most toddlers can recognize letters and have started learning their numbers (0-10) [22][23]. They also enjoy playing pretend, cooking, and drawing [24]. This research, along with our collective knowledge, from our past and from knowing kids around us, led us to a strong mind map of various interests of two to three year olds. This mind map helps ensure that we are coming up with toy themes that are within the interests of our target users.

Mind Map 4: Materials. The "Materials" mind map, depicted in Appendix A, Figure A4*,* helped us expand our ideas on what a toy could be made out of. When we listed different materials, we took to heart the "no idea is a bad idea" approach. As we created our mind map, the materials fell into two main categories: rigid and malleable. We listed more common materials used for toys, such as plastic, wood, fabrics and clay, and also listed more obscure materials, such as concrete, brick and pipe cleaners.

Individual Concept Generation - Round 2

After creating the four mind maps, discussed previously, we had another round of individual concept generation. Similar to the first round, each team member came up with twenty new concept ideas, bringing us to a total of 160 concepts between the first and second round of individual generation. During the second round, the mind maps were used as a way to generate new ideas, by picking one to two items from each mind map and bringing them together to form a new toy idea, similar to the process of using a morphological chart. We also used design heuristic cards, in tandem with our initial round of individual brainstorming, to help in the generation of new ideas.

Team Concept Generation: Screening - Round 1

As a team, we now had a collective 160 toy ideas. We needed to narrow this down to a more manageable number of ideas, as 160 ideas was a bit overwhelming. Thus, we performed our first round of screening. During this round of screening, we passed around each person's set of forty ideas and each person made note of which ideas they liked "best" from each person, which came out to around six to eight ideas from each person. "Best" in this case meant the ideas we found most fun, interesting and practical. Once everyone listed their favorite ideas from all four peoples' designs, which included themselves, we looked at which ideas people consistently liked. More specifically, we looked at one team member's ideas, and if three out of the four people (or two people that were not the people who created the idea) liked the same idea, we kept that idea. This led to around four to five ideas left from each member. Thus, through this screening, we narrowed our ideas down from 160 ideas to around 20 ideas. However, we later realized that this screening process was not the most effective way to find ideas that fit our requirements best.

Team Concept Generation: Screening - Round 2

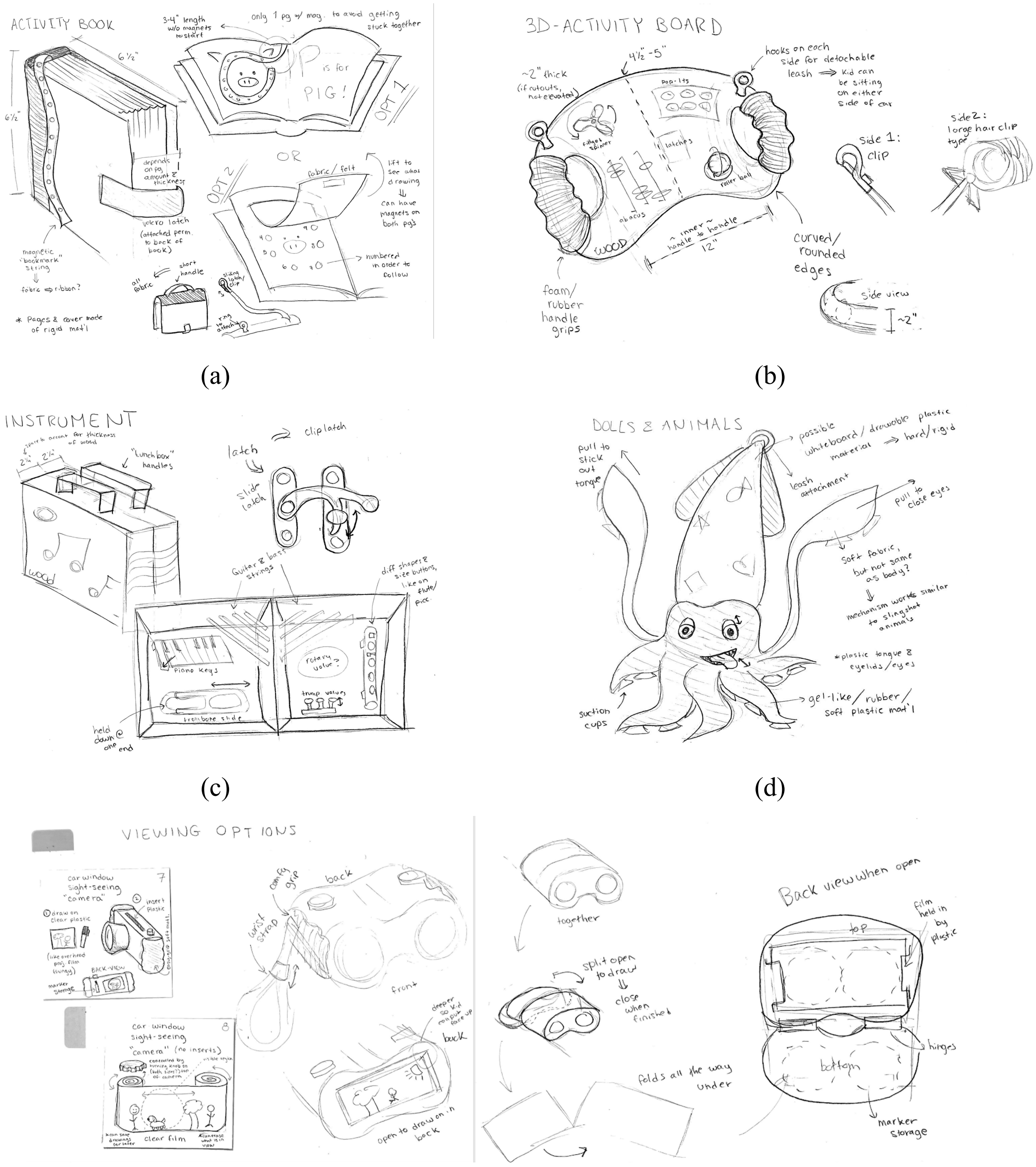
As previously mentioned, our first round of screening ideas was not the most effective way to find ideas that fit our requirements best; hence, we decided to look back at our original 160 ideas and perform a second round of screening. The second round of screening was much more structured. We used four different filters to narrow down our ideas. The first two were feasibility related. First, we asked: "Do we have the knowledge / technology and time to create this toy?”, if the toy was too complex or used technology that we do not have access to, that toy was canceled out. The second feasibility filter was “Is the toy age appropriate for a two to three year old?” Age appropriate toys were toys that had themes or activities that fit the cognitive and physical abilities of a two year old, such as numbers, letters and drawing. Another way to look at the age appropriateness filter was to ask “would a two to three year old play with the toy in the way it was intended?” or “would a two to three year old understand the purpose of the toy?”, if the answer was no to any of the previous questions on age appropriateness, we canceled out the toy. The other two filters we used, duration of entertainment and number of pieces, were related to our project requirements. Starting with the entertainment filter, we have a requirement that the toy entertains the child for at least 20 minutes. When looking through the list of toy ideas we had left, if the toy obviously could not entertain a kid for anywhere near 20 minutes, we canceled out the toy. Some toys that were eliminated, due to lack of entertainment, included a squirrel on a spring, blocks on a string and an inflatable tube guy. Lastly, we filtered our ideas based on the number of pieces. One of our requirements is that the toy cannot be easily displaced by a child and has an associated specification that the toy has less than or equal to five pieces. Thus, if any of the toys would have more than five pieces, the toy was eliminated. Our eliminations did have a caveat; if the toy could be changed in some way to satisfy the filter, such as if a toy with more than five pieces could be made with fewer pieces, then we would make a note of the change that would need to occur and we would keep the toy in the running. Overall, the second round of screening narrowed our concepts from 160 to 28.

Team Concept Generation: Mind Mapping - Round 2

With our new set of 28 concepts from screening round 2, we noticed there were some similarities between them in terms of their themes / general concepts. Thus, we categorized the 28 concepts and found that they all fell into one of five categories: 2D activities, 3D activities, instruments, dolls and animals, or viewing devices. To clarify, the difference between 2D and 3D activities is that 2D activities are flat activities, such as connecting the dots and drawing, or any activity that would be able to take place on a flat surface; whereas 3D activities are activities in 3D space, such as rattles, fidget spinners and balls. After creating the five categories, we took each category and mind mapped it to try and come up with more ideas in those spaces. See Appendix A, Figures A5-A9 for all the mind maps. In these mind maps, we outlined various aspects that could be included in a toy in each of these categories. For example, with the 2D activities category, a 2D activity could be structured as a book, a board or a mat with various flat activities on it. It could also have themes to the activities, such as shapes, animals, vehicles, etc. Overall, these mind maps helped us come up with more divergent ideas in each category.

Individual Concept Generation - Round 3

In an attempt to lower the number of toy concept designs to a manageable amount for comparison and selection, our team voted on the “best” characteristics of each of the five *MURAL* mind maps created during mind mapping round 2: 2D activities, 3D activities, instruments, dolls and animals, and viewing devices. We defined the “best” characteristics as being the traits of a toy that would help us accomplish all of our requirements and specifications. Once the team voted, the options with the majority vote were used to create a general toy description for each of the five categories. Then, each member of the team sketched a detailed concept for each category that fit that broad description. Therefore, at the next team meeting we had 20 total designs, four for each toy category. Comparing our four individual sketches for a specific category, we discussed and combined the traits that we felt would provide the best results, and created a final sketch for that category. The final five sketches can be seen in Figure 6 below on page 17. Our team aimed to include as much detail in each sketch as possible, so that we could best compare the ideas against each other during our concept selection process.



(a) (b)

(c) (d)

(e)

Figure 6. The images above show the sketches of the final five concept designs created to fit the general descriptions voted upon after mind mapping round 2. (a) The final 2D design shown is a magnetic, connect-the-dots activity book. (b) The final 3D design shown is a wooden activity board, equipped with many different types of fidget activities that would be held on a child's lap. (c) The instrument design resembled a lunchbox, but upon opening, a child would find various instrument elements. These included strings, keys and valves would create minimal or no noise. (d) For the dolls and animals category, a squid design was decided upon. A child would be able to open and close its eyes, stick out its tongue and draw on its head. (e) Finally, the viewing option category consisted of two options: a camera or binoculars. The design would allow for the child to draw their own picture on clear film, enclose it in the device, and look through the lens to see their creation.

CONCEPT SELECTION PROCESS

Through the concept generation methods described previously, our team was able to narrow our numerous toy design concepts down to five unique ideas. The method that we believed would be most effective in selecting our final design was to compare and rank the final five ideas in a pugh chart. Pugh charts are susceptible to bias as a consequence of a team assigning weights to categories themselves and subjective rankings of the actual designs. In order to reduce this unconscious bias that a pugh chart may lead to, we created two different ranking systems consisting of the same categories, but with different weight scales. The design with the highest score after using the chart would be selected as our alpha design. See Table 3 on page 20 for the full pugh chart.

Pugh Chart Categories

Before we could begin ranking our five final ideas (seen in Figure 6 on page 17), our team came up with a list of categories that we agreed were important to include in our future alpha design and were necessary to accomplish all our requirements in Table 2 on page 11. Ten categories were agreed upon by all team members: not complex, entertaining, uniqueness/originality, portable (size requirement), long term durability, easily fixed, non-distracting, portable (ease of transportation), displacability, and no small parts/no choking hazard. Each of these categories was given a weight to reflect its importance, with higher numbers representing a higher priority.

Not Complex. Complexity to build or manufacture the actual toy is a trait that our team felt should be considered as we were narrowing design ideas. It is not directly related to any of our requirements or specifications, but can greatly affect our team's success. We have a goal of having a working prototype by the end of the semester, therefore we did not want to choose a toy design that would require equipment that was not available, too expensive, or would take too long to create the toy. On both ranking scales the category received a weight of 2, as a difficult design would not entirely dissuade us from choosing a design that meets all other requirements.

Entertaining. Our team felt that the entertainment factor of a toy is one of the most important aspects of our design. If a toy is not entertaining enough for the child, the toy has no purpose. This category also relates directly to our requirement that our toy must keep a child occupied for the duration of travel, which we defined as at least 20 minutes. Therefore, the category on both ranking scales received the highest weight on the scale, a 3 or 5. We decided that for a toy design to receive a positive entertainment ranking it must have one repeatable activity that would take a toddler a longer amount of time to do, or it must have many smaller activities that the toddler could change between and revisit.

Unique/Originality. Our team has proven, through our previously described benchmarking, that despite the market for children's toys currently being very large, there are not many options available for children to play with in a travel setting. Therefore, we want our toy design to stand out and to be distinguishable from what is already sold on the market. We either want our product to be completely original, or use an already established idea in a new way, catered to toddlers. Originality is not a trait that is directly tied to either our requirements or specifications. Consequently, this trait was ranked a 3 on the 1 to 5 scale and a 2 on the 1 to 3 scale.

Portable (Size). Portability is one of the main functions that this toy must possess in order to be a successful solution to the problem presented in our problem statement. If the toy is too large or heavy to be held by a toddler or fit in the backseat of a car, then our team has not accomplished our goal. As portability, or adequate size for a toddler to play in a car, is on our high priority list of requirements, the highest weight was given on each scale.

Portable (Transportation). Two of our high priority requirements are related to portability. Our team wants to ensure that the toy we choose is easy for caretaker to pack and transport to various locations, therefore we have given this category the highest weight on each ranking scale, a 3 or 5, similar to the portability requirement that defines size constraints.

Durability (Long Term). One requirement that our team has defined for ourselves is that the child will not be able to permanently deform the toy while playing with it. Specifically, we want the toy to last at least 360, 20 minute play intervals. As a result, the toy design concepts will be ranked higher if we believe them to be less likely to break or be damaged. Although, the requirement itself is found lower on our list of priority. Due to its lower priority and knowing that the long term durability will be difficult to test in our short timeline, the trait was only ranked a 1 on both weight scales.

Easily Fixed. In close relation to durability, it was important for our team to consider how easy our toy concept would be to fix, should any part of it break. Our intention is for the toy we create to be able to be used for a long time, and the lifetime of the toy only increases if a parent is able to quickly fix the toy themselves. If the design concept would not require special materials and gives easy access to components that may break, it received a higher ranking. Similar to durability, we know that this long term wear and tear solution will not be easy to test given the time constraint of our project, so the category was given a weight of 1 on both scales.

Non-Distracting. Giving a child a loud, large, or overall distracting toy in a travel setting, such as a car, can prove to be very dangerous for those in the surrounding environment, especially the parent or caretaker behind the wheel. Our team feels that it is important that our design concept should be able to entertain the toddler while producing minimal noise (no louder than 50 dB) and be able to be safely played with by the child while not under constant, direct supervision. This goal does line up with one of our medium priority requirements and specifications, therefore the category was given a weight of 3 (on the 1 to 5 scale) and 2 (on the 1 to 3 scale).

Displacability. Toddlers, from ages 2 to 3 years old, do not always have the best grip strength, and tend to let their toys, intentionally or unintentionally, fall. At this age, the children must be seated in a car seat for the duration of the ride, and their arms are not long enough to bend over and pick up an object off of the car floor, or even the seat next to them. Distraction to the driver, adults, or others in a car travel setting are not only caused by noise or sightline blocking, they can also be caused from one attempting to retrieve a toy from someplace in the car in which the child dropped the toy. To make sure that our toy will not create a safety hazard to anyone in the vehicle, our team has placed a large emphasis on the toy having some type of mechanism that will allow the toy to be easily retrieved if dropped. A higher score for displacability indicates that the concept design has a method through which the toy is attachable and can conveniently be used by the child themselves to retrieve the toy if dropped. Due to the fact this category is strongly tied to safety concerns and a medium priority level requirement, it was given a weight of 4 out of 5, and 3 out of 3.

No Small Parts/No Choking Hazard. Safety of the toy is one of our team's biggest concerns for our design and is categorized by us as a high priority requirement. Normally, if a child was playing with a toy that included many small parts, a caretaker could give them their attention and prevent any accidents before they occur. However, a parent or caretaker in a car setting will most likely not be able to give a toddler their full attention while they play with a toy. We did not want our design to include any small or potential choking hazard parts that a toddler could swallow while unattended. Toy design concepts that are made up of few, large pieces were given higher rankings. Overall, the category was given the highest possible weights on each ranking scale, a 5 and 3.

Pugh Chart

In Table 3 below, the weights were given to all ten categories on scales that ranged both from 1 to 5 and 1 to 3. There are various popular methods that are commonly used in pugh charts to rank the ideas against each other. For this reason, we decided that we were going to assign each idea a score of -1, 0, or 1 depending on if the toy design concept failed to meet, met, or exceeded the category description, respectively. Once all of the ideas are ranked, their score for a specific category is multiplied by the corresponding weight, and then added to the total score. As a result of having two weight scales, each design concept produced two total scores.

Table 3. After ranking our teams top five design ideas from individual concept generation round 3 on a scale of -1 to 1 in a variety of categories, their scores were multiplied by their respective weights and totaled to find the design with the highest overall score. The toy concept that resulted in the highest score from both the 1 to 5 scale, with a score of 8, and the 1 to 3 scale, with a score of 4, was the interactive squid from the dolls and animals group.

Categories	Weight Scales		2D Activity	3D Activity	Instrument	Dolls and Animals	Viewing Activity
Not Complex	2	2	0	1	0	-1	-1
Entertaining	5	3	0	0	0	1	-1
Unique / Originality	3	2	0	-1	1	1	0
Portable (Size)	5	3	0	0	0	0	0
Portable (Transportation)	5	3	0	0	0	0	0
Durability (Long Term)	1	1	0	1	1	0	-1
Easily Fixed	1	1	0	0	-1	-1	1
Non-Distracting	3	2	1	0	0	1	1
Displacability	4	3	0	0	0	0	-1
No Small Parts / No Choking Hazard	5	3	0	0	0	0	1
	Total Score (1-5 Scale)		3	0	3	**8**	-3
	Total Score (1-3 Scale)		2	1	2	**4**	-2

All of the 5 designs listed above in Table 3 had categories that they performed better in than others. The 2D activity book design concept was generally ranked neutral, although we did believe it exceeded the expectations in the non-distracting category, as the toy required no sound element and no adult supervision or explanation. While the 3D activity board appeared easily manufactured and very durable, it lacked originality compared to the other toy designs. The instrument box concept design was unlike anything we could find on the market and due to the fact we intended to use real instrument parts we believed that it would meet our durability requirement. However, in the case that it did break, it would be quite difficult and expensive for a caretaker to fix or find replacement parts for. The interactive squid concept lacked manufacturing and repair simplicity compared to the other four options, but made up for its faults in its creativity, entertainment value, and ability to not distract the people in the surrounding area. Overall, the viewing activity had lower scores than we expected prior to ranking it. We found that it was too complex to implement, easily broken or lost, and was possibly required too much explanation for a toddler of ages 2 to 3 to use alone, therefore making it less entertaining for them. Prior to the rankings, our team expected to find the 3D activity as a frontrunner, but the results from ranking all five final design concepts in the pugh chart show that the interactive squid toy, from the dolls and animals group, won by multiple points on both ranking scales. It should be noted as well that the order of the resulting group totals was consistent between both ranking scales.

Alpha Design

Our alpha design - the design that we used as we entered the prototyping stage of our design process - was determined through our pugh chart results (Table 3 above on page 20) to be the interactive squid, shown below in Figure 7. The design concept includes features such as eight small tentacles with suction cups, a head that can be drawn on with an erasable marker, a ring on the top of the head to allow a leash-style attachment, and two long tentacles which can be pulled to control the squid's eyes and tongue. Our team intends to build the squid from a minimum of two different materials: a hard material that the child will be able to draw and erase on, and a soft material that will allow the limbs to be flexible. Although the toy is not as simply constructed as the other four contenders, and will likely not be easily fixed by the parent or caretaker if broken, we believe that multiple interactive, non-distracting elements will be able to uniquely entertain a child for our targeted length of time.

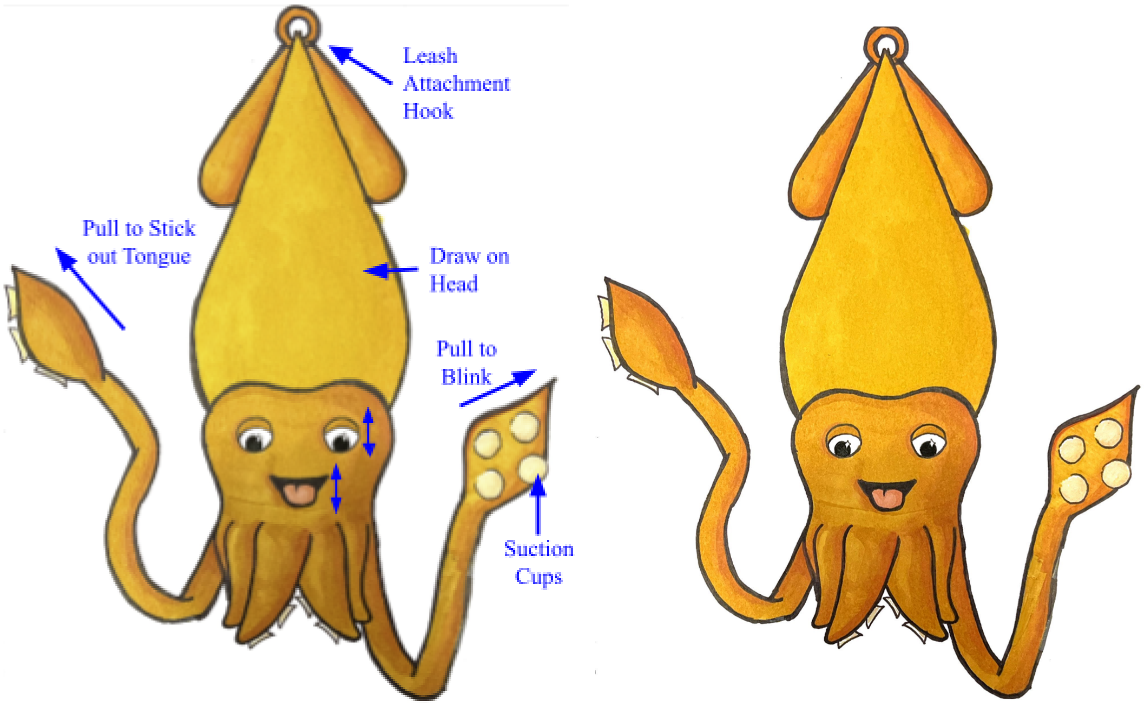


Figure 7. The interactive squid design shown in the alpha design drawing above illustrates four main interactive elements: a head that can be drawn on, eight movable tentacles with attached suction cups, one long tentacle that if pulled can make the squid blink, and one long tentacle that if pulled can make the squid stick out its tongue. The large head area is intended to be made of a rigid material, while the tentacles are to be made out of a soft material, so that they can be flexible. The design also features a ring at the top of the head, which will allow the squid to be attached to a component in the car through a type of hook or clamp and leash, so that the child can easily retrieve the toy if dropped.

Materials. As explained previously, our team is expecting to incorporate at least two different materials in this toy composition. The elongated head area will be made of a hard, rigid material that can be used in a similar fashion to a whiteboard or chalkboard. We have plans to experiment with whiteboard material, as well as various types of plastic, in our prototyping phase to determine which material allows the best visibility of the drawings and cleans with the most ease. Currently, our plan for the squid details, such as the tentacles (long and short) and the head fins, is to manufacture them from a soft, flexible material. One trait that our team has decided to focus on in regards to the materials we choose for the non-rigid components of the squid is how easily cleaned they are. A toddler with a marker can not be counted on to only color in the designated area, and to accommodate for these future messy incidents, the material that the many tentacles are composed of should be washable in some way. To begin prototyping, we will use a fabric to create these features and will test for how easily the material can be cleaned. We also aim to experiment with using a material closer in similarities to a rubber to create the eight smaller tentacles, although we anticipate cleaning difficulties. However, through this textual diversity, we hope to engage different sensory experiences for the child while playing with the toy, thus making it more entertaining.

Engineering Drawing and Analysis. Looking at Figure 8 on page 23, we have provided an engineering drawing to begin establishing dimensions of a prototype for the future. Most importantly, we wanted the height of the squid from the top of the head to the bottom of the short tentacles (also known as the body) to be under 10”. With a diameter at the widest point of 3” and a hooking mechanism on the top of the squid, we expect that a toy with these dimensions to not be difficult for a child to travel with or hold, or to be a distraction to the driver, as this is slightly larger than a water bottle in size. Once the prototyping of the body is underway, we plan to then get feedback from parents of toddlers and make adjustments to the size as necessary. Also pictured in Figure 9 on page 24 is a mockup CAD of the inner mechanism of the squid’s head that controls the blinking eyes and tongue of the squid. While this is an alpha design, and is subject to change as prototyping and testing goes on, the general idea for the controls of the facial mechanisms is to use a lever system in which an elastic string that runs from the top of the inside of the head to the bottom of the longer tentacle acts as the driving force. When one of the legs is pulled downwards, the string will pull the lever downward around a pivot bar that runs through the head of the squid. The opposite side of the lever will then move upwards, which will flick a rod attached to the eyelid or tongue, depending on which tentacle was pulled, making the squid blink or stick its tongue out respectively. When the leg is released, the string relaxes and returns the lever to its original position and opens the eye or pulls the tongue back in. Since this is an untested mockup, we anticipate that changes will have to be made in the future in order to make the mechanism work within our size constraints.

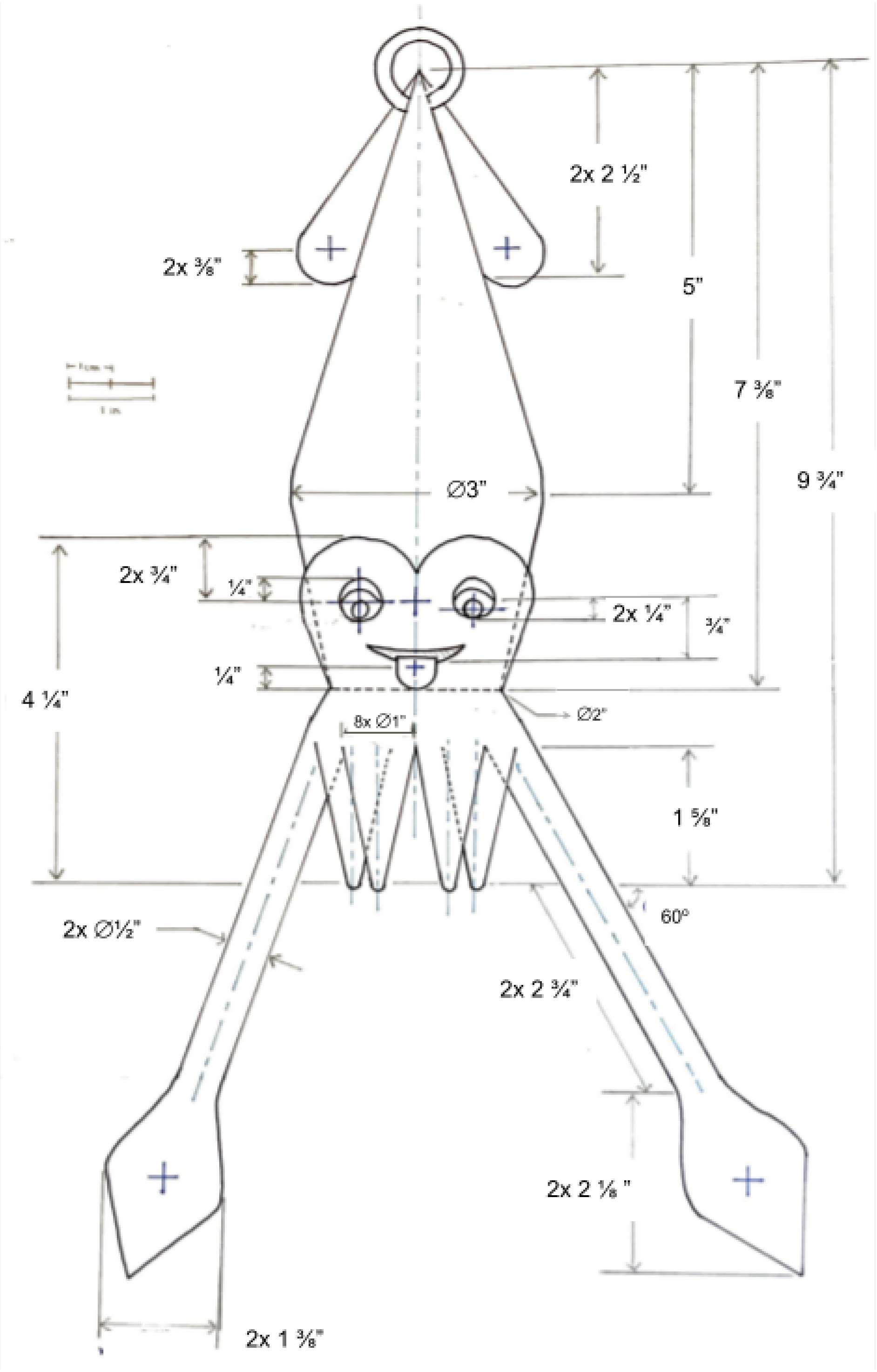


Figure 8. The engineering drawing shows how the height of the squid toy, from the top of its head to the bottom of the shorter tentacles, is less than 10 inches long, and the widest diameter of the head, just above the eyes, is only 3 inches wide, putting it at just over the size of a common plastic water bottle. With this size, it should be usable by a toddler in a car while not producing any significant vision impedance for the driver.

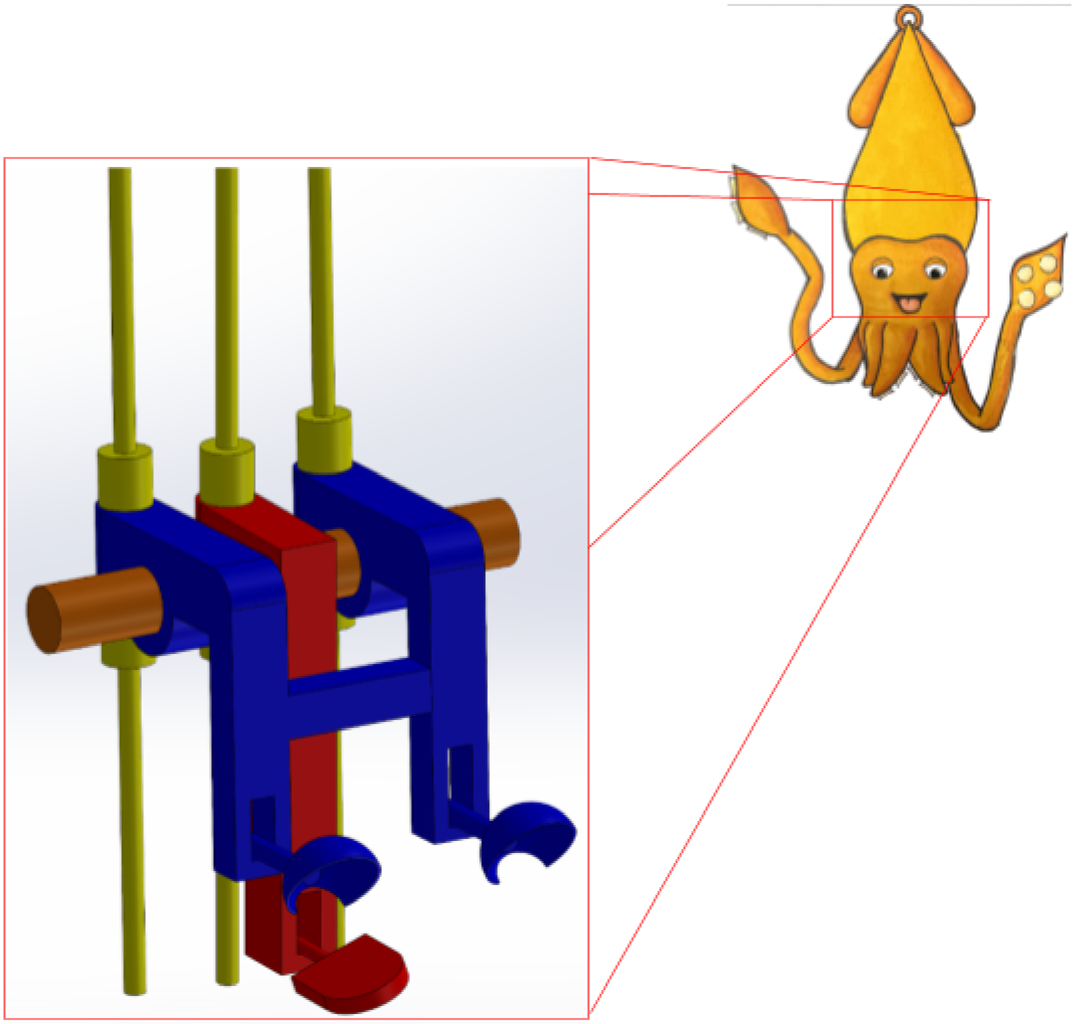


Figure 9. The CAD mockup of the inner mechanism shows the lever mechanism that is to be used to open and close the eyes or stick the tongue out. An elastic string (yellow) runs from the top of the inside of the head to the bottom of the long tentacles and acts as the driving force in the device. When the tentacle is pulled, the string extends and pulls the levers downwards around the pivot bar (orange). If the tentacle for the eyes is pulled, the eyelid lever (blue) is rotated and causes the side opposite the strings to move up. This will cause the lever to flick the rods attached to the eyelids upward, causing the eyelids to rotate downward in the shell of the head, simulating the eyes closing. Similarly, when the tentacle that drives the tongue is pulled, it causes the tongue lever (red) to rotate We upwards and flick the tongue's rod, which moves the tongue forward and down and makes the squid stick its tongue out. When the tentacle is released, the strings relax and the levers return to normal.

PROBLEM ANALYSIS AND ITERATION

Ability to Meet Requirements and Specifications

Overall, our alpha squid design was chosen, because we believe it would meet a majority, if not all, of our requirements. The requirements we feel are currently satisfied by the squid design include that it is portable (both for the parent and the kid), does not have any screens and is non-distracting to those around (as the toy has no noise elements).

The requirements we plan to ensure are satisfied as we prototype, but have not been fully decided yet are:

1. Safety of materials and that there are no choking parts, as that will come with figuring out what works best for our toy for materials and if there are any small pieces that could be choked on that we did not expect.
2. “Cannot be easily displaced by the child”. The toy already satisfies that it has less than five pieces and we already have in place the ring at the top of the squids head for easy attachment of a device (such as a leash) that will help prevent the kid from displacing the squid, but we have not fully planned out what kind of attachment device we will be using yet, which will come with our prototyping and testing.
3. “Keeps a child occupied for the duration of travel”. This is a hard one to test, so we are not certain if our squid can entertain a kid for at least 20 minutes, but we plan to perform some testing or surveying to get a better understanding of its ability to entertain a kid.
4. “Child will not be able to permanently deform the toy while playing with it”. We hope our squid will satisfy this requirement, but we have some worries about how much force the inner mechanism can handle without breaking when the arms of the squid are pulled. We truly do not know how our squid will hold up based on this requirement until we do the further testing.

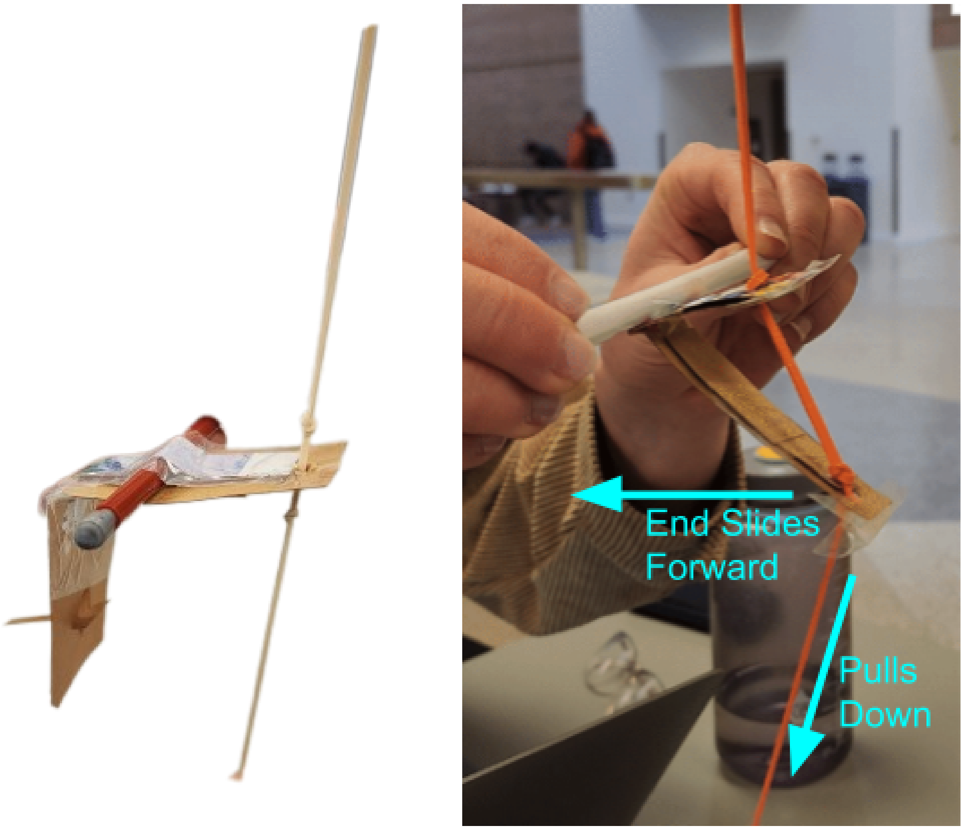
On the flip side, a requirement that will be difficult to satisfy or difficult to test is our requirement that our toy has “competitive pricing in relation to similar toys on the market”. We believe, with mass production, our squid would be competitively priced, but since we are creating a prototype from scratch, it will be hard to approximate what its production and market price would be as compared to the price that we have to pay to create the prototype of the squid. This is also out of scope for our semester project.

PROTOTYPING

Build and Final Design

Within the scope of our project, our build design and final design are one in the same. Our sponsor, Sarah Kreitman, communicated to us at the beginning of the semester that her expectation for our Final Design was that it should be a toy at the same level of quality that you would expect to see on the shelves at stores; she essentially wanted us to create an “off-the-shelf” fidelity toy. To create a design of that quality, we have to complete multiple iterations of prototyping and testing.

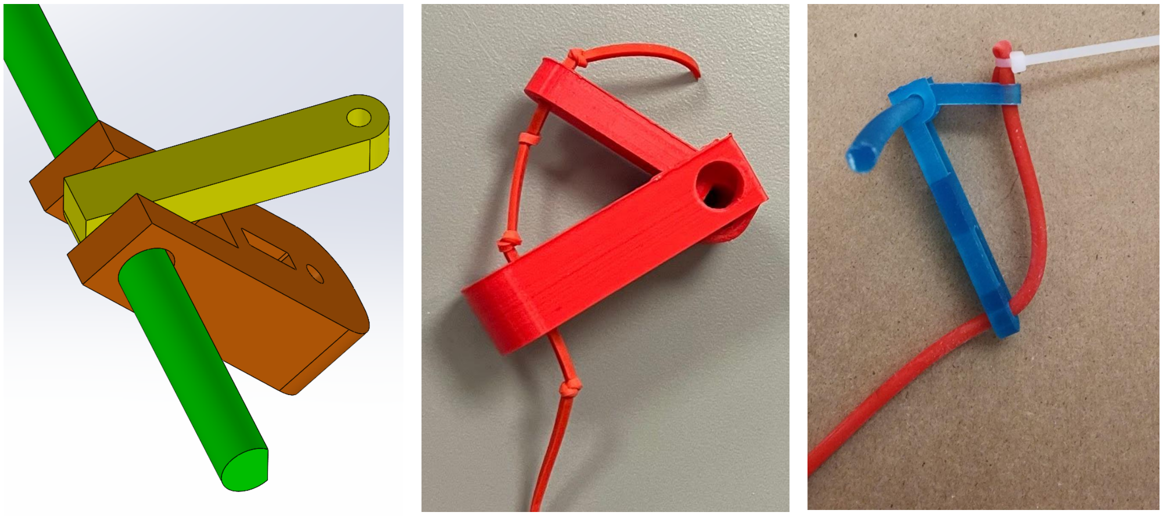
Inner Mechanism. In order to prototype the inner mechanism of the head, we began with some low fidelity prototyping to test the levers for the eyes and tongue. Using cardboard, tape, and pencils, we created a prototype of the initial mechanism idea, shown in Figure 10(a) on page 26, and found it would work for the eyelid mechanism, which required an up and down motion, but not work for the tongue, which would require a forward and backward motion. Looking to find an alternative for the tongue lever mechanism, we began testing ideas in the same way, finding a successful prototype in Figure 10(b) on page 26.



(a) (b)

Figure 10. (a) The original design for the tongue and eyelid mechanism. While the rubber band would move the lever up and down, it had a hard time producing the larger forward and backward motion needed to stick the tongue out. (b) The lever mechanism for the tongue after prototype iterations. After deciding to prototype new lever ideas, we ultimately determined that a more vertical lever with a rigid guide lever would provide a better range of motion for the tongue's movements.

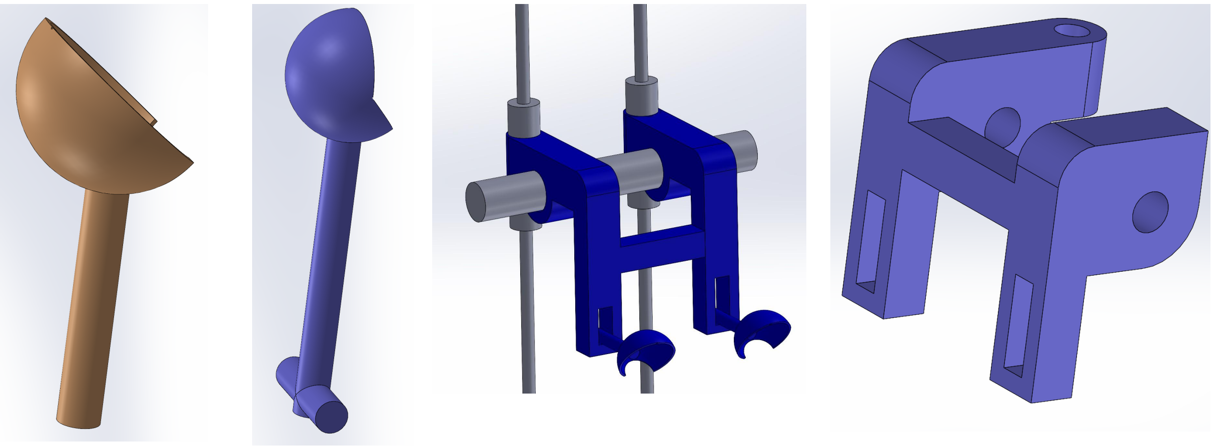
Our cardboard prototyping shown above in Figure 10 did not reflect the intended size for our final prototype. The main goal of the models were to determine if the range of motion we needed was possible. After our lo-fi prototyping of the mechanism, we updated our CAD to create a new model of the lever mechanism for the tongue, an example being shown in Figure 11(a) below on page 27. From there, we submitted our parts for 3D printing to begin doing some high fidelity prototyping. During our first iteration of 3D printing prototyping, we found that many of our tolerances were too tight for the capabilities of the 3D printing, and would have to be increased to prevent interferences. We specifically changed the tolerances of the holes in the levers so that the pieces could easily slide onto the rod and the elastic string would be able to fit through its designated hole. These tolerances were increased to 0.030 inch difference between parts. In the second iteration of 3D printing prototyping, we were able to narrow in the tolerances further (to 0.020 inch) and test if our mechanism would fit together how we want, an example of which is shown with the tongue mechanism in Figure 11(b) below on page 27. One last iteration of 3D printing was needed to lengthen the vertical tongue lever to 2.75 inches and the tongue piece to 2.5 inches. Also, to help improve the pieces fitting together, the final round of 3D printing was SLA instead of the standard FDM. These changes can be seen in Figure 11(c) below on page 27.



(a) (b) (c)

Figure 11. (a) After lo-fi testing the lever mechanisms inside the head, we updated our model to have one rigid guide lever (yellow) and one more vertical lever (orange). In order to keep the two levers rigid or moveable on the same pivot rod, we changed the rod to have a flat part so that the rigid lever would have an inside face that marched the flat (such as with a key), which the pivot arm could rotate freely. The approximate dimensions of the levers are 1.6 inches (orange) and 1.37 inches (yellow). The rod length is 3 inches and the diameter is approximately 0.25 inches. (b) Once we had updated our CAD, we sent in our parts to be 3D printed and began assembly. Our tongue mechanism appeared to then fit together how we had intended, allowing us to begin moving forward with refinement. (c) After iterating our designs, we eventually had our parts 3D printed with an SLA printer instead of an FDM printer to improve the quality of the print, changing the dimensions of the pivoting lever from 1.6 inches to 2.75 inches, and the length of the rod from 3 inches to 3.25 inches.

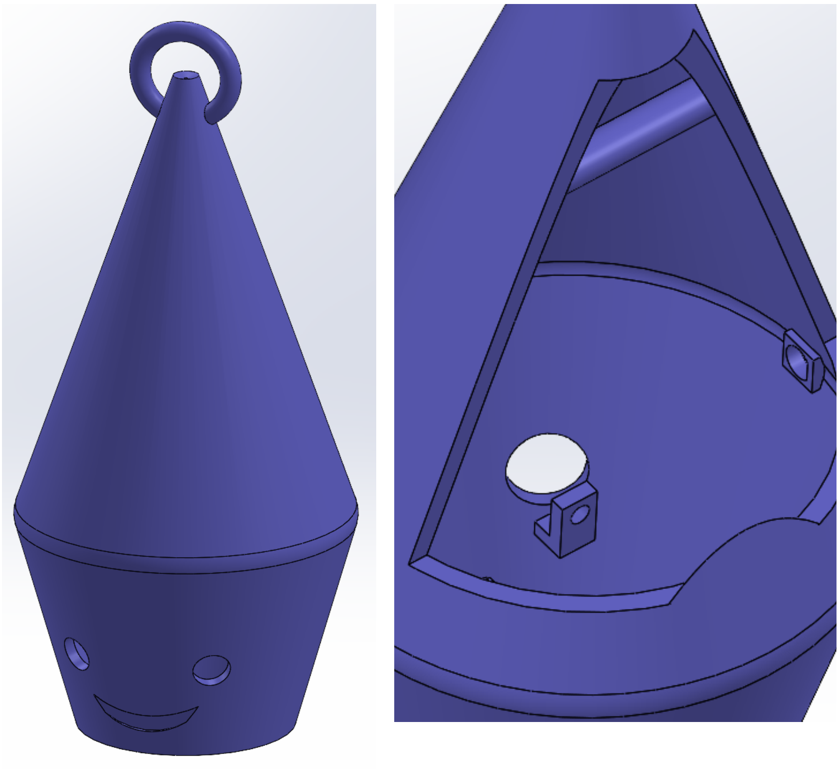
The eyelid mechanism went through several iterations as well, both in the lever piece and the eyelid pieces. Images for these iterations are also shown on Figure 12 on page 28 below. Our first eyelid design featured a rod section that acted as the lever between the eyelid (via direct attachment) and the pivoting lever. The eyelid had a radius of 0.26 inches and covered an angle of 137° (from the rod portion to the front of the eyelid), and the rod had a length of 0.68 inches. However, we found that the eyelid didn’t have enough of an angle to create a blinking action, and lacked a way to lock the eyelid piece into the lever piece’s slots, so in later designs, we would add a “T”-portion to the other end of the eyelid rod, with length of 0.44 inches, and increase the coverage angle of the eyelid to 221°. The length of the rod was also increased to 1.03 inches. Our eyelid lever originally featured two holes for the elastic band, both of diameter 0.18 inches, but in later iterations was changed to only have one after testing found that the lever could be driven with only one elastic band instead of two. While this would reduce print time and materials used, it was primarily to simplify the inside of the head by having only two strings in the head instead of three.



(a) (b) (c) (d)

Figure 12. (a) The first iteration of our eyelid pieces. The rod at the bottom was about two third of how long it would eventually be, and nearly 90° smaller in semi circle curvature (going from 137° to 221^{0}), and lacked the T shape at the end of the rod. (b) The final iteration of the eyelids, this one was 1.03 inches long, had a more complete 221° of the circle to make up the eyelid, and added a T shape at the back to prevent the eyelid from slipping out of the slots of the lever mechanism. The rods making up the cross of the T was a total length of 0.44 inches. (c) The first iteration of the lever mechanism that would flick the eyelids open and close. The original design used two individual strings (pictured in gray at the back of the part) in order to offset any unwanted moments applied to the lever and the main supporting rod. However, after testing with the first 3D printed parts, we found that this wasn't an issue. (d) The final iteration of the eyelid lever. There is now only one hole on the back of the part, to remove the need for another piece of tubing to run through the head. The leg of the mechanism meant for flicking the eyelids was also reduced in both height and depth, from 1.75 inches to 1.375 inches, and 1.45 inches to 0.75 inches (excluding the additional section for the tubing hole) respectively.

Head. After 3D printing parts for the inner mechanism, we began prototyping the head of the toy. Since we needed to make sure that the subcomponents of the inner mechanism of the head would fit inside the constraints, but also wanted to maximize the use of 3D print material, we had two different prototyping parts happening at the same time. First, we began the CAD mock up of the head, which we hoped to begin printing after some iterative changes. The approximate height of our CAD head was 8.5 inches, with the largest inner diameter measuring 3.25 inches. On the inside of the head, two brackets were located under the eye holes, which included a hole on the vertical part of the bracket for the eye to attach to. Aside from the eye brackets, there is also plastic that extends out from under the tongue, which acts as a track for the tongue to lay on when inside the head. This piece also prevents the tongue from being knocked out of place when fully inside the head, ensuring that the tongue piece will always be ready to stick out when the string is pulled. At the top of the head there is a rod (diameter of 0.25 inches) which the ends of the elastic strings are fastened to. Finally, small indents are made in the sides of the head to lock the main rod in place, on which all of the mechanisms rest. The CAD mock up we have since produced is shown in Figure 13 on page 29.



(a) (b)

Figure 13. (a) The exterior CAD mock up of our squid head. (b) An inside view of the squid head, using the removed back. By creating the squid with a park of the back missing, we can insert the eyes and tongue, and accompanying mechanisms before replacing the opening with another 3D printed cover. From the back, we can see the brackets for the eyes to attach to (only the right eye bracket is currently shown), one of the holes for the rod the mechanism will be inserted into, and the bar at the top of the interior of the head to which the tubing will be tied.

While the CAD was being created for the head to eventually be 3D printed, we also crafted a lo-fi prototype of the head to test if the mechanism would fit, and begin working through how we plan to get the mechanism into the head. Using the measurements from the engineering drawing, we created another cardboard prototype in the shape of the head, shown in Figure 14(a) on page 30. While we were able to fit the mechanism into the head, we found the eye levers didn't have a large enough range of motion to flick the eyelids, so we made note and planned to return to the CAD in the near future. We also were able to prototype how to get the mechanism into the head and found that the best way to do so would be to print the head of the squid with a piece removable from the back. Then, once the mechanism had been inserted into the head, we would adhere the piece in place using some form of adhesive or glue. The first iteration of printing the head can be seen below in Figure 14(b) on page 30. During the FDM printing process, the top ring broke off, but all other aspects printed successfully. Attempting to attach an eye to the inner wall eye bracket broke the thin piece, therefore we knew edits had to be made to the CAD before our second round of printing. The second iteration of 3D printing was then conducted in SLA instead of FDM to improve our tolerances and surface finish (Figure 14(c) on page 30).

(a) (b) (c)

Figure 14. (a) The eye and tongue mechanism inside a mockup of the squid head. The eyelid levers were too long and couldn't move enough to flick the eyelids closed, so we decided to shorten them. We also found that having the back of the head missing made it easier to insert the head, especially if there is a part covering the bottom hole of the head in the future. (b) Our first iteration of the head was FDM 3D printed, including the inner features such as the eye brackets, top rod and tongue slot. The surface finish was rough and some parts needed to be smoothed with sandpaper. (3) Our second iteration of the head was SLA printed, had adjusted tolerances, and a smoother surface finish.

For the outside of the head, we originally had a plan to make the head of the squid some sort of drawable material on the outside. Our original thought was to use a white board like material or drawing material that would need a marker to draw on. Due to concerns about kids being able to draw on the car and anything surrounding the toy, along with the choking hazards of the marker and marker cap, we needed to come up with a new idea for the head. We still wanted to follow our original idea of being able to draw on the head, but we needed some material that would not need a marker. We ended up finding inspiration from suede couches, which many of the people on our team had as a kid. With this material, you are able to "draw" on the couch using just your hands, because the fabric changes from light to dark depending on the direction you rub the material. Thus, we transformed our idea for the head to be a fabric you can draw on using just your hands. A few members of our team took a trip to Joann Fabrics to look at options for the fabric for the head. As we looked around, most fabrics that we looked at, that were similar to the couch material we remember from when we were kids (suede, velvet type fabrics), either did not have enough contrast to be able to tell what you are drawing or they were all boring colors (browns and grays), which would not satisfy our need for the toy. We eventually found a fuzzy fleece material that had high contrast, with the blue shade having the highest contrast, as shown in Figure 15 on page 31. This fabric not only fit our need for a high contrast, drawable material, but it also removed the concerns, from parents and fellow students, relating to using a marker based drawing material (the mess and choking hazards). We do realize that this material is less obviously a drawable surface than having a white board or marker based drawing board, but we realized that when two to three year old children draw, they often are scribbling rather than designing specific pictures, in which case, having a more sensory based material (such as the fabric we chose) is better for stimulating our target audience than our original drawing option [25].

Figure 15. An image of the material we are planning to use for the cone part of the head of our squid toy. This material is fuzzy and has high contrast, allowing it to be “drawn on” using only your hands.

Long Tentacles. The longer arms, or tentacles, of the squid, which are pulled in order to blink the eyes and stick out the tongue, are made of two major parts. On the outside is a fleece fabric, see Figure 16(a) below, and on the inside is an elastic tube, see Figure 16(b) below.

(a) (b)

Figure 16. Images (a) and (b) are the two major materials that make up the long tentacles of the squid. (a) shows the outer fleece fabric that will cover (b) the inner elastic tubing of the long tentacles.

The inner elastic tubing attaches to the inner mechanism of the head and is pulled in order to blink the eyes and stick out the tongue. When trying to find a good elastic material for pulling, we originally tested various sized rubber bands, but we found that they broke too easily and would start to crack and tear after only a few pulls of the rubber band. Thus, we looked to other kids toys that have similar pulling elements to try to find a more durable elastic material. We ended up finding a slingshot monkey toy that uses an elastic rubber hose as the slingshot mechanism [26]. We found a similar rubber hose material on Amazon that would fit our toy perfectly, in terms of size and elasticity [27]. We have already received the elastic hose material and tested it with just our physical strength and the material stretches really well, with no signs of cracking or any fatigue in the material. We planned to perform more sophisticated force testing on the material before being confident that we should use the elastic hose material. Once we confirmed the elastic hose material was durable enough, we sewed a tube of the fleece outside fabric, depicted in Figure 16(a) on page 31, around each arm's elastic hose. We cut the fabric tube to be the maximum length of the extended elastic hose length (that we choose to be 12 inches based on safety standards and testing of the inner mechanism with the elastic), so when the tube is relaxed it will crumple up and when it is stretched, the hose stretch length will be restricted based on the arm fabric's length. Once the elastic hose is cut to the right length, it is fed through the fabric arm, then the elastic is folded over (so it is double the thickness) and zip tied to hold it together. In addition, the "wrist" part of the arm was sewn so the opening is small enough so the doubled elastic cannot slip through it. Finally, the rest of the arm fabric was sewn together.

Small Tentacles. One of our more complex aspects to the toy are the eight shorter leg tentacles. Like we said in our original design of the squid, we want the texture of the tentacles to be rubbery. To try to figure out how we would do this, we talked with William Van den Bogert, a Graduate Student Instructor for Manufacturing Processes (MECHENG 481) who specializes in plastics and 3D printing of plastics and silicon based materials. When we talked with him about wanting a squishy, rubbery leg material, he said that injection molding with silicon would be our best option. More specifically, we would need to create a CAD design of a mold for the legs, which includes an injection site for the silicon gel and air exit holes throughout. We would then 3D print that mold using a Stereolithography (SLA) 3D printer, which would give us a smooth, high resolution mold. Once we have the mold, we would need to prepare the silicon for injection, which consists of taking part A and part B of the silicone and mixing them together, potentially with a blue dye, in a centrifuge, in order to get rid of air bubbles, and then inject it into the mold. We were recommended, by William, to get a silicone elastomer material with a shore hardness value of 20 or less, in order to have a squishy material that will still be strong enough to withstand the roughness of playing with it. Using a shore hardness of 20 as our starting point, we made a trip to *Resaline Inc.*, which sells and provides the injection molding silicone materials we were searching for. After viewing the various silicone samples they provided, we determined that the ideal shore harness we required to achieve the correct tentacle texture was 5. Appendix D shows the specifications for the silicon material, *TC-5110 A/B 5 Shore A Translucent Silicone Rubber*, we purchased for our prototyping use.

Our plan was to create a mold of one tentacle and injection mold each individual tentacle. If we found out that the silicon would not work for our toy or we do not have enough time to have it work for our toy, we planned to create the small tentacles out of a soft, bumpy fabric, that resembles a tentacle like texture and would give some added sensory elements, since we would no longer have the silicon texture. The mold went through two variations of suction cup designs, but the decided upon design included four suction cups and had dimensions 1.18" x 1.16" x 3.18". Material ejection holes were included at each of the suction cups and one was included near the top, thickest part of the tentacle. The purpose of these ejection holes was to ensure that every area of the mold was being completely filled with material and that there would be no air pockets. A lip was added on one side of the mold and a corresponding cut was made on the other, which functioned like a lid to ensure the mold would not move during the injection process. One side of the tentacle mold CAD can be seen in Figure 17 below on page 33. We had two molds SLA 3D printed, one with clear and the other with white material. Our team then proceeded to injection mold two tentacles a day, until we had 6 small tentacles of the correct texture and hardness. Our original design had 8 small tentacles, but we found that having 8 would be very crowded, so we decided to only have 6 small tentacles on our toy.

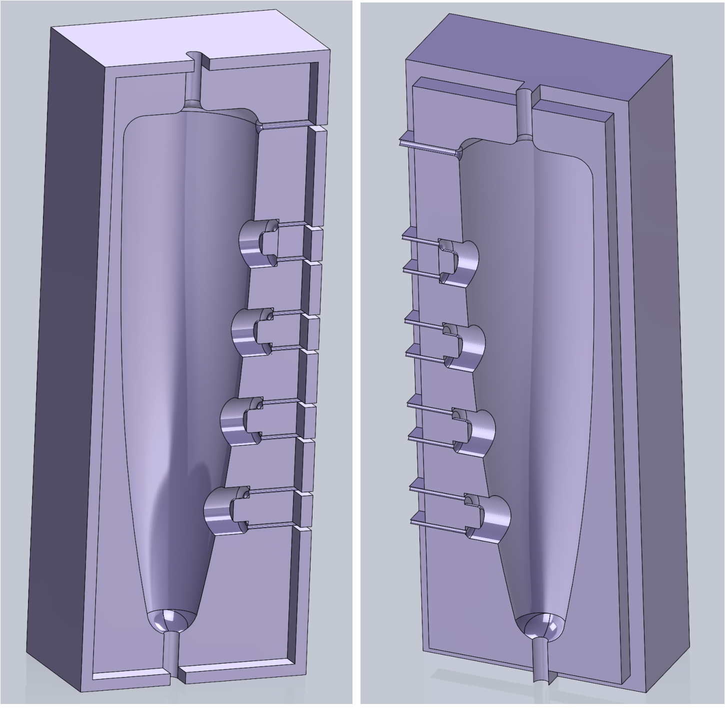


Figure 17. The mold created for the silicone injection molding process created an approximately 2.65 inch tentacle with four suction cups. Material ejection holes were placed near the widest part of the tentacle and on each side of every suction cup. The mold was cut in half, with one half having a lip around the edge (left) and the other half having a corresponding cut (right). Two holes (with 1 mm diameters) were included at the top and bottom of the tentacle, to act as possible injection sites. Two full molds were SLA 3D printed based off of the CAD file.

Design Critique

After prototyping all of the separate pieces, our team finally put together the final design. The steps of the manufacturing process that we performed along with a manufacturing plan can be found in Appendix E.2. As previously stated, the 3D printed inner mechanisms were assembled inside the 3D printed head. Then the two-toned blue fabric was glued onto the upper cone of the head. The darker fabric was then used to create a sort of sleeve, with six holes in the bottom to place the small silicone tentacles and two holes in the sides to feed through the elastic string. The string was encased in the same dark blue fabric, which was then sewn onto the face fabric, to create the long tentacles. The final design can be seen in Figure 18 below on page 34.

Figure 18. Our final squid design combined all the 3D printed, fabric, and silicone elements that were created during the prototyping phase. The components were joined together using either glue or sewing methods.

The final prototype design did provide our group with some challenges. Despite the tongue mechanism working very well, when implementing the eye mechanism we experienced difficulty. As explained in the inner mechanism prototyping subsection above, when we implemented the eyelid system, the eyelid did not have enough length to fully cover the eye when the string was pulled and would easily be knocked out of position. If we had time for a redesign, our group would insert some type of upper eye bracket or slot onto the inner wall, which would hold the eyelid piece into place when the part is fully inside the head. Another weakness that we found during the prototyping process was the top ring. In our initial design, a ring on the top of the head was included so that the toy would be able to be leashed to a location in the car and be easily retrieved by the child if it fell to the floor. As stated in the head subsection above, during round one of the 3D printing process the ring was broken off, and during round two, the piece was too tall to be printed by the machine if the ring was included. Rather than including the ring in the 3D print, our team has discussed that if we had time available for a redesign, we would have drilled two small holes on the opposite sides of the upper head and inserted a ring of a different material, similar to a binder ring. Our team also had a bit of difficulty assembling together so many different types of materials. We were able to accomplish what we needed through gluing, sewing, and the “pants” method of attaching the small tentacles, although we would have liked to have combined elements, such as making the 6 tentacles into one mold, to ease the assembly process. Finally, the squid would have a more cohesive appearance and aesthetic if the small tentacles were a blue instead of their current cloudy white color. Due to only making a single prototype, our group did not feel that paying for expensive silicone dye would be a valuable use of our budget; however, if this toy were to be mass manufactured the cost of the blue dye would be more justified.

VERIFICATION

Verification Plans

Initially, when we discussed the nonnegotiable requirements and specifications for our project, we knew that they had to be testable in order to be useful in guiding our solution to our problem statement. As shown above in Table 2 on page 11, we organized our requirements based on high to low priority as they related to our problem statement, and the high priority requirements are those that we intend on testing. Our biggest priorities are to create both a safe and portable toddler toy, so we have designed a set of tests in order to do so. Those tests are outlined below in Table C1 in Appendix C.

Portable: Adequate Size for a Toddler to Play with in a Car. For our toy to be able to be held by or lay in the lap of a toddler in a car setting, we determined that the toy must weigh no more than 2 pounds. This is to ensure that the child can pick it up easily and move it around or utilize its functions as need be. The verification method that we will be using in order to test this requirement and specification is to weigh the final toy with an Imperial scale.

Portable: Easy for Caretaker to Pack and Transport to Various Locations. For our toy to be considered portable in the sense that a caretaker can carry or move it to and from a car setting we have outlined that the toy must not exceed the dimensions of 13in x 13in x 13 in, or 33cm x 33cm x 33cm. This would ensure that the toy can be easily held by an adult or would easily lay in the lap of a toddler in a car while they sit in their car seat. In order to ensure that we adhere to the engineering specifications that we set for this requirement, we will both abide by our CAD dimensions and measure the final toy upon completion with an appropriate measuring tool. We did satisfy this requirement by both measuring it and watching a 2 year old play with the toy both in and out of the car and seeing that it is easy to transport and play with for that 2 year old.

Safe: No Toy Parts are Small Enough to be a Choking Hazard. For our toy to ethically be used by children, we must make sure that there is no way for a child to injure themselves while using our toy, especially because they will be unsupervised in the backseat of a car. As stated earlier in the report on page 11 in Table 2, in order for a toy to be considered safe and not put a child at risk of choking, none of its pieces, when attached or removed from the toy in the event of permanent deformation, can fit in the center of a Small Parts Test Figure, which simulates the mouth and throat of a child. The verification methods that we planned to perform to test this requirement are: a Torsion Test, a Tensile Test, a Compression Test, and a Drop Test. The Torsion test would be performed by attaching a Torque gauge to various parts of the toy, applying torque until failure in order to determine the maximum twist that our toy could withstand to ensure that a child would not be able to apply that twist and be put at risk of choking on the part that fails. The Tensile and Compression tests would be performed in a similar manner, applying tensile and compression loads with a force gauge. The last test that would be performed on our toy is the Drop test, which we would execute after the Final Design Expo in the event that our toy fails under the impact of the drop.

Competitive Pricing. One of our previously listed requirements for this toy is that it should have competitive pricing in relation to similar toys on the market. After background and market research, our team had determined this to be a price of ≤ $35. Ideally, our team would be able to determine if this requirement is met once the toy has been mass manufactured and listed on the market. We understand that if the toy was mass manufactured, the prices would likely be lower due to the benefits of buying in bulk, but in order to approximate our pricing, we intend to create a bill of materials (BOM), which will list our materials used for prototyping the toy and its related price for each item. It is also important that a parent or caretaker will be willing to buy our toy within our listed price range, therefore we plan to send out a survey, before and after our final prototype is complete, with a question to gauge what price range the caretakers or parents would be willing to pay for the toy if they saw it on a shelf in a store.

Child Will Not be Able to Permanently Deform the Toy While Playing with it. Again, in order for our toy to be ethically used by children, we must make sure that there is no way for a child to injure themselves while using our toy, especially because they will be unsupervised in the backseat of a car. To ensure that our toy is safe, we must also adhere to the requirement that a child will not be able to permanently deform the toy while playing with it, meaning that the child should not be able to apply a force or moment to the toy that would result in pieces breaking off or being destroyed. The requirements for said forces and moments can be found on page 11 in Table 2. The verification methods that we envisioned to test this requirement are: a Torsion Test, a Tensile Test, a Compression Test, and a Drop Test. The processes by which these tests are to be performed are detailed in the safety subsection prior to this.

Verification Results

Following our previously outlined verification plans, our group performed various tests on the many components of our toy squid prototype. Due to safety concerns, limited time and limited resources, our group did not perform our own flammability or toxicology tests. Instead, we conducted a lot of research on the different types of materials we included in our squid, taking note of materials that have already been used in other toys on the market, and made sure that their properties did not violate any of the ASTM specifications.Testing was able to be performed on both elastic and inelastic parts to ensure that pieces would withstand enough force, described by our safety and deformation specifications.

Inner Mechanism Force Test Results. According to the ASTM Toy Safety Standards [11], a non-elastic toy must be able to withstand a force of 15 ± 0.5 lbf applied in tension, both parallel and perpendicular to the major axis without failing. The non-elastic elements of our toy consist mainly of FDM 3D printed material. To ensure that these inner mechanisms and head pieces would not break under the force of a child pulling on them, either directly or indirectly through the string, we tested their strength. We attached a digital force gauge to each piece, securing the other end of the piece to the table, then pulled until the device read larger than 15.5 lbf. Each component was tested three times and all pieces yielded successful results. After the tests, no visible damage was observed on any area of the piece, such as cracks, dents or deformation. Since none of the pieces failed, we feel confident that they will remain intact inside of our toy, especially since they are unlikely to be subjected to such a large force from the young children.

Elastic String Force Test Results. If there are any elements in the toy that are elastic, or extend off of the main body of the toy, the appendage must be able to withstand a force of 5lbs, while not extending more than 12 inches. This specification was listed specifically for children 18 months or younger, which is below our targeted age range of 2-3 years old, however we aimed to accomplish this goal to ensure the best safety. To test this specification, we secured one end of our chosen elastic string material to the end of the digital force gauge. Then one member of our team proceeded to pull on the other end until the gauge read over 5lbs. The same string was put through five trials of testing and the results of this experiment can be seen in Table G1 in Appendix G. The string was able to complete all five trials successfully, without snapping or any evidence of wear. Although the string was able to withstand the 5lbs, we do not anticipate a child being able to pull that hard. The elastic string will be fully covered by the long tentacle fabric, so make sure the appendage can not be pulled longer than the specification allows, the length of the arm fabric, fully extended, will be a maximum of 12 inches.

This test also helped us determine our string attachment method to the inner part of the head. While testing the strength with the force gauge, it was evident that just tying the string around the rod in the head would not be a reliable enough connection. The string would untie itself under the tension of 5lbs, so our group sought a different solution. We landed on the solution of Zip Ties, which proved to be a valid solution and withstood all of our testing without slipping or failing.

Bill of Materials. In order to verify our pricing requirement in the scope of the semester, we have created a bill of materials (BOM), which lists all our materials used in the prototyping of the toy and its related price (see Appendix E.1, Table E1). Based on our BOM, our projected cost to build one toy is $28.94, which will satisfy our pricing specification of ≤ $35. Additionally, if this toy were mass manufactured, the price per toy would likely decrease, therefore increasing our potential profit if we were to sell the toy at a price approximately $35.

VALIDATION

Validation Plans

For our project to be successful, our toy not only should be functional, but it should be able to fulfill all of the goals outlined in our problem statement. Our problem statement outlines that our toy should be entertaining, non-distracting, and a preferable option to parents than screen entertainment. In order to gather accurate validation information, we would need access to large focus groups of parents and children and more than a few weeks of time, therefore our ideal plans are mostly out-of-scope for the semester. However, despite our time and resource limitations, we have plans to attempt a smaller scale validation and gather results that will give us a general consensus about certain aspects of our toy.

Entertaining to Children. According to our toy concept requirements and problem statement, our final toy should be able to keep a child (2 - 3 years old) occupied for the duration of travel, which we have defined previously as greater than or equal to 20 minutes. With unlimited time and resources, our team would perform multiple trials of user testing and record how long toddlers within our specified age range play with the toy before becoming bored or moving onto a new activity. To ensure the most accurate results, the testing groups would contain a large number of children participants, but unfortunately tests on this large of a scale are not feasible for our group to complete with a single toy prototype and in the time before the end of the semester. We plan to get some user feedback, allowing a small group of children to test the toy, but understand the results will be less accurate and we will have to consider their biases. Along with user testing, we plan to send out two surveys, one before and one after the final prototype has been completed, to gather opinions of parents and caretakers on how long they believe this toy will be able to entertain their kid.

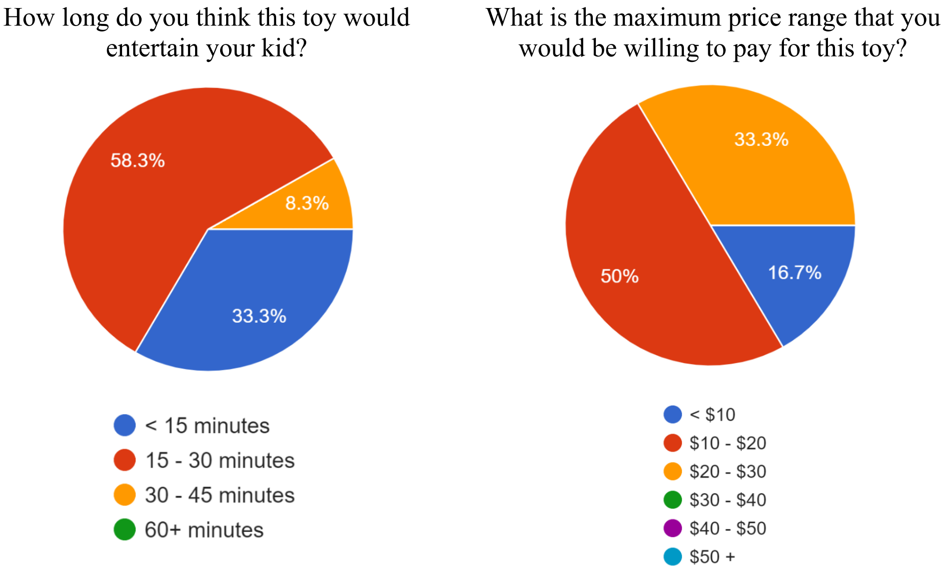
Non-Distracting. Our team wants to verify that our toy meets the requirement of being non-distracting to surrounding people. Our specifications listed are related to the sound element of the toy, however due to the fact our toy has no intentional noise element, we plan to focus on checking that the toy is not visually distracting to the parent, caretaker or driver of the car during travel. Similar to the children's entertainment testing plans, if work on this project were to continue outside of this semester, we would gather large focus groups of parents and caretakers, and allow them to sit in a car while the toy is being played with, and gather their thoughts and concerns. In the scope of the semester, we plan to add questions to our initial and final surveys, which will show the toy design and ask parents, based on their experience with other toys, if the toy will cause them to be distracted.

Preferable to Screen Entertainment. Although it is not listed directly as one of our requirements or specifications, the only way this toy is a success is if the parents and caretakers choose to buy this toy as a replacement to any form of screen entertainment. To find out accurately if this toy would be successful, this toy would have to be mass manufactured and sold in stores, where we could then monitor the sales and determine if parents are willing to buy it for their children over other (screen) toy options. Our team will have produced only one prototype by the end of the semester, so we will be unable to perform this large scale test. Despite not being able to use that market sales method, we plan to gain feedback on the likelihood of the toy being bought from parents through our multiple surveys.

Validation Tests and Results

Our team has determined that many of our ideal validation methods are out-of-scope for us, needing more time, resources or equipment than what is currently available to us this semester. In spite of that fact, we have decided to gather some validation data, even if it is not as accurate as possible, through small focus group user testing and a survey.

Initial Validation Survey. Before we began the majority of our high fidelity prototyping, we sent out an initial survey, which aimed to validate our previous background information on safety and screen use, and collect parents and caretakers first thoughts or concerns about our alpha design concept. If the participants in the survey raised any concerns, our team wanted to address them early in the prototyping stages, before we spent too much time, effort or money on a part of the project that needs to be changed. The survey began by asking background questions, such as their kids' age, the allowed frequency of their children's screen use, and their kids favorite toys. In total, thirteen parents or caretakers participated in our survey, nine of which had children within the age range of 2 - 5 years old. Those who did not have kids in that age range took care of children who were younger than 2 years old. The end of the survey contained a description of our problem statement, alpha design, and specific questions that would help validate our cost, entertainment, and distraction requirements. To justify our pre-established price range goal, we included a question on the survey that asked, based on the toy alpha concept presented, what is the maximum price range they would be willing to pay if they were to purchase the toy. Another important question we asked was how long do they think the toy would be able to entertain their kid for. The results were used to confirm that our toy will be entertaining enough to reach our minimum 20 minute goal. Both of the question results were shown in Figure 19 below.



How long do you think this toy would entertain your kid?

What is the maximum price range that you would be willing to pay for this toy?

Figure 19. Both pie charts above show the results from questions asked in our initial validation survey. The chart on the left was used to help us validate our entertainment requirement and specification. According to the results, 66.6% of the survey participants believe, based on the alpha toy concept, that their child would play with the toy for over 15 minutes, which is approximately our specification of 20 minutes. The chart on the right was used to help us validate our price range requirement. None of the participants responded that they would pay over $30 for the toy, which aliens with our specification price range of a max of $35.

The results in Figure 19 above on page 38 help us confirm that we are achieving our entertainment and prince range requirements and specifications. All of the participants are only willing to pay prices below $35, and 66.6% of the participants believe the toy will entertain their kid for over 15 minutes. Multiple other questions pertaining to portability, willingness to buy, and any overall concerns were also asked, and the results can be seen in Appendix F, Figures F1 - F5. At the end of the survey we provided a spot for the parents and caretakers to write in any comments or concerns about the toy, which we then collected and reviewed to see how we were able to improve the toy design. The concern that was brought up most in the comments was that the marker and whiteboard design on the head would potentially be very messy and the cap of the marker may present a choking hazard. These comments, combined with comments from our peers during the design reviews, were the main reason behind our switch from a whiteboard material to a two-toned fabric. Choking hazards in general, not regarding the marker, were a concern, specifically with the suction cups on the bottom of the tentacles. We decided to address this concern by integrating the suction cups with the smaller tentacles, making sure that they cannot be pulled off of the eight limbs. Finally, the participants were worried about the durability of the toy, which we plan to test through tension, torsion and drop tests.

When sending out the initial validation survey, all members of our group sent the link to any parents or caretakers with children within our targeted age range that we knew. We understand that with our smaller focus group sizes and relationship with some of the participants, the survey results may be biased. Also, participants in the survey may lie about the results. The most accurate results would come from observing the parents and child's interactions with the toy and putting the toy on the market and tracking their sales, but due to our constrained timeline and resources, we are performing whatever validation methods we are able to before the end of the semester. We have also extended our survey's reach by asking members of our class and non-engineering peers to send the link to people they believe will be willing participants as well. Finally, in an attempt to gather more responses, the surveys are still open and available for people to fill out, and will continue to be until the semester is over.

User Feedback. In spite of the fact that we were not able to make multiple prototypes and gather large focus groups of children and parents, we were able to give our final prototype to our sponsor’s niece. As a group we wanted to see how a toddler, within our designated age range, would react to the toy. Specifically we were interested in how long she would play with the toy and which elements she found most entertaining. Photos of her niece playing with the toy can be seen in Figure 20 below on page 40. These images are also useful to see the relative size of the toy, and confirm that the toy is a car-travel compatible size.

Figure 20. Both images above show our sponsor's niece playing with our final toy design. The picture on the left shows how the toy is able to comfortably fit onto her lap while in her car seat during a drive. On the right, you can see that she has no issue carrying the squid toy on her own

In further detail, on Sunday April 23, Angela and Sedona met our sponsor, Sarah, in addition to our primary user, her niece Isla, at the Ann Arbor Public Library. The purpose of this meeting was to give Isla our finalized squid toy and to observe her interactions with it. We hoped to see her use all of the sensory elements of our toy, entertaining herself without prompting from her parents or our sponsor, her aunt. Throughout the thirty minute period in which we spent with Isla, we were pleasantly surprised by our toy's success in entertaining her. She had just spent the morning at the hands-on museum with her family, so she was tired and hungry upon our meeting, but she immediately smiled upon seeing our goofy looking toy. Sarah prompted her to pull the long tentacle to stick the squid's tongue out, and from then on, Isla was very proud of herself every time she was prompted to perform the toy's function and could do so with ease. She ran around with the toy, sometimes dragging it from the long tentacle. She accidentally dropped the toy once or twice, and nothing broke off from the toy and it did not appear to have collected any dirt from the floor upon impact. To us, it seemed like Isla's favorite part about the toy was the fact that it was a new cute friend for her to take places. She formed an instant bond with our toy, and she carried it to multiple locations with her throughout the duration of our meeting at the library.

Additionally, one of the librarians approached us upon seeing Angela pull the toy out of her bag and asked, "Where did you guys get that? Did you make it?" She then proceeded to explain to us that her six year old son is obsessed with cephalopods and would love our toy. She then took a picture of our toy to show her son once she saw him next. This was an important moment of validation for us as it proved that our design is cute and universally interesting to boys and girls alike. We only wished that we had another prototype to give to the librarian to take home to her son.

PROJECT PLAN AND STATUS

Our semester plan is divided up into four major units, as displayed in Table 4 below on page 41 and 42: Design Review 1, Design Review 2, Design Review 3 and Final Steps. So far we have completed all of Design Review 1 topics, which were focused on defining our problem and the requirements and specifications associated with it, as well as Design Review 2 topics, starting with some individual concept generation, getting as many ideas out of each teammate without any influence from each other. After that we came together with all of our ideas, compared them, and performed further concept generation as a team. Individual and team concept generation will be repeated multiple times to ensure we are happy with our chosen concept. Finally we took all of our ideas and compared them in a Pugh Chart to determine which concept we will move forward with as we move into Design Review 3. In Design Review 3, all the way to Final Steps, we worked on creating a working prototype of our chosen concept and doing any necessary testing on that prototype. We began by lo-fi prototyping and testing the inner mechanism that will allow the eye blinking and tongue function. Then we moved on to create a lo-fi prototype of the head casing and body design, redesigning in iterations when necessary. Once our group was confident that the inner mechanism prototype would function as we would like, we manufactured a hi-fi prototype with the appropriate 3D printed materials. Our team sent out an initial validation survey and made any corresponding changes based on parent and caretaker concerns, which involved changing the alpha design concept to no longer include a whiteboard and marker combo, but instead a fabric. After changing directions, we met with a manufacturing graduate student instructor and discussed future plans for injection molding the small tentacles with a silicone elastomer. Once all of the separate pieces were manufactured, we assembled them together. With this assembled final prototype we performed all of our tensile force tests to check if our specifications were met, and had a final toy design to present at the design expo. Finally, we presented our toy to our sponsor's niece and was able to receive feedback on the toy from a child within our targeted age range.

Table 4. Project plan for the semester starting from receiving the travel-compatible toddler toy project, all the way to the creation of a prototype to the final report.

	Task	Date Range	Leader
Design Review 1	Establish need and create problem statement	January 13 - January 23	Sedona
	Benchmarking/Research on topic	January 13 - January 25	Cayla
	Define Requirements and Specifications	January 18 - January 25	Sam
	Prepare DR1 Presentation	January 22 - January 26	Angela
	Write DR1 Report	January 24 - February 2	Sedona
Design Review 2	Individual concept generation → Come up with 20 designs each (x2)	February 2 - February 5	Cayla *Task: Ensure everyone completes tasks, facilitate conversations*
	Team concept generation → Mind map as necessary to come up with more ideas → Screen concepts using various filters (based on feasibility and requirements) → Generate ideas as a team in longer ideation sessions (~3hrs) → Re-design concepts at least 3x	February 5 - February 14	Round 1: Sedona Round 2: Angela Round 3: Sam *Task: Facilitate conversations, record keeping/sketch designs*
	Rank concepts (pugh chart) → Perform after screening of ideas → Use two different ranking systems	February 9 - February 16	Round 1: Sedona Round 2: Angela Round 3: Sam *Task: Prepare for meeting, facilitate conversations, record keeping*
	Prepare DR2 Presentation	February 9 - February 16	Cayla
	Write DR2 Report	February 14 - February 23	Sam

Design Review 3	Review/adjust concept → Perform a final round of concept generation based on DR2 feedback → Discuss testing, resources and spaces needed	February 23 - March 6	Cayla
	Inner mechanisms → Prototype → Test is functions → Force test → Redesign	March 6 - March 14	Sam *Task: Find a space to prototype in, collect materials*
	Prototyping body → Lo-Fi prototype for general idea of sizing → Redesign → Collect all materials necessary → Hi-fi prototype with appropriate materials → Test Functionality → Test standards	March 9 - March 17	Lo-Fi: Angela Hi-Fi: Sedona
	Prepare DR3 Presentation	March 16 - March 21	Cayla
	Write DR3 Report	March 21 - March 28	Sam
Final Steps	Inner Mechanism → adjust CAD & 3D print prototype	March 20 - 24	Sam
	Prototype Head → lo-fi prototype (sizing) → adjust CAD & 3D print	March 19 - 23	Cayla & Sam
	Prototyping Body → Silicon Elastomer Process → create SLA mold → order materials → Lo-fi prototype of long tentacles → Hi-fi prototype of long tentacles	March 23 - April 7	Angela
	Durability Test → slingshot string tension test → head torsion & tension test → drop test → individual parts → full prototype	March 28 - April 12	Sedona
	Write DR3 Report	March 21 - 27	All
	Prepare for Design Expo	March 29 - April 12	All
	Finish producing silicon tentacles	April 12 - April 19	All
	Assemble toy - final version	April 19 - April 23	All
	Small Scale User Testing	April 13	All
	Test toy with Sarah’s niece	April 23	Sedona, Angela
	Send Final Survey	April 13 - 23	All

In order to perform our major concept generation, prototyping and testing tasks, we needed an open space. We found that the Lurie Biomedical Engineering Building has numerous prototyping and collaboration spaces, which includes a wide variety of prototyping materials and resources, including 3D printers. The X50 lab in George G. Brown Laboratories (GGBL) was a major resource that we utilized for the rest of our project.

Problem Domain Analysis and Challenges
As we started looking at our problem and determining what needs to be done in around four months, a few challenges came up, as categorized below.

Limited Time. Since this project has to be completed in one semester, we only have around four months to go from defining the problem all the way to having a solution. In our case, we wish to have a fully functioning prototype of a travel-compatible toy, which consists of numerous concept generation sessions, CADing the chosen design, prototyping the design, doing any necessary testing to ensure the design meets are requirements, and then repeating any steps that need to be repeated to ensure the prototype is to our, and our sponsors, satisfaction. In addition to that we have presentations to prepare for and reports to write along the way. In order to try to overcome this challenge, we have made a plan for the semester that we hope will keep us on track. The goal that our sponsor set for us is to have a working prototype, similar to something that you might see on the shelf at a store, so moving from selecting our alpha design to finishing a working product will have us pressed for time.

Meeting Standards. Since we are creating a children's toy, there are a vast amount of standards we need to meet to ensure the safety of the user. Some of which include toxicity standards, sharpness and choking hazard standards, flammability standards and labeling standards. Not only do we have to ensure all toy related standards are met, as specified by the ASTM F963-17 standard, but we also need to ensure any car rules and regulations are satisfied, since we are creating a travel-compatible device. With this multitude of standards, our team is anticipating a major challenge in meeting all these standards. As a way to help minimize the challenge and keep ourselves organized, we plan to read through all standards and create a list of the most important standards that relate to our project. Now that we have narrowed down to our alpha design, the squid, we have begun research into the types of standards associated with plastic toys, as well as for fabrics.

Testing. Along with the challenge of meeting all standards related to our project, trying to perform the appropriate tests to ensure the satisfaction of all standards consists of large amounts of research to figure out how to test each standard, obtaining expensive testing tools that we do not currently have access to, and a huge time commitment to perform the tests. In addition to all the testing to meet the standards discussed in the challenge of “Meeting Standards” above, we also need to satisfy all of our requirements, through testing our prototype based on our specifications. One challenge we will face with testing our specifications is that some of them are not very clear as to what success looks like. For example, our requirement “keeps a child occupied for the duration of travel” has a specification “child is occupied for ≥ 20 min”. In this case, it is unclear how we would test if a child is truly occupied for at least 20 minutes and how we would determine if this would be true for the majority of children without having to test a multitude of kids. Thus, our team needs to create a plan for what tests we plan to run and how we are going to run those tests.

Entertaining Kids. We want our toy to be universally entertaining, across cultures and genders. Our major challenge is that not all kids are interested in the same toys or topics. Thus, creating a toy that the majority of kids would be entertained by is going to be difficult. We hope to use our knowledge about diversity, equity and inclusion along with research on what toys are successful on the market to try and combat this challenge, but, without having the ability to test our toy on a multitude of kids, it will be difficult to truly determine if our toy is universally interesting.

End-of-Life. Toys are either used for one child for a couple of years and then thrown out or they are passed on to be used by multiple children and multiple families, lasting numerous years. The very different life paths of toys makes it difficult to determine the end-of-life journey we want our toy to take. More specifically, we need a durable toy for the cases that the toy is passed down to multiple kids and lasts many years, but we also want to make sure that the toy is made in such a way that when it is disposed of it is not sitting in a landfill for hundreds of years waiting to break down. With that, we need to consider what materials we want to use and how we want the toy to be disposed of, ensuring the construction of the toy and disposal method works for all lifespans of the toy.

Application of Engineering Principles

As mechanical engineers, we have learned, through previous design courses, how to think critically and creatively when coming up with different design ideas. Some applicable engineering knowledge that we have on the topic of concept generation include applying design heuristic cards to come up with new design ideas and using a pugh chart to compare different concepts and evaluate which is the best option. We also have knowledge on manufacturing processes for producing a variety of different parts, such as injection molding and die casting. This knowledge will come in handy when we are trying to decide what materials to use to have the most sustainable manufacturing process that we can. In addition, for flammability testing, we will be using our knowledge of heat transfer and knowledge of different materials and their melting points to predict which materials will satisfy the flammability standards that our toy must meet. On the flip side, we have little knowledge about toxicity of materials or sharp edges and choking hazard testing with materials. Thus, we will have to expand our knowledge in those areas throughout this project.

REFLECTION

Our project makes the world work better for parents and children alike. We have developed a mentally enriching toy that is suitable for the entertainment of a toddler in a car travel setting. Our sponsor communicated that there were no satisfactory toys on the market already that had the specific intended use case as for travel. Our toy eliminates the need for tablets and phones to entertain children for long car rides. Instead, our toy provides sensory stimulation that is a better alternative for cognitive development in toddlers. Our toy allows the toddler to express its creativity, engage with silly expressions, and develop a relationship. As our group and others can relate, some of our most valued childhood “best friends” were stuffed animals. Our highest values for the toy remained safety and portability throughout the course of the semester, although we struggled to maintain our safety requirements and specifications as we hand-constructed the toy from scratch.

In theory, the toy itself would not have a back that detaches upon impact and the tentacles would be better adhered to the toy through our “pants” method. During the interaction we had with our sponsor’s niece on Sunday April 23, the toy was able to sustain being accidentally dropped by the child from a height of approximately two feet. We did have to supervise our sponsor’s niece while she was using the toy because we were not certain that our final prototype would withstand the rough play toddlers engage in with their toys.

Potential Impacts

Public health, safety, and welfare are certainly relevant to our final project. Some of our highest priority requirements revolved around developing a toy that is safe above all else. Our toy itself is to be used by toddlers, 2 to 3 years of age, in theory unsupervised, in the backseat of a car while a parent or caretaker is driving. Toddlers can be unpredictable, so our goal has always been to include a variety of safety features in addition to fun features.

Our design might be of benefit in a global marketplace because it highlights the gap in which our problem statement lies. Introducing our product to the global population would allow larger toy companies to understand and assist in our development of a seamless toy, or create their own version of a travel compatible toy, improving the lives of many.

Ideally, our toy would be durable for an entire human lifetime, allowing for it to be passed down from generation to generation. The majority of toys do end up in landfills, so that would be an unfortunate social end-of-life impact, but our hope is that the amount of use pre-disposal will outweigh the negative consequences of its disposal.

Economically, our toy doesn't have a high relevance factor. The cost of our toy is low in order to be competitive in the free market, so ideally we wouldn't have much of an economic impact to the consumers, both in purchasing and use. Our disposal cost, which is more difficult to analyze given the expected vs ideal life of our toy, is still likely to be quite low given that the dimensions and weight of our toy make it compact enough to dispose of with ease once it reaches the end of life.

In order to further understand the social impacts of our product, we used some basic tools such as stakeholder maps, pugh charts and a toilet paper roll. Initially we created a stakeholder map (see Figure 3 on page 7) that listed out all possible groups of people that could be affected by our toy. The main ones being parents and children, but we also realized, depending on how safe our toy is and how loud it is, that hospitals/medical staff and bystanders could be affected by our toy. In addition, once we came up with a few toy designs, we used a pugh chart to rank the safety and portability of our toy (along with other factors), which would play a major role in how the toy affected our stakeholders. Finally, we used a toilet paper tube to ensure there were no choking hazards on our toy, as the toilet paper tube signifies the size of a child's esophagus. Between these three basic tools and many others, we were able to understand the social impacts our toy may have.

Team Identity, Inclusion and Equity

Our group consists of three female and one male engineer. We do not feel that this dynamic significantly contributed for or against the development of our squid design aside from our desire to create a toy that could equally entertain children regardless of gender. We, as a group, have relatively similar backgrounds and upbringings, so our ideas of toys that we enjoyed as children were similar. We could relate to each other about what things would be within the price range of our own parents as well as the types of things that they would have and wouldn't have allowed us to play with as toddlers. We also understand that we are privileged individuals in the sense that we would have had the opportunity to use screen entertainment as children, and that the prices we originally selected as affordable in our minds may not have been affordable for other families of different economic backgrounds. While affordability is important to us because we want our toy to be universally accessible for all parents and children, we do understand that if the toy were to be mass produced that the manufacturers would competitively price the toy on the market.

Our close relationship with our sponsor, Sarah, as a result of weekly meetings did influence our design processes and final design. Sarah was great at communicating with us about the types of toy that her niece has previously enjoyed, as well as communicating with us about her sister's struggles to entertain her daughter during long car rides. Our relationship with our sponsor was unique in the sense that she is a Ross Masters student whose undergraduate degree obtained the year prior is in mechanical engineering. She took ME450 last year, so had a vast amount of understanding and respect for the amount of work expected of us throughout the duration of the semester. She was helpful in guiding us through any hiccups and standstills that we encountered throughout our unique design process. In terms of our power dynamic with her, we were able to take creative liberties with the direction in which our toy was going, with her only hard requirement being that she did not want the toy to use a screen for entertainment. Her identity as an aunt to her sister's daughter provided us with some insight into how children's toys have changed and have been valued as of recently.

Ethics

Throughout the course of the semester, we had to be cognizant of the fact that the intended use of our finalized product would be for toddlers, 2 to 3 years of age. We had to be conscious of the fact that the materials used, sizing, and aesthetics of the product had to be appropriate for children. Looking forward, if our project product were to enter the marketplace and be mass produced, higher intensity safety testing would be required to ensure that the product does not fail under any circumstances. Our toy would need to be properly labeled and refined in order to be able to be used by children without constant supervision. Our method of attaching the fabric to the 3D printed skeleton inner mechanism using fabric glue would need to be altered so that the fabric adheres throughout the toy's entire lifetime. Our personal ethics are in line with the professional ethics we are expected to uphold by the University of Michigan because in both cases our solution to a given problem is only useful if it does more good than harm and poses no external threats.

As stated in the NSPE Code of Ethics for Engineers, engineers shall hold paramount the safety, health and welfare of the public.[29] Our toy would be made repeatedly with the same honesty and integrity that we hold as personal values. We would aim to never compromise our values for the quality or safety of our product, ensuring that the toy we would put out on the market is something that each of us are proud of. We could enter into conflict if our toy idea gets bought up by a larger company that has stricter deadlines. We could imagine that under a higher pressure circumstance with higher stakes that our personal ethics might conflict with the goals of the larger company.

RECOMMENDATIONS

As the semester draws to a close, our group is satisfied with the performance of our final prototype, although, if allotted more time, we acknowledge that there are improvements to it that could be made. We would like to make a couple recommendations to our sponsor, in the event that she continues to improve our prototype to a higher "off-the-shelf" quality than we were able to produce in the short couple of months we had to undergo our design process. We would like to suggest that, should our sponsor continue to refine and prototype with the design, any 3D print that is done should be done with an SLA printer as opposed to an FDM printer, as the SLA printers have a smoother surface finish, stronger subsection, which becomes important for smaller pieces, and have less of a chance for failure during the print. However, if she were to pursue mass manufacturing, we would recommend looking into injection modeling of plastics for the production of the head shell and mechanism, as this would be a much faster process compared to 3D printing. We would also recommend that changes to the eye brackets be made to allow for a direct connection with the eyelid pieces, such as having the eyelids clip into the bracket and having a defined pivot axis, as the current design doesn't hold the eyelids in place so they only rotate, causing unwanted movement and displacement. Our direct recommendation might be to change the lever so it is above the eyes, and a rod or string hands down that attaches to the back of the eyelids, allowing for more freedom with tolerances. Finally, we would recommend working to make the smaller tentacles of the body into one whole piece, as this would make it easier to attach to the body using "pants' since the silicone legs would all be attached to something inside the "pants" of the toy.

CONCLUSIONS

We seek to create a travel compatible toy, for children ages 2 to 3 that provides an alternative to screen entertainment. Throughout this project, thus far, we have established a clear understanding of the need for our product. We have assessed the market to document what criteria prevents current toys from being used in a travel setting to further understand why parents are resorting to screen entertainment for their children. We dove into research on the detrimental effects of screens on children's development, in order to defend our desire to create a screenless source of entertainment. Further, we understand that we have many safety concerns, standards and regulations to keep in mind in order to create an ethical and safe toy for use. Our biggest priorities are to develop a toy that is portable and safe.

There are many different people, companies, and organizations that are invested in the success or failure of this toddler toy product. Our group has deemed parents, children, and our sponsor as the most important stakeholders to our project. Given that we have a limited timeline, our primary stakeholders will be most impacted by our end product, and therefore have the most influence on the toy requirements and specifications. Our most important user requirements are in accordance with our problem statement, relating to both portability and safety. Our goal is to develop a product that is an adequate size for a toddler to play in a car, and that is easy for a caretaker to pack and transport to various locations. It is also crucial that our product is made of materials that will not be harmful to children and that our toy does not have any parts small enough to be considered a choking hazard.

During our concept generation process, we performed both individual and team concept generation, including mind-mapping and screening, to come up with toy designs that satisfy our requirements. To select our final design, we used a pugh chart, which ranked various categories, which included many of our requirements, for our top five chosen toys. The pugh chart led us to our chosen design: a squid toy that is around 10 inches tall and 3 inches in diameter. If you pull the longer arms of the squid, you can blink the squid's eyes and move its tongue. The body of the squid is made out of fabric, the head is made out of a white-board like material that a kid can draw on, with a ring at the top to attach a device to prevent displacement of the toy.

We began prototyping our build design, focusing initially on the inner mechanism components. Using cardboard, tape, and other cheap materials, our team met and made low fidelity prototypes of the eye lever, tongue lever, and head. Once we felt confident in our design, we 3D printed the parts, but upon testing them we determined that we had to adjust our CAD models. To receive some validation of our alpha design concept before finishing prototyping, we sent an initial survey. Through the survey we discovered that many parents were concerned about the marker being a choking hazard and a mess, therefore we changed course and decided to use a two-toned fabric to simulate drawing, instead of an actual whiteboard material. As a team we also finalized the types of fabric which will be needed to wrap the head and form the long tentacles. To create the small tentacles, we met with a graduate student instructor from a different manufacturing course we all share, and decided to pursue injection molding.

We performed force tests on the separate components with a digital force gauge, both non-elastic and elastic, and confirmed that they met our specifications. After successfully injection molding our small tentacles, reprinting our 3D printed materials and assembling the inner mechanism, our team was able to start putting all of the different components together. The head fabric was glued on and the fabric to hold the short tentacles and cover the long tentacles was sewn together. Once the toy was assembled fully, we were able to receive feedback and investigate the interaction of a child with our toy.

ACKNOWLEDGEMENTS

We would like to acknowledge, first and foremost, our sponsor Sarah Kreitman. Thank you for allowing us the opportunity to express our creativity and contribute to a problem that lies close to your heart. You have allowed us to learn and grow while working under your leadership. Your unwavering support throughout the course of the semester not only motivated us, but also made us feel confident in our design process and capabilities as mechanical engineers.

We would also like to acknowledge our lovely professor, Professor Sita Syal. You have been such a joy to have in class as our mentor and guide. Your undying enthusiasm and positive attitude encouraged us to push ourselves throughout the course of our semester to be our best and put forth our best efforts. From the initial “Sedona Squid” to the final “Dave-Gunky Squid,” we appreciate your support, and we wish that we had another squid to give to you and your future child.

We would also like to acknowledge William Van den Bogert, our GSI from ME481. We appreciate your assistance in learning the necessary skills to injection mold, as well as your excitement about our final product. We know you are a busy student yourself, so we especially appreciate you taking the time to dedicate to us and our journey through navigating our capstone project.

Lastly, we would like to acknowledge Isla. You are adorable. Thank you for being the reason behind such a unique problem statement, and we hope that you enjoy the squid that your dad affectionately nicknamed “Calamari.”

REFERENCES

[1] 60 Minutes. “Internet Addiction Disorder Affecting Toddlers | 60 Minutes Australia.” *YouTube*, 60 Minutes Australia, 29 Jan. 2020, https://www.youtube.com/watch?v=qyMqljINR74.

[2] Charles Nechtem Associates. “The Impact of Technology on Children.” Cerritos College, Aug. 2021, https://www.cerritos.edu/hr/_includes/docs/August_2021_The_Impact_of_Technology_on_Children_ua.pdf.

[3] Keikha, Mojtaba, et al. “Screen Time Activities and Aggressive Behaviors among Children and Adolescents: A Systematic Review.” *International Journal of Preventive Medicine*, U.S. National Library of Medicine, 19 May 2020, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7297421/.

[4] AACAP. Screen Time and Children, Feb. 2020, https://www.aacap.org/AACAP/Families_and_Youth/Facts_for_Families/FFF-Guide/Children-And-Watching-TV-054.aspx.

[5] CNLD Testing & Therapy. “How Long Should a Child's Attention Span Be?” CNLD Testing & Therapy, 28 Apr. 2022, https://www.cnld.org/how-long-should-a-childs-attention-span-be/.

[6] “Normal Attention Span Expectations by Age.” Brain Balance Achievement Centers, https://www.brainbalancecenters.com/blog/normal-attention-span-expectations-by-age.

[7] Shrier, Carrie. “What Are the Best Toys for Children?” Early Childhood Development, 21 Jan. 2022, https://www.canr.msu.edu/news/what-are-the-best-toys-for-children.

[8] Cyr, C, et al. “Preventing Choking and Suffocation in Children.” *Academic.oup.com*, Feb. 2012, https://academic.oup.com/pch/article/17/2/91/2638862.

[9] American Academy of Pediatrics. “Prevention of Choking Among Children.” *Publications.aap.org*, Mar. 2010, https://publications.aap.org/pediatrics/article/125/3/601/72642/Prevention-of-Choking-Among-Children

[10] “‘Toilet+Paper+Roll’ Images – Browse 0 Stock Photos, Vectors, and Video.” Adobe Stock, https://stock.adobe.com/search/images?k=%22toilet%2Bpaper%2Broll%22&asset_id=132081600.

[11] American Society for Testing and Materials International. Standard Consumer Safety Specification for Toy Safety. F963 - 17. West Conshohocken, PA: ASTM International, approved May 1, 2017.

[12] Committee on Injury and Poison Prevention. “Selecting and Using the Most Appropriate Car Safety Seats for Growing Children: Guidelines for Counseling Parents.” *Publications.aap.org*, Mar. 2002, https://publications.aap.org/pediatrics/article-abstract/109/3/550/79823/Selecting-and-Using-the-Most-Appropriate-Car?redirectedFrom=fulltext.

[13] Ayça Berfu Ünal, et al. “The Influence of Music on Mental Effort and Driving Performance.” *Accident Analysis & Prevention*, Pergamon, 22 Feb. 2012. https://www.sciencedirect.com/science/article/abs/pii/S000145751200036X?fr=RR-2&ref=pdf_download&rr=78f499a70a0586ed

[14] "Fisher-Price Deluxe Kick & Play Removable Piano Gym." Mattel Shop, https://shop.mattel.com/products/fisher-price-deluxe-kick-play-piano-gym-fvy53.

[15] "Fisher-Price Animal Activity Jumperoo with Music, Lights & Sounds." *Mattel Shop*, https://shop.mattel.com/products/fisher-price-animal-activity-jumperoo-ffj00.

[16] Zhang, K. "Is China the World Factory?: 26: China as the World Factory: Kevin." *Taylor & Francis*, Taylor & Francis, 27 Sept. 2006, https://www.taylorfrancis.com/chapters/edit/10.4324/9780203799529-26/china-world-factory-kevin-honglin-zhang.

[17] Siu, Kaxton. "Continuity and Change in the Everyday Lives of Chinese Migrant Factory Workers." *Brill*, Brill, 1 Jan. 2017, https://brill.com/display/book/9789004304987/B9789004304987-s043.xml.

[18] "1500.49 Technical Requirements for Determining a Sharp Metal or Glass Edge in Toys and Other Articles Intended for Use by Children under 8 Years of Age." *Code of Federal Regulations*, https://www.ecfr.gov/current/title-16/chapter-II/subchapter-C/part-1500/section-1500.49.

[19] "Backpack Safety (for Parents) - Nemours Kidshealth." Edited by Larissa Hirsch, *KidsHealth*, The Nemours Foundation, May 2020, https://kidshealth.org/en/parents/backpack.html#:~:text=Doctors%20and%20physical%20therapists%20recommend,body%20weight%20in%20their%20packs.

[20] Maria Masters, Contributing Writer/Editor. "Your 2-Year-Olds Child Development." *What to Expect*, WhattoExpect, 22 Mar. 2022, https://www.whattoexpect.com/toddler/24-month-old.aspx#:~:text=Your%202%2Dyear%2Dold%20child's%20growth,32%20to%2037%20inches%20tall.

[21] "Noise Sources and Their Effects." *Noise Comparisons*, https://www.chem.purdue.edu/chemsafety/Training/PPETrain/dblevels.htm.

[22] Spellings, Margaret. "Typical Language Accomplishments for Children, Birth to Age 6 -- Helping Your Child Become a Reader." U.S. Department of Education, Education Publications Center, 15 Dec. 2005, https://www2.ed.gov/parents/academic/help/reader/part9.html.

[23] Bennett, Stacie. "When Do Kids Start Counting to 10?" Speech Blubs, 12 Feb. 2023, https://speechblubs.com/blog/toddler-activities-learning-numbers/#:~:text=Children%20don%27t%20actually%20start,often%20see%20this%20during%20playtime.

[24] "2-3 Years: Toddler Development." Raising Children Network, Australian Government Department of Social Services, 15 Dec. 2022, https://raisingchildren.net.au/toddlers/development/development-tracker-1-3-years/2-3-years#:~:text=At%202%2D3%20years%2C%20you,with%20others%20and%20cooking%20together.

[25] Thomas, Dr. Liji. "Importance of Sensory Stimulation for Babies." *News*, 28 Oct. 2022, https://www.news-medical.net/health/Importance-of-Sensory-Stimulation-for-Babies.aspx#:~:text=Taken%20together%2C%20sensory%20stimulation%20is,form%20attachments%20to%20other%20people.

[26]"Flying Sling Shot Shrieking Monkey Plush Toy." Progress Promotional Products, 31 Aug. 2022, https://www.progresspromo.com/product/flying-sling-shot-shrieking-monkey-plush-toy/.

[27] “Amazon.com: Dilwe Latex Tube, 16.4ft Elastic Band Tubing, 3mm ID/7mm OD ...” Amazon, https://www.amazon.com/Dilwe-Elastic-Slingshot-Catapult-Outdoor/dp/B08TGQB12F.

[28] “Liquid Silicone Rubber.” Factor2.Com, https://www.factor2.com/A_RTV_10_Liquid_Silicone_Rubber_p/a-rtv-4410.htm.

[29] *Code of Ethics for Engineers - National Society of Professional Engineers*. https://www.nspe.org/sites/default/files/resources/pdfs/Ethics/CodeofEthics/NSPECodeofEthicsforEngineers.pdf.

APPENDIX A

Included in this appendix are the various mind maps that were created by the team during our group ideation sessions. The first four (Figures A1 - A4 below) were made during the first iteration of our group concept generation, and were used as a visual brainstorm to help influence our second round of individual concept generation. The remaining mind maps (Figures A5 - A9 below) were a result of grouping together designs from our filtered toy idea list, which had similar characteristics. We wrote down the similar traits and brainstormed new ones that also fit the description that we had not thought about previously.

Figure A1: In order to create a toy design that meets all requirements and specifications, our team brainstormed attachment locations so that the toy cannot be easily displaced by the toddler. Since the toddler will ideally be using the toy during car travel, the locations we came up with are all possibilities of places where a toy could be tethered to inside a car.

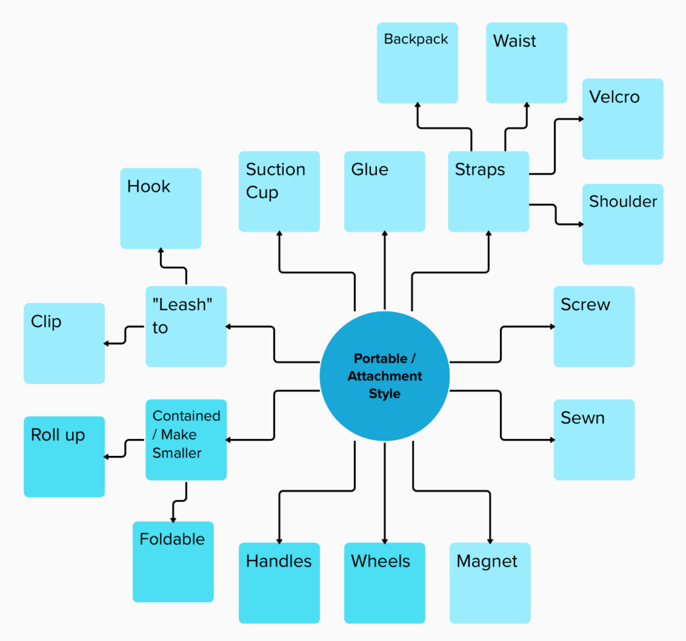


Figure A2: Our team brainstormed methods that would allow the toy to be attached to the locations listed in Figure A1 on the previous page. We also discussed ways in which the toy could be made easily portable, and included it in the map above due to many of the ideas being a solution to both situations.

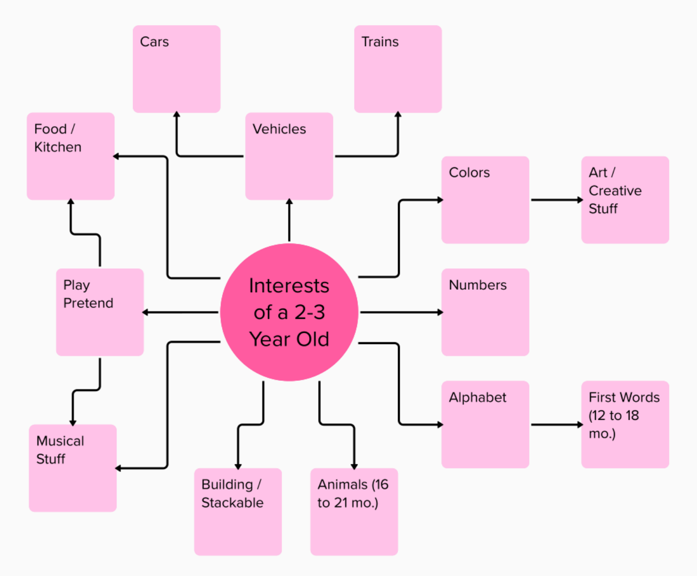


Figure A3: Our team discussed various interests of toddlers (2-3 years old) to increase the likelihood of the toddlers finding the toy entertaining enough to play with for more than or equal to 20 minutes. We also did not want to design a toy that requires too complex of an understanding or is not age-appropriate.

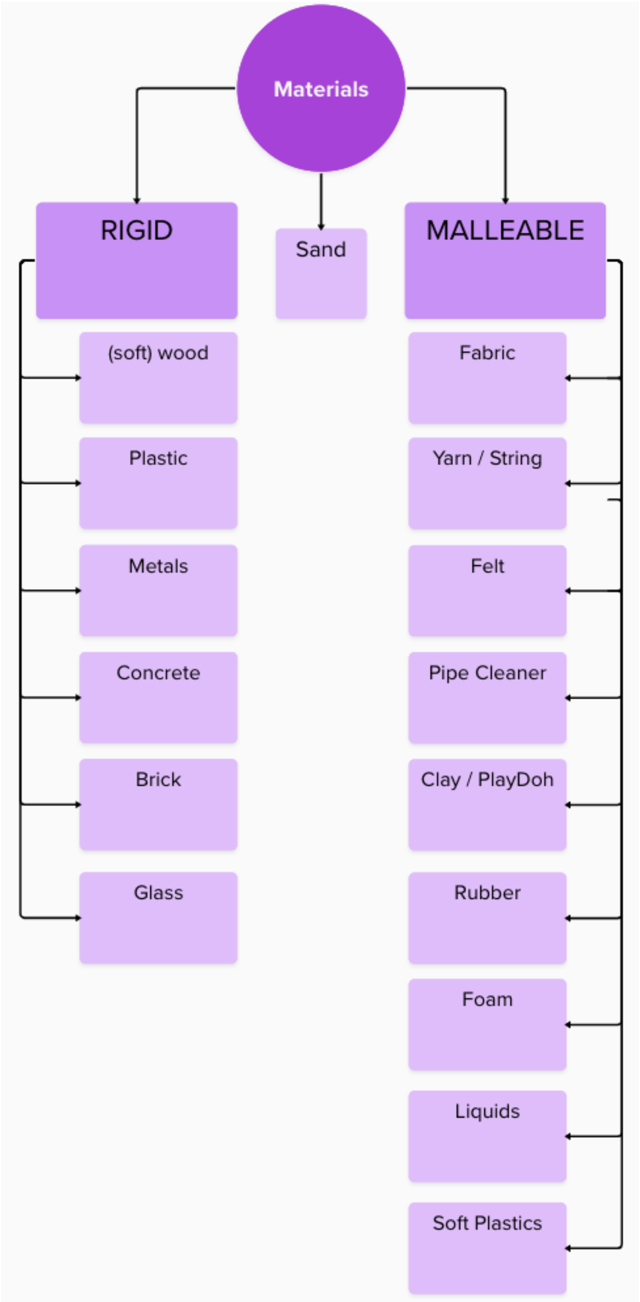


Figure A4: To inspire creativity and not be influenced by what is already on the toy market, we came up with a list of various materials that a toy could be made of. This map was to inspire our second round of individual concept generation, so safety considerations did not eliminate choices or effect which materials we included in the map. Although, in further iterations of design concept generation we did look into which of these materials would be safe for a toddler to use, as safety is deemed a high priority requirement by our team.

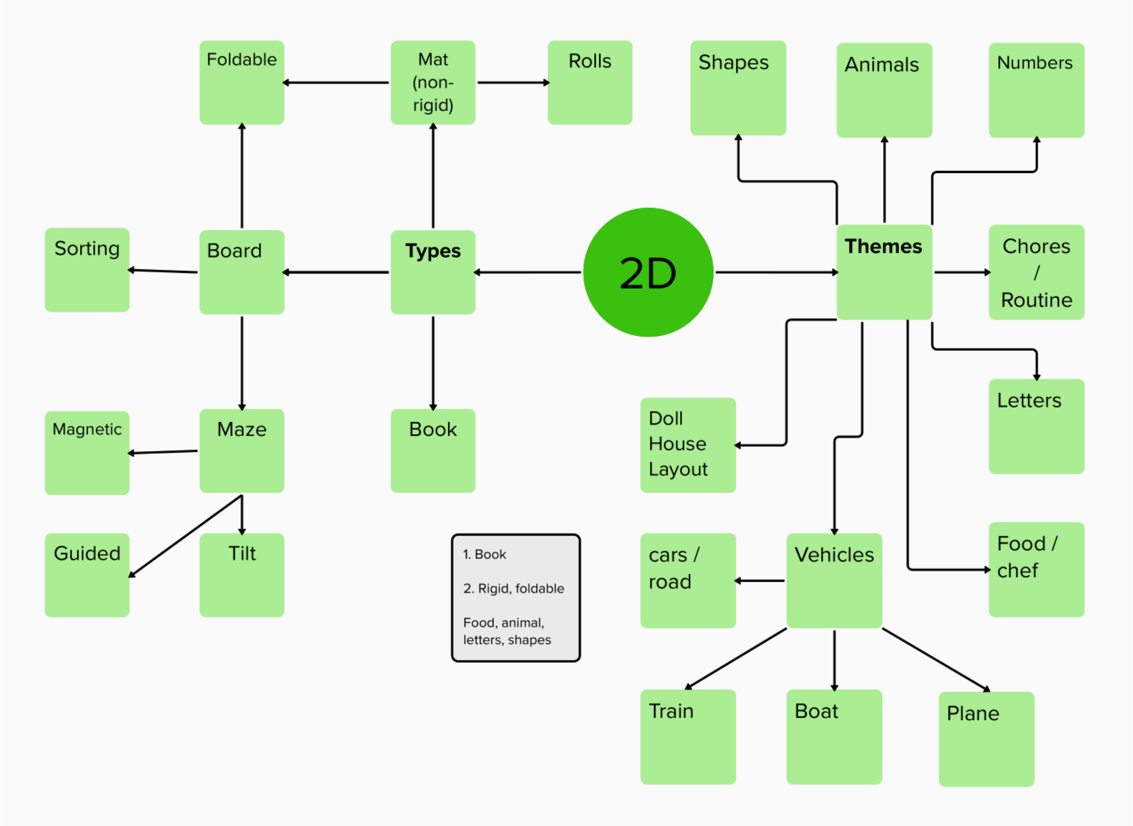


Figure A5: One of the groupings that our team decided to mind map was two dimensional toys. We analyzed some of the common traits that the designs of each of our individually brainstormed toys contained for this category and then expanded further upon them in order to potentially inspire more designs. We primarily focused on the types of two dimensional toys we could create as well as the potential themes of toys that we could create. Our themes connected to the interests of a 2-3 year old child mind map. We as a group voted on the top characteristics we believed a toy that fell in this category would contain, those being that it would be a book that is rigid and foldable, with the theme(s) of food, animals, letters and/or shapes as their central focus.

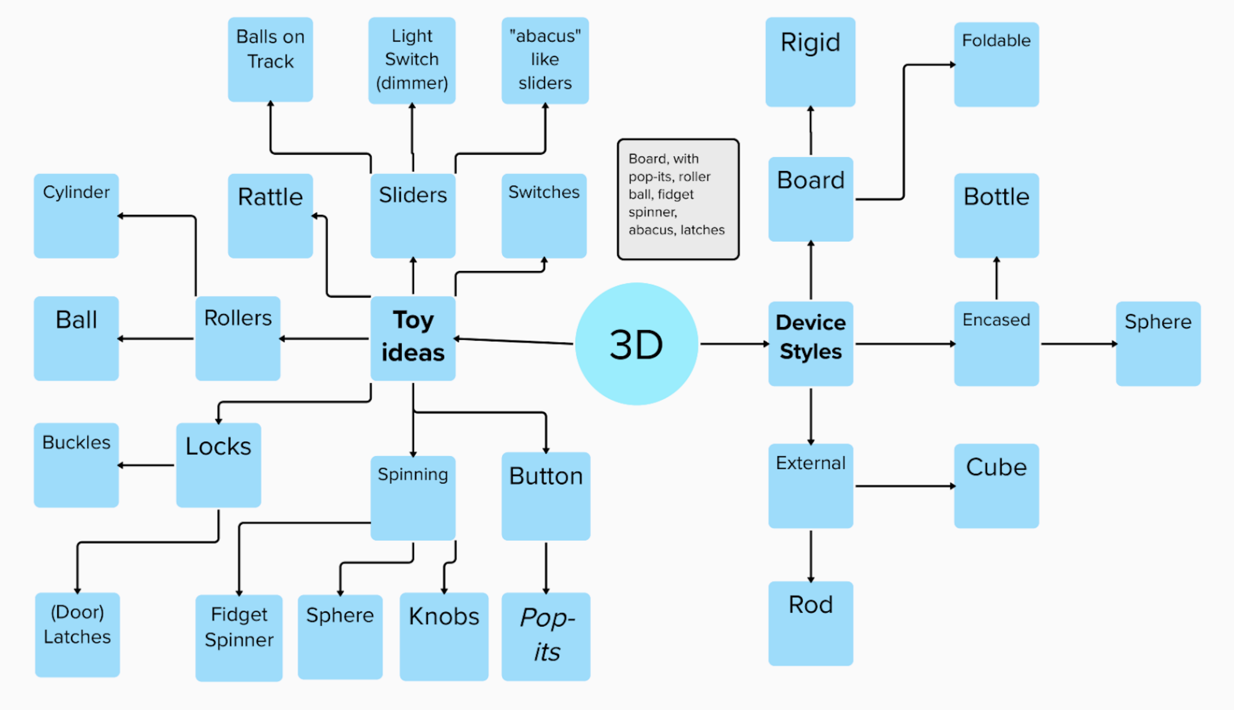


Figure A6: Another one of the groupings that our team decided to mind map was three dimensional toys. We, again, analyzed some of the common traits that the designs of each of our individually brainstormed toys contained for this category and then expanded further upon them in order to potentially inspire more designs. We primarily focused on the device style that a 3D toy would emulate, as well as specific features or toy ideas that could be represented. Again, we then voted as a group on the top characteristics that we thought that a toy that fell within this category would contain. We settled on the fact that the toy would be a board with the following: pop-its, roller balls, fidget spinners, abacuses, and latches.

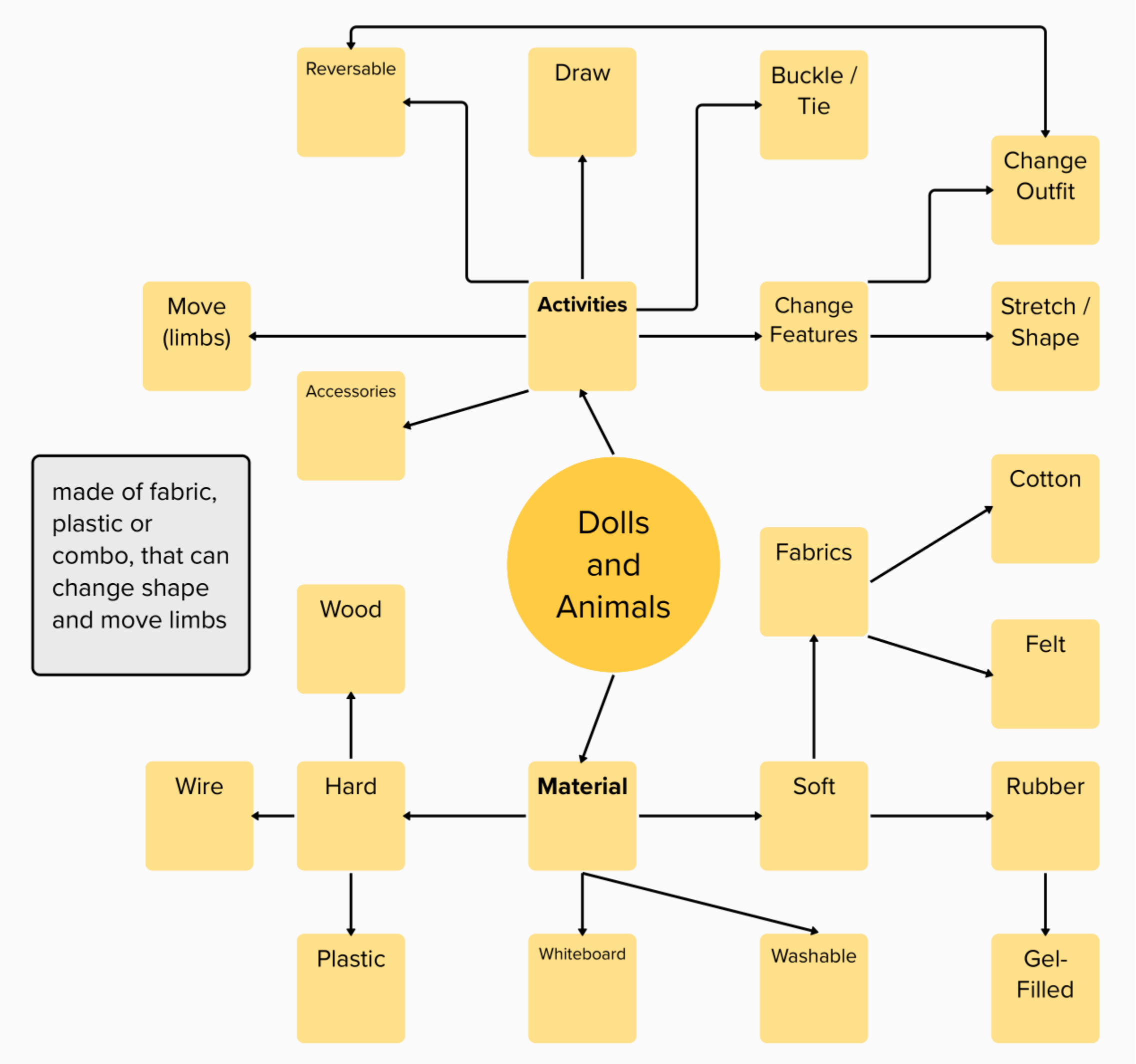


Figure A7: Another popular grouping amongst the ideas that we imagined in our individual sessions were dolls and animals, grouped together for simplicity. For this grouping, we dove into the types of activities that a doll or animal toy could perform as well as the type of material that this type of toy could be made of. We voted as a group and honed in on the fact that this type of toy should be made of fabric, plastic or a combination of the two, and that it should be able to change shape and move its limbs.

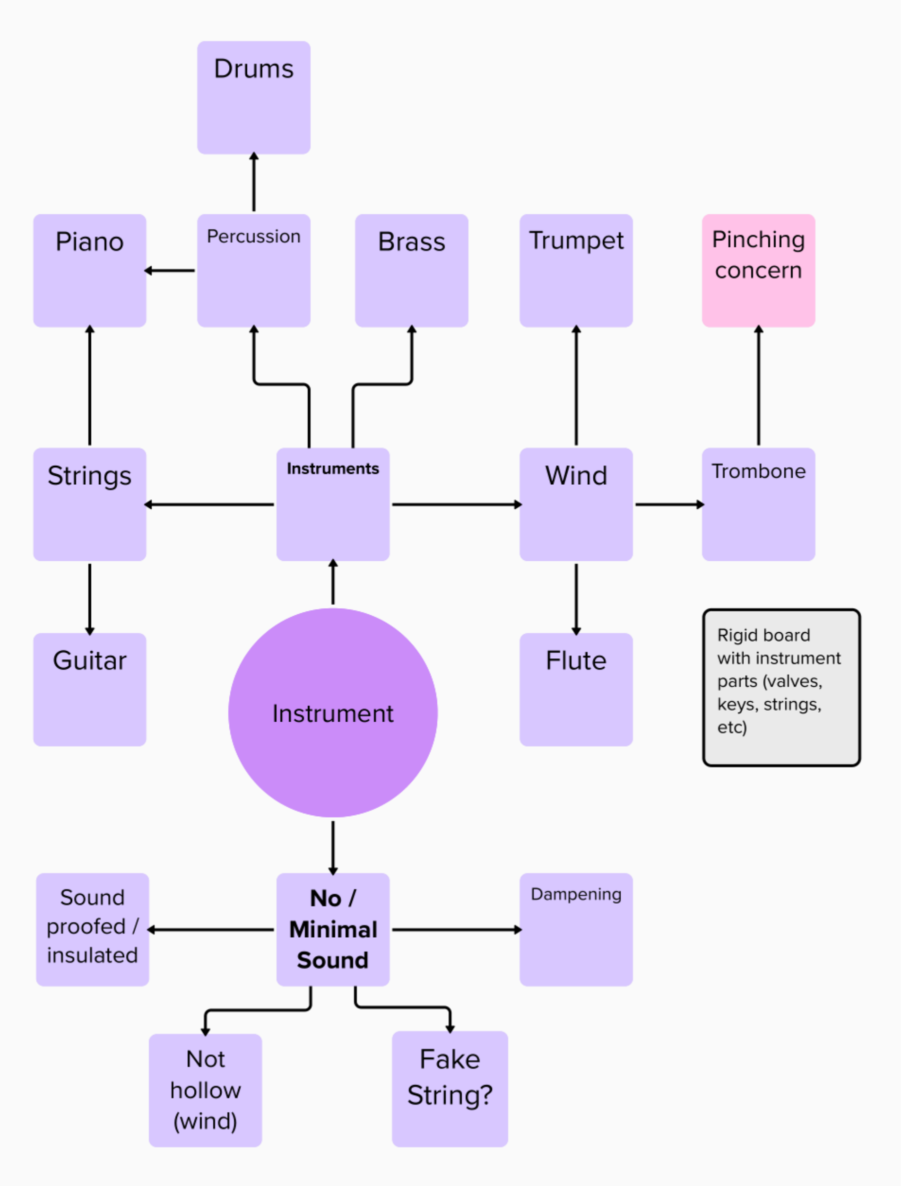


Figure A8: Another popular grouping of our individual ideas was inspired by instruments. One of our biggest concerns as it relates to these types of toys is that with sound they could be distracting within our use case setting. Therefore, we mind mapped how we could have either no or minimal sound for this type of toy in addition to the type of instrument that the toy could be representative of. We voted and decided on the fact that an instrument toy should be a rigid board with instrument parts such as valves, keys, strings, etc, and that it should make no noise and more so be for feel.

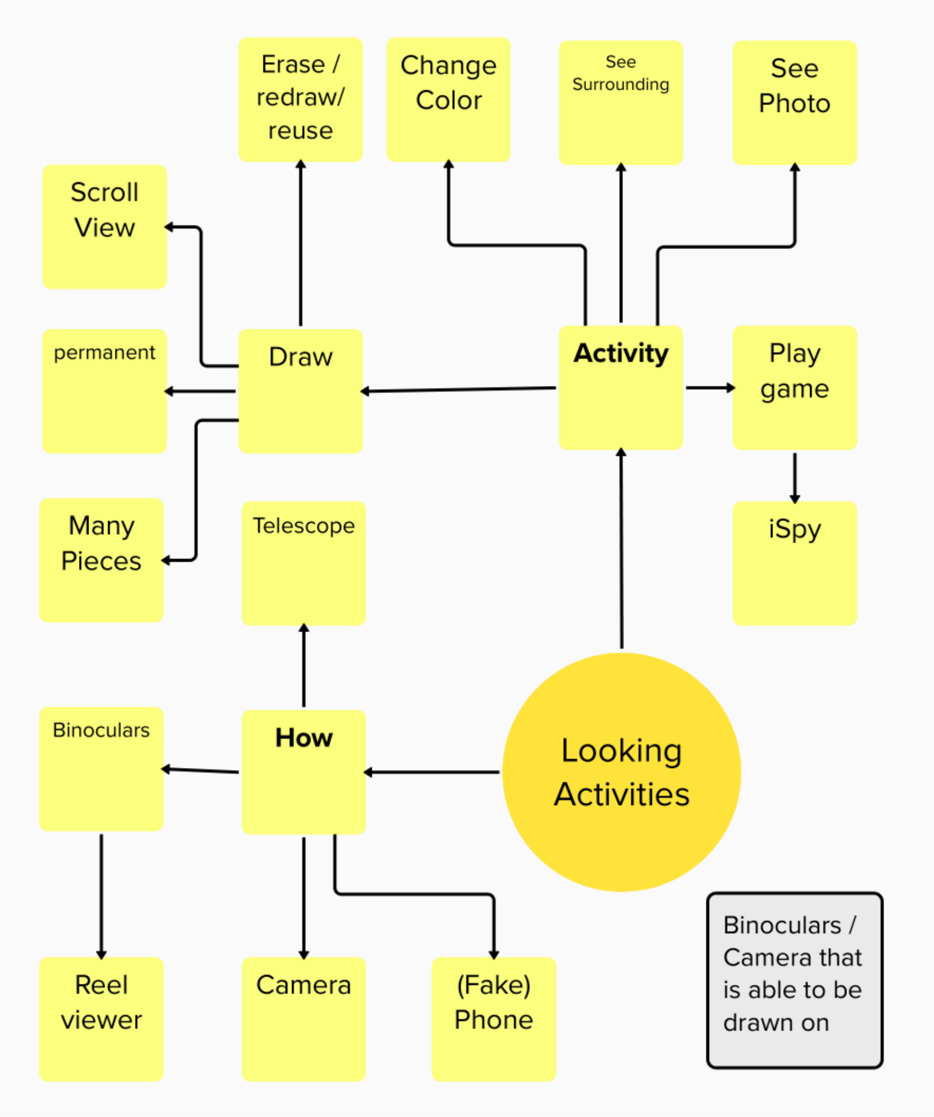
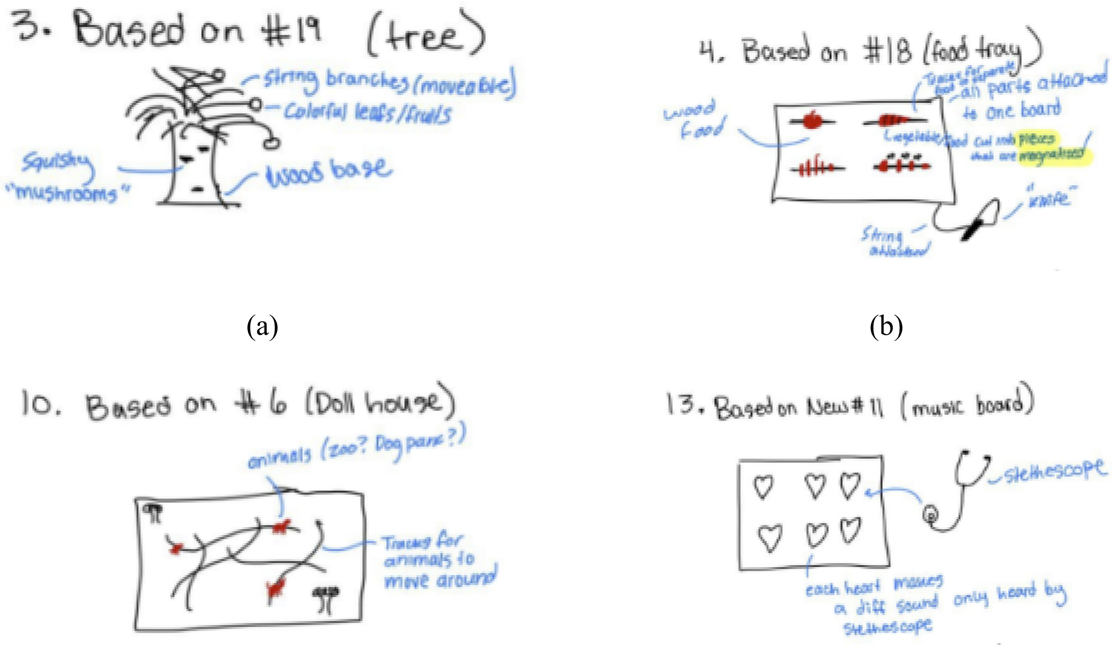


Figure A9: The last category of toy that we decided upon in terms of similarities amongst our individual ideas was looking activities. For this category, we decided to explore the type of activity a kid could perform with this toy as well as how the activity itself is performed. After voting, we determined that the best way for this toy to work would be to have binoculars or a camera that is able to be drawn on.

APPENDIX B

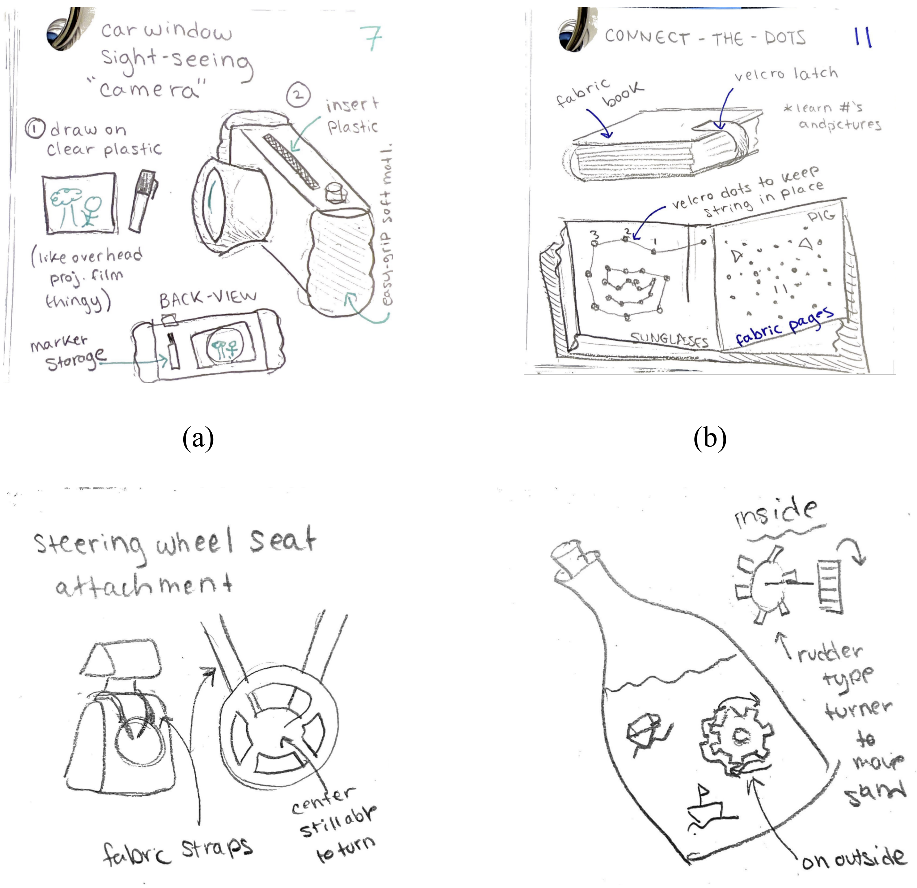
This appendix contains 17 of the design ideas that were individually developed by each team member throughout the course of our completion of the Concept Generation Learning Block. We have included them in this appendix to demonstrate how unsimilar the majority of our initial ideas were. We utilized many of the skills learned throughout the Block, including the fact that “no idea is a bad idea” in order to encourage creativity in the early stages of concept generation.



(a) (b)

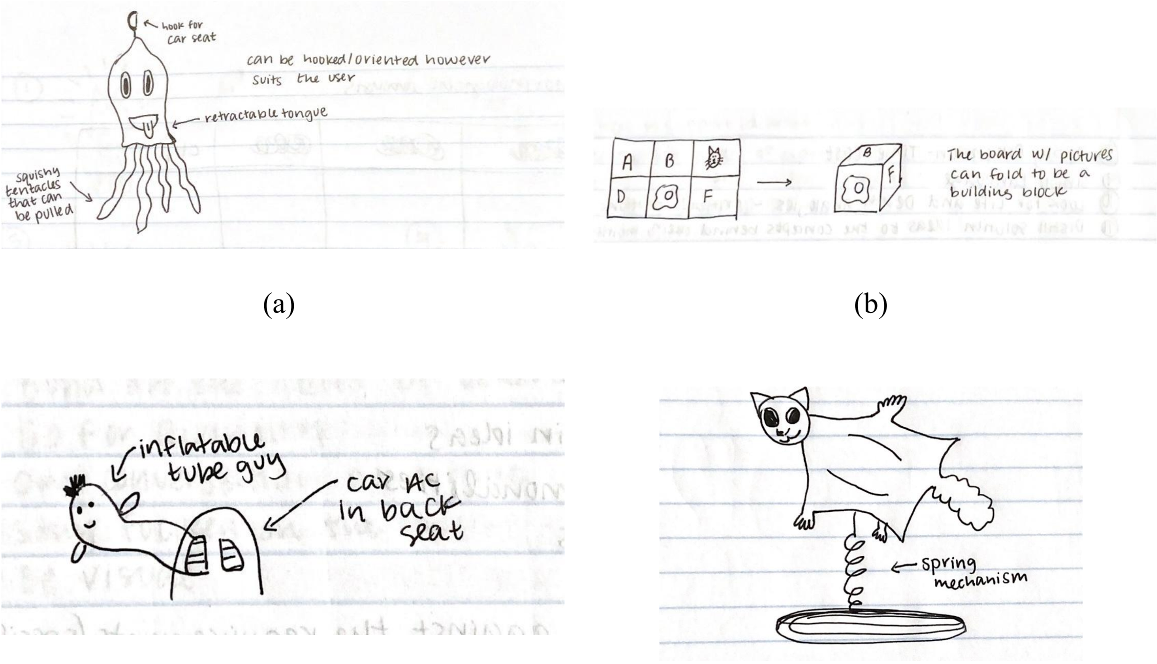
(c) (d)

Figure B1(a)-(d). The above images are the four designs that we narrowed down from Angela’s initial list of ideas. These ideas were selected using our “how much do we like it” methodology from our first round of screening.These ideas later showed back up in our mind maps in terms of types of toys or themes of toys that children would find entertaining. Figure B1(a) you can see a textured tree, which features many different components that have a different physical feel such as: squishy mushrooms, a silky strong wood base, and moveable string branches with colorful leaves and fruit. Figure B1(b) shows a food tray where the fruit pieces are abacus structures and there is an attachable knife to “cut” the fruit apart. Figure B1(c) shows a dollhouse where the dolls or characters on the interior of the house are on tracks and can slide around easily to simulate natural motion. Figure B1(d) is a heart board with an attached stethoscope. Each heart shape makes a different sound for the user to hear as they press the bottom of the stethoscope to the heart with the earpieces in.



(a) (b) (c) (d)

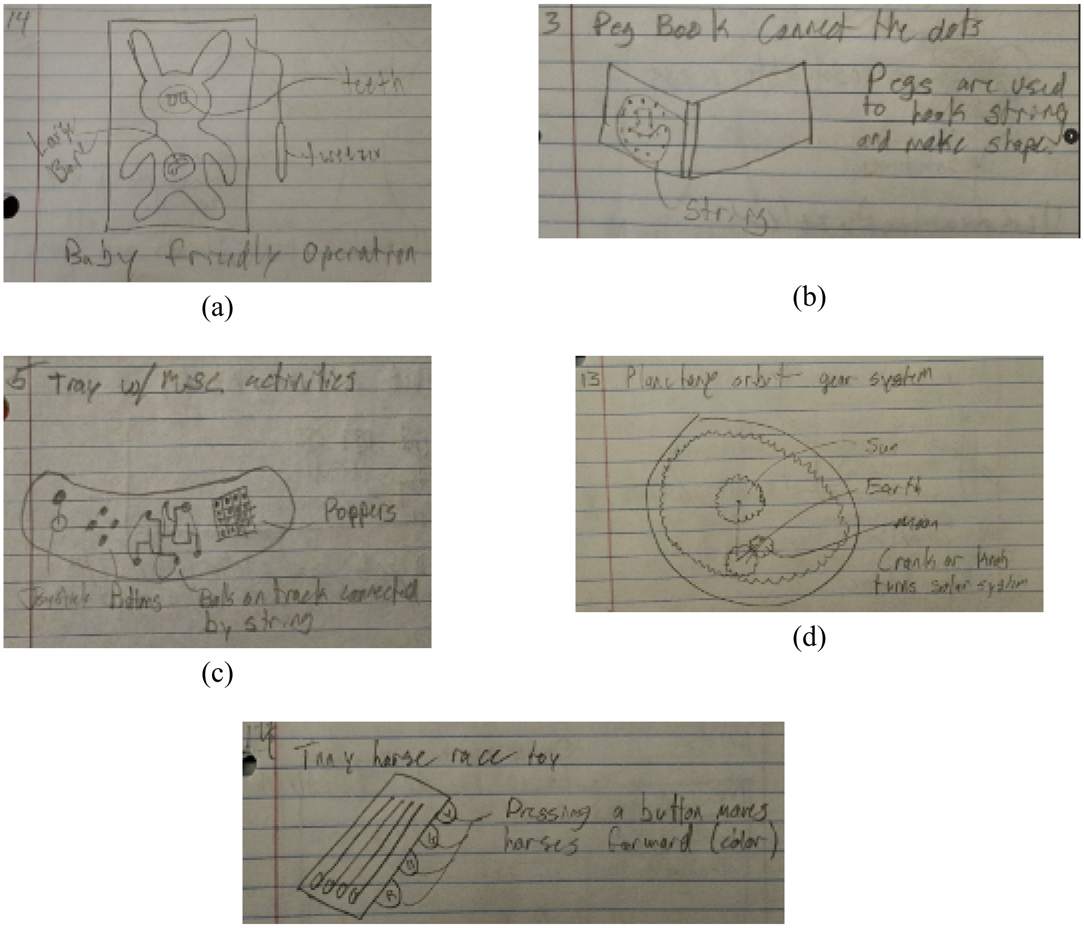
Figures B2(a)-(d). The four images above are the four designs that we narrowed down from Cayla's initial set of concept generation. Again, these ideas were selected based on the criteria of how much we liked them. These ideas later showed back up in our mind maps in terms of types of toys or themes of toys that children would find entertaining. Figure B2(a) shows a car window sight-seeing camera in which the child can draw on a clear plastic film and insert it into the camera for his or her viewing. This idea ended up influencing a mind map itself later on in our team's concept generation sessions. Figure B2(b) shows a felt connect-the-dots book. The booklet was to have a magnetic bookmark attached to the spine of the book that would act as the mechanism to connect the dots outlined by numbers 1-10. An example theme demonstrated is farm animals based off of things 2-3 year olds are interested in. Figure B2(c) shows a steering wheel that would attach to the seat in front of the child in a car setting. The child would be able to feel as though they are just like their parent, twisting and turning the steering wheel however they please. Figure B2(d) shows a tilt and search bottle. The idea with this toy is that there would be hidden ships and loot to adhere to a pirate theme. There would be a rudder type mechanism that would help turn the sand for the child as they tilted the toy from left to right, up and down.



(a) (b)

(c) (d)

Figures B3(a)-(d). The images above are indicative of the four designs we narrowed down from Sedona's initial set of concept generation. Again, these ideas were selected based on the criteria of how much we liked them. These ideas later showed back up in our mind maps in terms of types of toys or themes of toys that children would find entertaining. Additionally, as noted earlier in the report, although the interactive squid was one of the initial designs from a member of our team, we did not have any bias towards the selection of this idea from the beginning of our design process. The design simply reappeared in multiple rounds of our concept generation. Figure B3(a) shows the interactive squid in its initial phase. The squid was to have a hook on top of its head so as to attach itself to either the seat in front of the child of the grab handle, to have pullable arms that made the tongue and eyelids go in and out and open and close respectively, and to have squishy to feel tentacles. Figure B3(b) shows a foldable block with letters on it. The idea behind this toy was that the box would be able to unfold to a flat board and each letter would be able to slide open and closed to reveal a photo of an item or food that began with the letter (shown in the sketch, E is for egg). Figure B3(c) shows an inflatable tube guy, similar to those that you may find at a car dealership. It attaches itself to a car's backseat AC system, allowing itself to swish in the breeze. Figure B3(c) shows a flying squirrel attached to a spring. The idea with this toy is that it would sit in the lap of a child and bounce in any which way the child pushed it as a result of the spring mechanism.



(a)

(b)

(c)

(d)

(e)

Figures B4(a)-(e). The five images above are representative of Sam's ideas in our initial phase of individual concept generation. Again, these ideas were selected based on the criteria of how much we liked them. These ideas later showed back up in our mind maps in terms of types of toys or themes of toys that children would find entertaining. Figure B4(a) shows the idea of baby-friendly operation. This toy would function as Operation, the toy already on the market, does, except the cavities and pieces to withdraw would be much larger. Figure B4(b) shows a similar concept to the idea shown in B2(b). This toy would be a connect-the-dots book with some type of string attached to the spine of the book to use to connect the dots numbered 1-10, however, instead of magnets as shown in B2(b) this idea would have raised pegs to wrap the string around. Figure B4(c) shows the concept of an activity board with miscellaneous entertaining "fidget" activities. The board contains poppers, balls on a track connected by strings, buttons, and a joystick. Figure B4(d) shows the idea of a planetary orbit gear system. The idea behind this toy was that the moon, sun, and the Earth would all be on a gear track that rotates based on the user pulling a crank or twisting a knob. This toy would allow a child to conceptualize our solar system at a very low level. Figure B4(e) shows a tiny horse race toy. This toy would be best used with many children, as it shows four different tracks with four different associated buttons. Each child would push the button rapidly to advance their tiny horse to the finish line.

APPENDIX C
This appendix includes a chart with combined verification and validation plans for each one of our requirements and specifications.

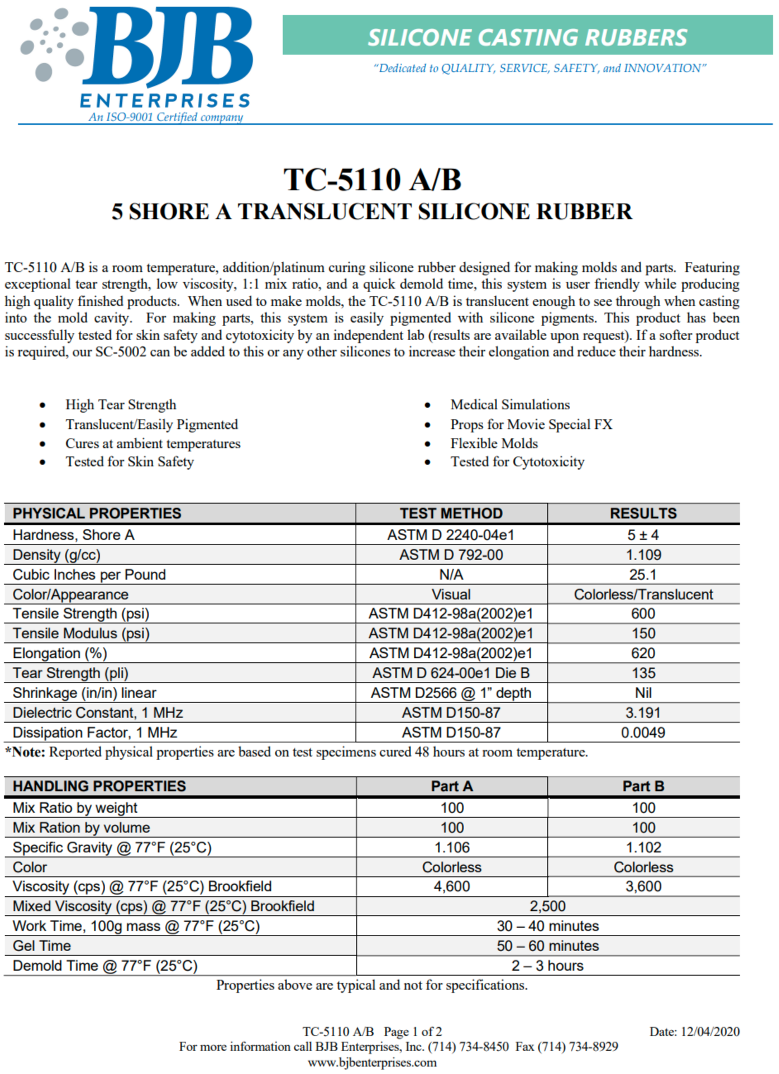
Table C1. The table below describes whether each requirement and specification must be verified or validated, what the verification or validation plan is, and when we plan to execute these plans.

Requirements	Specifications	Verification or Validation	Testing	Date
Portable: Adequate size for toddler to play in a car	- Weight: ≤ 2 pounds	Verification	Weigh the final object	4/12
Portable: Easy for caretaker to pack and transport to various locations	- Able to fit on toddlers lap (33x33x33cm / 13x13x13in)	Verification	Measure the final object; we are making sure in CAD that our size is acceptable	4/12
Safe: Materials toys are comprised of are not harmful to children	- Toy has a burn rate averaged over 4 tests is less than 0.1 in/s [11] - Material used in toy production is previously found to be nontoxic [11] - Toy edges should not produce a cut in polytetrafluoroethylene tape longer than ½ inch, as per a sharp edge test [18] - Proper "Warning" and "Caution" labels on the toy that identifies potential hazards [11]	Verification	Outside of scope – just planning to select safe materials based on the ASTM Standards	3/27
Safe: No toy parts are small enough to be a choking hazard	- Small parts test figure (SPTF) — a truncated cylinder with diameter of 3.17 cm/1.25 inch simulating the mouth and a depth of 2.54-5.71 cm/1-2.25 inch simulating the pharynx [9] - Proper "Warning" and "Caution" labels on the toy that identifies potential hazards [11]	Verification	Torsion Test Tensile Test Compression Test Drop Test FEA	4/14 to 4/24
No screens	- Zero screens on toy	Validation	Ours has no screen, unnecessary	4/14
Non-distracting to surrounding people	- ≤ 50 dB - On/off function for sounds	Verification & Validation	Survey / small group testing; ensure parents are not distracted by it in a car	4/14

Cannot be easily displaced by child	- ≤ 5 pieces - Toy has a mechanism that attaches it to the front seat or grab handle in the car so that it can be retrieved by the child if dropped	Verification & Validation	Count the number of pieces Inclusion of a leash or clip with string; able to hold the weight / support it ; attached somewhere convenient	4/14
Keeps a child occupied for duration of travel	- Child is occupied for ≥ 20 min	Validation	Survey → dives more into validation which is outside class scope but we can discuss any further user testing plans we could maybe do after the class ends → observation of a small group of children, maybe in a class setting	4/14 to 4/24
Competitive Pricing in relation to similar toys on the market	- Sells for ≤ $35 per toy	Verification & Validation	Survey / budgeting info → take a look at how much it costs us to manufacture / estimate if mass manufactured process → survey results (before and after) final design “would you be willing to pay…?” (consider bias)	4/14 to 4/24
Child will not be able to permanently deform toy while playing with it	- Uses: 360 times, 20 min duration each play -Toy can be dropped 4 times from a height of 3 ft ± 0.5 in without breaking [11] - Toy can withstand an applied torque of 3 ± 0.2 in-lbf clockwise and counterclockwise without breaking [11] - Toy can withstand 15 ± 0.5 lbf applied in tension parallel and perpendicular to major axis without breaking [11] - Toy can withstand 25 ± 0.5 lbf in compression without breaking [11]	Verification	Torsion Test Tensile Test Compression Test Drop Test FEA → wait to complete some of these until after Expo , discuss project challenge of what happens if the whole thing breaks during any one of these tests	3/28 4/14

APPENDIX D

In order to create our injection molded silicone based tentacles, we used the following silicon material: *TC-5110 A/B 5 Shore A Translucent Silicone Rubber*. The specifications for the silicon are in Figure D1 on pages 66 and 67.



BJB ENTERPRISES
An ISO-9001 Certified company

SILICONE CASTING RUBBERS

"Dedicated to QUALITY, SERVICE, SAFETY, and INNOVATION"

TC-5110 A/B

5 SHORE A TRANSLUCENT SILICONE RUBBER

TC-5110 A/B is a room temperature, addition/platinum curing silicone rubber designed for making molds and parts. Featuring exceptional tear strength, low viscosity, 1:1 mix ratio, and a quick demold time, this system is user friendly while producing high quality finished products. When used to make molds, the TC-5110 A/B is translucent enough to see through when casting into the mold cavity. For making parts, this system is easily pigmented with silicone pigments. This product has been successfully tested for skin safety and cytotoxicity by an independent lab (results are available upon request). If a softer product is required, our SC-5002 can be added to this or any other silicones to increase their elongation and reduce their hardness.

- High Tear Strength
- Translucent/Easily Pigmented
- Cures at ambient temperatures
- Tested for Skin Safety
- Medical Simulations
- Props for Movie Special FX
- Flexible Molds
- Tested for Cytotoxicity

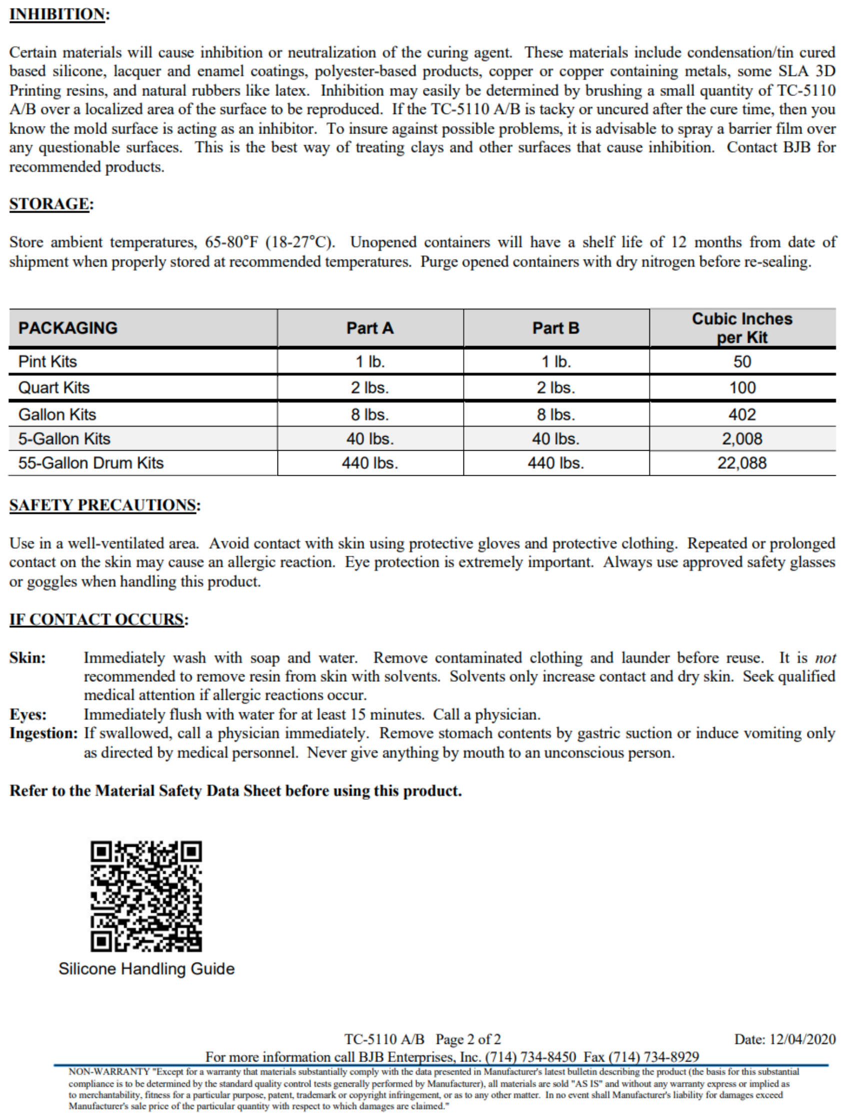
PHYSICAL PROPERTIES	TEST METHOD	RESULTS
Hardness, Shore A	ASTM D 2240-04e1	5 ± 4
Density (g/cc)	ASTM D 792-00	1.109
Cubic Inches per Pound	N/A	25.1
Color/Appearance	Visual	Colorless/Translucent
Tensile Strength (psi)	ASTM D412-98a(2002)e1	600
Tensile Modulus (psi)	ASTM D412-98a(2002)e1	150
Elongation (%)	ASTM D412-98a(2002)e1	620
Tear Strength (pli)	ASTM D 624-00e1 Die B	135
Shrinkage (in/in) linear	ASTM D2566 @ 1" depth	Nil
Dielectric Constant, 1 MHz	ASTM D150-87	3.191
Dissipation Factor, 1 MHz	ASTM D150-87	0.0049

***Note:** Reported physical properties are based on test specimens cured 48 hours at room temperature.

HANDLING PROPERTIES	Part A	Part B
Mix Ratio by weight	100	100
Mix Ration by volume	100	100
Specific Gravity @ 77°F (25°C)	1.106	1.102
Color	Colorless	Colorless
Viscosity (cps) @ 77°F (25°C) Brookfield	4,600	3,600
Mixed Viscosity (cps) @ 77°F (25°C) Brookfield	2,500	
Work Time, 100g mass @ 77°F (25°C)	30 – 40 minutes	
Gel Time	50 – 60 minutes	
Demold Time @ 77°F (25°C)	2 – 3 hours	

Properties above are typical and not for specifications.

TC-5110 A/B Page 1 of 2 Date: 12/04/2020
For more information call BJB Enterprises, Inc. (714) 734-8450 Fax (714) 734-8929
www.bjbenterprises.com



INHIBITION:

Certain materials will cause inhibition or neutralization of the curing agent. These materials include condensation/tin cured based silicone, lacquer and enamel coatings, polyester-based products, copper or copper containing metals, some SLA 3D Printing resins, and natural rubbers like latex. Inhibition may easily be determined by brushing a small quantity of TC-5110 A/B over a localized area of the surface to be reproduced. If the TC-5110 A/B is tacky or uncured after the cure time, then you know the mold surface is acting as an inhibitor. To insure against possible problems, it is advisable to spray a barrier film over any questionable surfaces. This is the best way of treating clays and other surfaces that cause inhibition. Contact BJB for recommended products.

STORAGE:

Store ambient temperatures, 65-80°F (18-27°C). Unopened containers will have a shelf life of 12 months from date of shipment when properly stored at recommended temperatures. Purge opened containers with dry nitrogen before re-sealing.

PACKAGING	**Part A**	**Part B**	**Cubic Inches per Kit**
Pint Kits	1 lb.	1 lb.	50
Quart Kits	2 lbs.	2 lbs.	100
Gallon Kits	8 lbs.	8 lbs.	402
5-Gallon Kits	40 lbs.	40 lbs.	2,008
55-Gallon Drum Kits	440 lbs.	440 lbs.	22,088

SAFETY PRECAUTIONS:

Use in a well-ventilated area. Avoid contact with skin using protective gloves and protective clothing. Repeated or prolonged contact on the skin may cause an allergic reaction. Eye protection is extremely important. Always use approved safety glasses or goggles when handling this product.

IF CONTACT OCCURS:

Skin: Immediately wash with soap and water. Remove contaminated clothing and launder before reuse. It is *not* recommended to remove resin from skin with solvents. Solvents only increase contact and dry skin. Seek qualified medical attention if allergic reactions occur.

Eyes: Immediately flush with water for at least 15 minutes. Call a physician.

Ingestion: If swallowed, call a physician immediately. Remove stomach contents by gastric suction or induce vomiting only as directed by medical personnel. Never give anything by mouth to an unconscious person.

Refer to the Material Safety Data Sheet before using this product.

Silicone Handling Guide

TC-5110 A/B Page 2 of 2 Date: 12/04/2020

For more information call BJB Enterprises, Inc. (714) 734-8450 Fax (714) 734-8929

Figures D1. The two page specifications of the silicon material we used for created our injection molded tentacles. The material is *TC-5110 A/B 5 Shore A Translucent Silicone Rubber.*

APPENDIX E

E.1. Bill Of Materials

In order to predict the final manufacturing cost of each toy and validate our price range that we set in the requirements and specifications, our team kept track of the materials bought and used during the initial prototyping stages. The materials and cost per part are organized in the following bill of materials (BOM). As a note, we 3D printed multiple parts, which we did not receive a quote for. Thus, we approximated the cost of each part based on its volume converted into kilograms and then used the knowledge that one spool of PLA 3D printing material costs around $18.99 (on Amazon) and produces 1 kg of product per spool to calculate the price per part. According to the BOM in Table E1 below, the total cost to manufacture this toy was $28.94, which would confirm our selling price range is not too low, and potentially make us a profit.

Table E1. The BOM below documents the descriptions of the materials bought and used to prototype the toy, which part of the toy the material belongs to, the quantity used in our prototype, the cost of the package, the cost per unit, and the total cost for the whole toy. Adding up all costs, our group spent $28.94 on the total toy.

Description	Part of Toy	Quantity	Units	Cost of Package	Cost per Unit	Total for Toy
Elastic Latex Hose	Arms	40	inches	$12.99	$0.03	$1.32
Plastic Safety Eyes	Head	2	eyes	$9.99	$0.02	$0.04
Fuzzy fabric for head (Blue Ashes SL)	Head	0.05	yards^2	$5.40	$7.20	$0.36
Soft fabric for arms (Medieval Blue Pure Plush)	Arms	0.2	yards^2	$5.00	$6.67	$1.33
Sewing thread	Arms	1	yards	$4.49	$5.99	$5.99
FDM 3D Printing for inner mechanism	Inner Mechanism	8	parts	N/A	N/A	$2.50
Eye lever		1	parts	N/A	$0.23	$0.23
Eyelids		2	parts	N/A	$0.00	$0.01
Head of squid		1	parts	N/A	$2.12	$2.12
Pivot rod		1	parts	N/A	$0.03	$0.03
Tongue lever - pivot		1	parts	N/A	$0.08	$0.08
Tongue lever - rigid		1	parts	N/A	$0.01	$0.01
Tongue		1	parts	N/A	$0.02	$0.02
Silicon elastomer for injection molding	Legs	8	oz	$61.95	$1.94	$15.49
Fabric for leash (Medieval Blue Pure Plush)	Attachment	0.0625	yards^2	$5.00	$6.67	$0.42
Clip for leash	Attachment	1	clip	$3.00	$1.50	$1.50
					Total Cost of Toy	$28.94

E.2. Manufacturing Plan

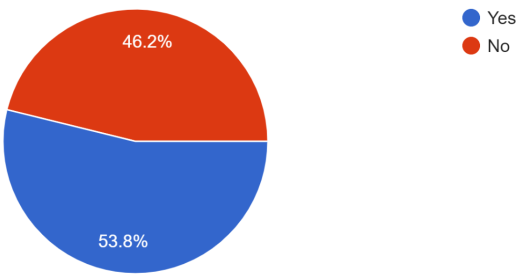
Since we only created one toy, but in the real world the toy would be mass manufactured, thinking through and writing up a manufacturing plan is vital to the success of our squid toy long term. Our manufacturing plan includes the materials and manufacturing processes for each individual part of the toy (organized by the section of the toy) and how to assemble the various parts of the toy in a manufacturing setting. A brief discussion was made about critical tolerances for each part/process as well.

Toy Part	**Material**	**Manufacturing Process** *Machine tools/operations*	**Critical Tolerances / Considerations**
Head / Inner Mechanism	Resin → *Red for tongue* → *Blue for all other parts*	SLA 3D printing *(1) Print the material on SLA printer* *(2) Post processing of the part* → *Washing* → *Curing* → *Sanding (if necessary)* Then assemble all parts together, including adding the elastic hose through the parts. Glue on eyes as well.	→ Holes for elastic hose to go through can be 0.02 inches larger than the outer diameter of hose. → Holes for support rod to fit through should be 0.02 inches larger in diameter. → Slot for tongue and eyes to go through the head shell should be 0.015 inches larger on each constraining side.
Leg Tentacles	Silicon	Injection molding *(1) Print the tentacle mold using SLA printer* *(2) Mix two parts (A & B) of silicon together* *(3) Inject silicon mix into the mold* *(4) Let set for ~12 hrs* *(5) Release tentacles from the mold and repeat for all 6 legs* *(6) Trim off flash/excess material from molded silicone part*	Ensure injection sites/holes and air release holes have enough tolerance to still function when part is printed. → Injection site must be at least 1 mm in diameter → Air release holes must have a diameter of at least 0.5 mm
Fuzzy head fabric (attachment)	Blue Ashes SL Fabric	(1) Use a robot/assembly line roller to cover the cone part of the head shell with a thin layer of fabric glue. (2) Roll the fuzzy fabric onto the head and cut off excess	N/A
Fabric body (“pants”) squid	Medieval Blue Pure Plush Fabric	(1) Cut out fabric for long arm tentacles (using a stencil) and fabric “pants” (2) Sew (with sewing machine) the arms tentacle cut outs together, then sew those to the “pants” fabric. (3) Insert silicon leg tentacles into “pants” and insert elastic hose through fabric arms. (4) add a thin layer of fabric glue to the lower part of the head shell and slide pants onto the head shell. (5) Perform a final round of sewing to ensure all parts of the toy are closed and secured.	Silicon leg holes must be big enough so that the legs can fit through, but small enough so that they don’t fall out.

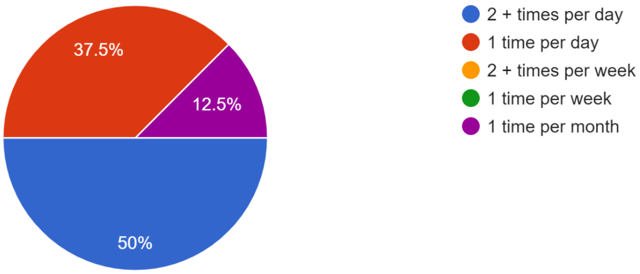
APPENDIX F

An initial validation survey was sent to parents or caretakers of children ages 0 - 8 years old, preferably 2 - 5 years old, to validate our previously found background information and gauge their initial thoughts on the alpha design concept. After sending out the survey, we received 13 responses, all of which had or took care of children younger than 5 years old. The remaining results can be seen in the Figures E1-E5 below.

Is your child allowed to play with a Smartphone/iPad/Tablet in a car (travel) setting?
13 responses



If yes, how often are they allowed to use it?
8 responses



If yes, how long are they allowed to use it?
9 responses

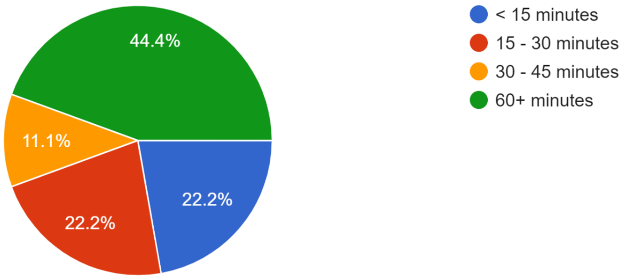
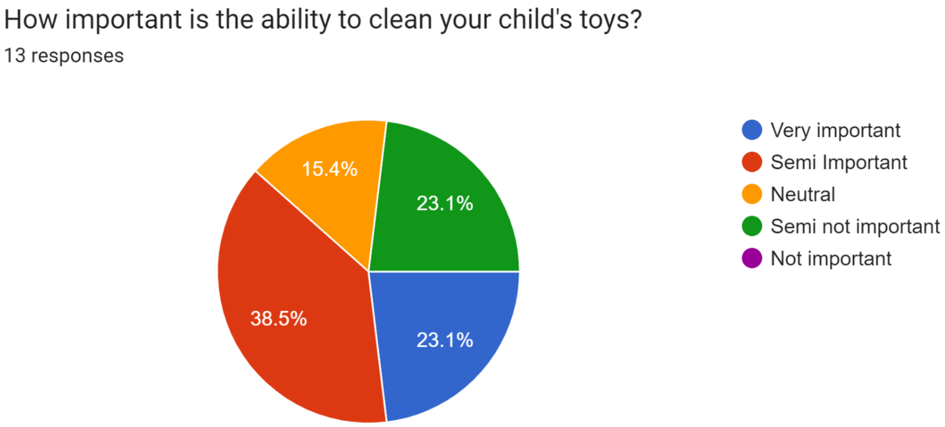
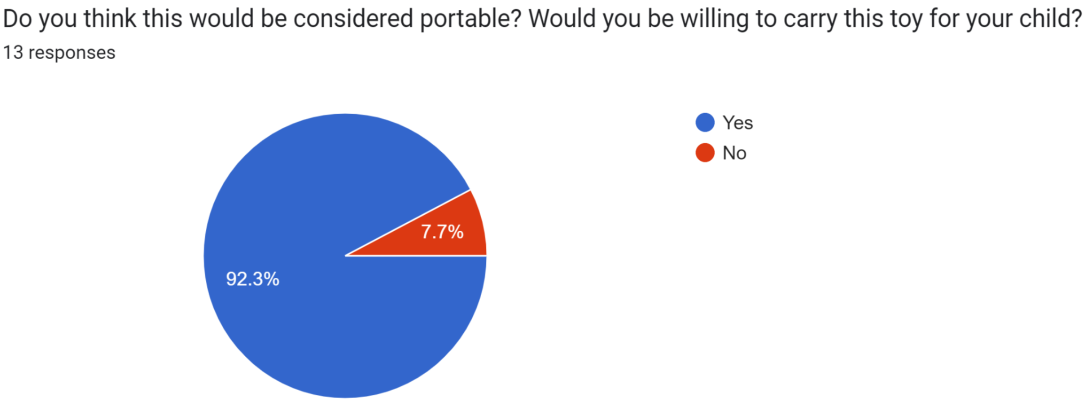


Figure F1. The three related questions above were used to validate our background research on current children's usage of screens during travel. According to the survey, 53.6% of the respondents allow their children to play with a screen device in the car during traveling. Of those that said yes 50% said they can play more than once a day, while the other 50% said their kids cannot play more than once a day. Also, 44.4% of participants said that their kids are allowed to play for more than 60 minutes, while only 22.2% said they are only allowed to play for under 15 minutes.


How important is the ability to clean your child's toys?

13 responses

Figure F2. While determining the materials that we plan to prototype and build our final design with, we wanted to weigh the importance of ease of cleaning to parents and caretakers. After seeing the results, we can see that no respondents voted for very important, but 38.5% did say it was semi-important. Knowing this, our team has taken into consideration how easy the material is to clean as we have been choosing fabrics, silicone materials, and other elements of the squid.

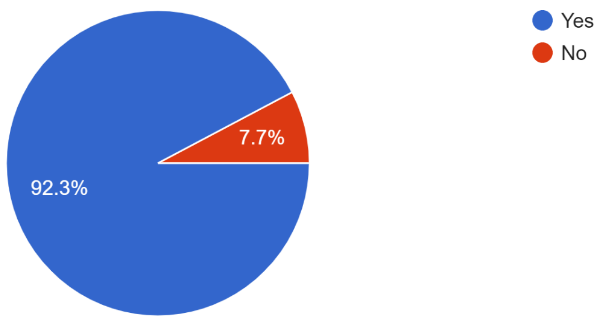

Do you think this would be considered portable? Would you be willing to carry this toy for your child?

13 responses

Figure F3. Although there are ways to measure portability of the toy, which we have outlined in our specifications, we wanted to verify that parents and caretakers find the toy easily portable. Our initial survey said that 92.3% of the participants would consider this toy to be portable or would be willing to carry this toy for their child. Due to the positive results, we do not believe that we have to make any significant changes to the size or shape of the toy.

If you saw this toy at a store, would you consider buying it for your kid?

13 responses



If yes, what is the maximum price range that you would be willing to pay for this?

13 responses

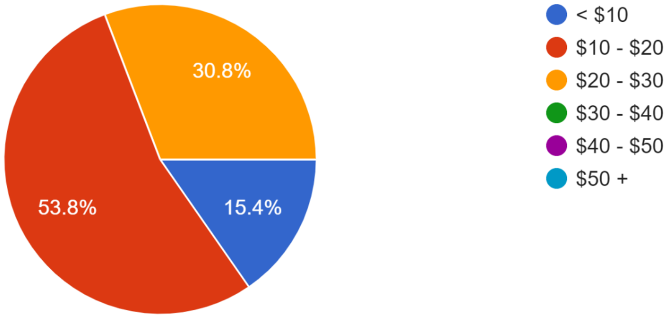


Figure F4. The two questions above were included in the initial survey to gain an understanding of if parents and caretakers would buy this toy if it were out in stores. This is the only method that our team came up with to try and employ to gauge the toy's future success on the market, even if it is on a much smaller scale. 92.3% of the participants did say they would buy this toy for their kid, and all that said yes confirmed they would only pay a maximum of $30. The maximum price range results helped validate our specification choice of a price that is less and or equal than $35.

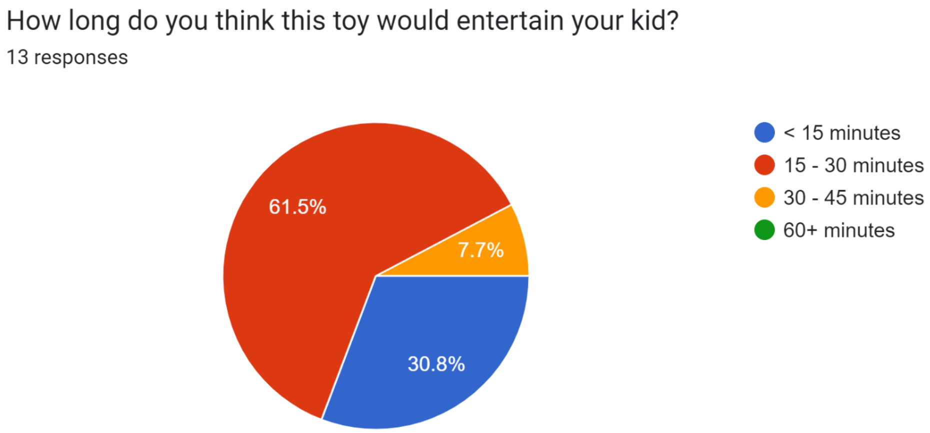


Figure F5. The most efficient way that our group could come up with to initially test the duration of entertainment in the scope of the semester is through a survey question. 69.2% of the respondents validate our entertainment specification of over 20 minutes, because the results say that they would predict their kids would play with the toy for longer than 15 minutes.

APPENDIX G

In order to verify the elastic string and 3D printed components that we are planning to use in our final design will meet the ASTM Toy Standards [11], we performed multiple tensile force trials with a digital force gauge. The 3D printed parts needed to withstand a force of at least 15.5 lbs, whereas the string needed to remain intact after a much lower force of at least 5 lbs. During the string tests, the 4 inch string sample used was attached to the gauge by Zip Tie and was pulled until the reported force was over 5lbs. This was repeated five times on the same string and no signs of wear were evident after the stretching. The results of the pulls were recorded in Table F1 below.

Table F1. Seen below are the forces that were achieved for each tensile force trial that was performed on the 4 inch sample string. These results were obtained by a digital force gauge. It is important to note that after all 5 trials on the same string there were no visible signs of wear or breakage.

Trial	Force (lbs)
1	**5.42**
2	**5.23**
3	**5.18**
4	**5.1**
5	**5.06**

TEAM MEMBER BIOS

Angela Peterson

From: Waterford, MI

Why Mechanical Engineering?
When I was first trying to choose an engineering discipline, I filtered through all possible options and landed on Mechanical Engineering, because of how broad it is and how hands on you get to be. Not only that, but I have an interest in many areas (food industry, waste and sustainability, and medical devices) and I felt ME was one of the few disciplines that would allow me to pursue any of those interests.

Future Plans:
I will be graduating in May 2023 with my BSE in Mechanical Engineering and a minor in German. Post graduation I will be moving to Minnesota to work at General Mills as a Manufacturing Engineering Associate at their Chanhassen Plant.

Fun Facts:
I am scuba diving certified, I have run a marathon and my favorite place I have ever traveled is Japan.

Cayla Kadets

From: Shelby Township, MI

Why Mechanical Engineering?
Throughout high school, I always enjoyed and performed well in STEM focused classes. I also loved to take various art and design classes. I figured that engineering would be a career path that would allow me to participate in both. Going into college, I was undecided on which engineering I should pursue, but eventually I decided on Mechanical Engineering. I chose ME because I believed it was the broadest of the disciplines, which would allow me to adjust my interests as I continued my college years until I discovered what I was most passionate about.

Future Plans:
I will graduate in May 2023 with a BSE in Mechanical Engineering and a minor in German Studies. After graduation, I plan to continue working with Android Industries, a manufacturing company near my home that I have interned with since last summer, as a Manufacturing Engineer.

Fun facts:
One of my hobbies that I enjoy most is drawing, and I took an art class every year of middle school and high school. I also spend a majority of my freetime reading. Over the past two years, I have read 312 books!

Sam Weller

From: Grand Rapids, MI

Why Mechanical Engineering?

I first fell in love with mechanics in high school when I took my first calculus and physics classes, thanks in large part to the teachers I had. From there, I applied to the College of Engineering at Michigan and continued to explore concepts I enjoyed, such as thermodynamics and manufacturing processes. I spent the early years of college focused strictly on Mechanical Engineering, but later on I found the same love in teaching mechanics as I had found learning it, leading to my eventual future in ME and teaching.

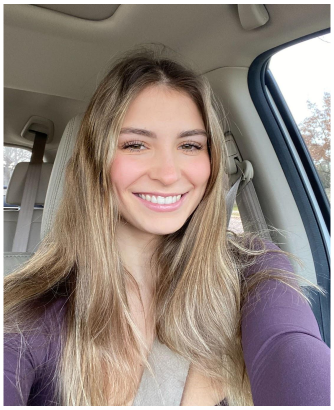
Future Plans:

After graduating this spring, I plan to return to the University of Michigan in July to begin a one year School of Education masters program to receive secondary teacher certification in math and physics. After that, I plan to begin teaching high school in the state of Michigan.

Fun facts:

I spent 5 years in the Michigan Marching Band playing bass trombone, where I went to the Citrus, Orange, and Fiesta Bowl, and the B1G Championship twice. I have also written a full, first draft of a novel.

Sedona Giambalvo



From: Plano, Texas

Why Mechanical Engineering?

When I first entered college, I thought that biomedical engineering was for me, but that quickly changed when I discovered just how much I disliked biology. I chose mechanical engineering because of its broadness in scope. I knew that although I was unsure of what exactly I wanted to do, I loved that I was not confined to a small box of opportunities with ME. I enjoyed the freedom of being able to choose whether I would later pursue a career in healthcare, automotive, food and sustainability, to name a few of many. Additionally, I loved the “learning by doing”, collaborative mentality, because I am very much a hands-on learner.

Future Plans:

I am going to graduate at the end of April 2023 with a BSE in Mechanical Engineering. I would love to move to a major city in the United States.

Fun facts:

I am a dual citizen of the United States and Canada because I was born in Canada. I love to cook and bake! I play on the Women’s Club Volleyball team here at Michigan as a libero. My favorite TV show is Scandal. My favorite place that I have traveled to is Amsterdam, and I would love to go back.