Interactive STEAM Education for Young Children:
Ball Wall Interactive Qualifying Project

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ABSTRACT

The Westborough YWCA (a non-profit organization) educates children ages one to five years of age, teaching them how to develop social and thinking skills through science, technology, engineering, art, and math (STEAM). This project focused on furthering this goal by designing and constructing a low-cost STEAM-oriented wall that children could play with using plastic balls at the childcare center. Using an engineering design process, we gathered background information about early childhood education, surveyed the YWCA staff for their specific desires for the wall, and designed and built a STEAM ball wall that incorporated the needs of the YWCA. Once we completed the final ball wall construction, we implemented the wall in the STEAM room of the Westborough YWCA.

ACKNOWLEDGEMENTS

Our project would not have been completed without the help and generosity of many people. We would like to thank our advisor Katherine C. Chen for guiding us through the steps necessary in creating a ball wall that not only is engineered by our team, but also considers the Westborough community and their specific needs for the wall. She would meet with us weekly, if not more often to help us prepare for visits to the Westborough YWCA, meetings with other important individuals that contributed to our success, and presentations to give to the WPI community and the YWCA Board of Directors.

We would also like to extend our gratitude to Jessica Rosewitz and Luisa Palladino for creating this project idea, as well as guiding us through the process. Jessica Rosewitz provided our team with workspaces and recycled materials, as well as took time out of her day to check our progress either through meetings or helping with the editing process of this paper. Luisa was in direct contact with the team throughout the whole project, adjusting the YWCA class schedules as needed to allow our team to visit, as well as providing important information to the team and offering Westborough YWCA donations for the wall to be completed. The efforts of these women were huge contributors to the success to our project, and we are extremely thankful for the time and effort that they have provided to us to make this project a success.

The research and data collection processes were eased through the contributions of Laura Robinson and Mia Dubosarksy. Laura, a previous librarian at WPI, guided us in our research and citation process. Mia works in the STEM Education center at WPI and directed us to useful resources in our research of current STEAM education for children, as well as information about early childcare learning goals and objectives.

We would not have been able to achieve our goal of making this project as cost friendly as possible without the generous donors of our local community. Thank you to the Worcester Home Depot for donating plywood to our team. Your contribution allowed our team to save the parent donations from the Westborough YWCA, meaning that the school can use those donations to further improve the education of children attending the Westborough YWCA. We would also like to thank WPI's Kaven Hall and Washburn Shops for providing scrap materials and tools for the team to work with throughout the project.

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EXECUTIVE SUMMARY

Introduction

The Westborough YWCA has a childcare center that teaches science, technology, engineering, art, and math (STEAM) concepts to children with their STEAM room. They support children ages one and a half to five years old by helping them develop through lesson plans based around Massachusetts curriculum framework for toddlers and pre-Kindergarten level material. The Westborough YWCA teachers and staff wanted to implement a new, hands-on element to their STEAM room that allowed children to observe and experiment with STEAM concepts. The childcare center already owned small plastic balls, which they hoped could be used as a basis for creating a “ball wall.” The ball wall would be mounted to the back of three adjacent bookshelves at the Westborough YWCA. This ball wall would also be built to satisfy the specific needs of the school, thus requiring the input of the community. The goal of this project was to design and build a ball wall specifically for the Westborough YWCA needs, and the project objectives were to:

1. Incorporate the current STEAM education goals and developmental stages for pre-K children and toddlers when designing the hands-on experiences for the users of the ball wall.

2. Design and construct the ball wall to be safe, cost friendly, fun, and interactive.

3. Utilize the engineering design process of prototyping parts of the ball wall to build, test, and redesign while also getting feedback from multiple stakeholders in order to build the final product.

4. Capture the project process framed through the engineering design process through a storybook to be presented to the YWCA.

Methodology

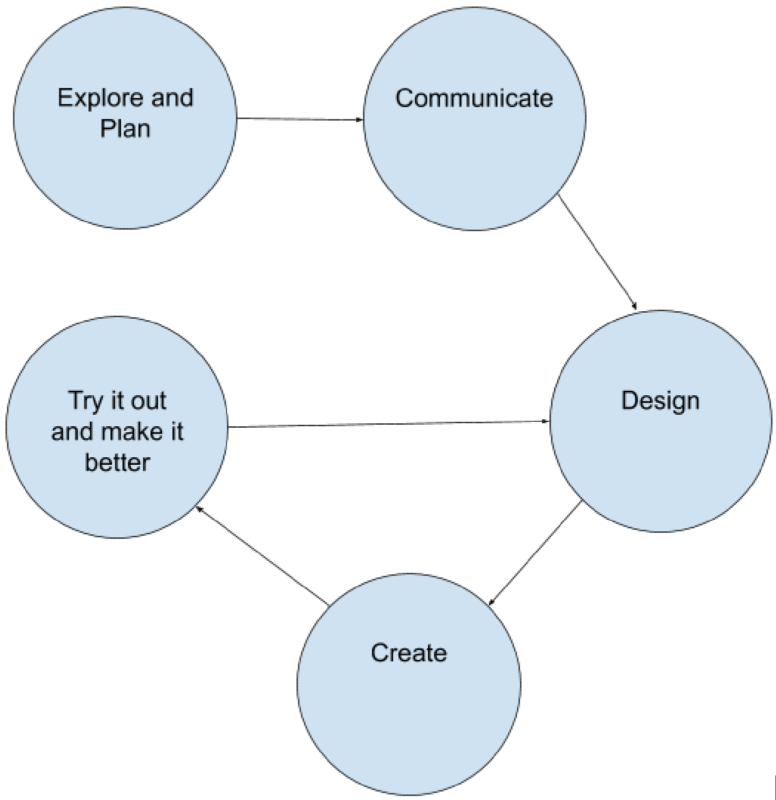

Figure 1: Engineering process we used for building the ball wall.

To achieve the goals for this project, we followed the engineering process (Figure 1). We explored and planned through research of child education, safety measures, and inspirational references of existing ball walls. We also observed each age group for learning and behavioural characteristics. We then created surveys to the community, which were meant to create a framework for the specific needs that the Westborough YWCA desired for the final ball wall. With this base framework, we were able to draft designs of the ball wall. We then gathered materials and created prototypes from our ideas. To make sure that these prototypes worked, we would test them out and figure out what could be improved. Once we found out what needed to be improved, we returned to our design process, testing and reiterating before finally implementing the final ball wall in the YWCA STEAM room. We also created storybook memorabilia for the YWCA to keep so that they could look at pictures of our engineering process.

Results

Our final ball wall was comprised of three different sections: the toddler (ages 1.5 – 3) section, the transition section, and the pre-schooler (ages 3-5) section. The toddler and pre-schooler sections were designed based on our research and observations of each age group. The transition section was built to combine the needs of the toddlers and pre-schoolers. We built each section of the ball wall out of donated materials or from purchasing through limited funds from the Westborough YWCA. By creating a tight schedule to follow, we were able to complete all sections on time with a few design changes. Despite the ball wall being built for separate age groups, we hoped for all Westborough YWCA children to utilize all parts of the wall. We wanted to allow the children to have creativity with how the ball moved across each section. We made the ball wall personal by creating a cut-out of the YWCA's main class pet and putting it at the top of the ball wall. The final ball wall was revealed to the families of the YWCA at a YWCA family reveal day, and we delivered out storybook, "Thumper's Ball Wall Adventure!", to the YWCA.

Final Recommendations

For those interested in participating in a similar project to the Ball Wall IQP, we recommend doing meaningful background research to direct your design process. We also recommend receiving as much feedback as possible from the community that the ball wall is intended for. Receiving feedback from the community is crucial in guiding the design process and making sure that the final product is catered towards the needs of the specific community. Doing these two steps as early and quickly as possible is crucial to allow more time for constructing the final ball wall, which was a challenge our team faced. It is also important to test your components of the wall to see what changes need to be made. No corners should be cut in testing the ball wall; testing is crucial for ensuring the safety and integrity of the ball wall. Lastly, look for as many resources as possible for scrap and recyclable materials, and be able to adjust existing designs to cater towards using the recycled materials found.

CHAPTER 1: INTRODUCTION

This Interactive Qualifying Project (IQP) focused on providing social, environmental, and emotional stimuli to children from 1.5 to 4 years of age at the Westborough YWCA through interactive play with a wall structure that we designed and built. The wall structure was designed to include the use of plastic toy balls already owned by the Westborough YWCA. Thus, throughout this paper, we refer to this STEAM (science, technology, engineering, art, and math) themed wall structure as a “ball wall.” This ball wall is an interactive structure with multiple components that can engage an entire group of students, as well as individual students that will play with it alone. It was designed with the specific needs of the Westborough YWCA in mind. Thus, our process involved discussing their intentions for the ball wall, developing a plan and designing through the engineering design process, and implementing the final design in the Westborough YWCA STEAM education room.

This project began through the Westborough YWCA teachers and staff. They brainstormed ideas of how to improve their STEAM room, and the idea of a ball wall came about. Danielle St. Amand reached out to Jessica Rosewitz, a Worcester Polytechnic Institute (WPI) civil engineering grad student and parent of a child attending the Westborough YWCA childcare program. Jessica then presented the ball wall idea to WPI STEM Education Center as a project, and the idea was developed into an IQP in the STEM Education Project Center of Worcester Polytechnic Institute (WPI).

This on-campus IQP had a variety of stakeholders including the Worcester Polytechnic Institute (WPI), the WPI STEM Education Center, the ball wall IQP members, the YWCA, and the Westborough community. When making decisions about what was best for this project, it was critical to engage with these entities to ensure we satisfied the requirements of all stakeholders.

The importance of both early childhood education and education within STEAM fields has been highlighted in many studies (Kazakoff, E 2013). The first five years of a person’s life have been found to be some of the most important years of development. During this time, providing the needed social and emotional stimuli is crucial for a person’s growth (Halfon, N 2001). These stimuli can be provided in a variety of different methods including STEAM, which has been a significant topic for educators over the past decade. As technology continues to advance, the demand for skilled labor is ever increasing (Berger, N 2013). STEAM education is being implemented from a progressively younger age all over the country and the world. As this progression continues, the team tried to build a ball wall that will stimulate STEAM learning.

The goal of our project was to create a STEAM ball wall that was designed specifically for the Westborough YWCA students and their early childhood education and development program. The project objectives were to:

1. Incorporate the current STEAM education goals and developmental stages for pre-K children and toddlers when designing the hands-on experiences for the users of the ball wall.

2. Design and construct the ball wall to be safe, cost friendly, fun, and interactive.

3. Utilize the engineering design process of prototyping parts of the ball wall to build, test, and redesign while also getting feedback from multiple stakeholders in order to build the final product.

4. Capture the project process framed through the engineering design process through a storybook to be presented to the YWCA.

CHAPTER 2: BACKGROUND/LITERATURE REVIEW

2.1 Child Development and the Effects of Early Childcare

2.1.1 Early Childhood and Sensory Motor Development

From the day they are born, children are in a sensitive state where everything around them influences their development and learning. In fact, the nervous system undergoes its most dramatic development during the first few years of life (Shonkoff, 2000). It is the early stages of development where parents will notice their children communicating in other ways besides crying; they may laugh or mumble, and even speak comprehensible words. It is important to help children along with this process, as studies have shown that early childhood development play a direct role in academic skills at school entry (Shonkoff, 2000), and can even predict high school completion (Brooks-Gunn et al., 1993). Thus, language development is one of the main learning objectives for toddlers and Pre-K children in current US childcare programs.

In the process of building our interactive STEAM ball wall, we needed to consider the different developmental stages between different childhood age groups and how they differ in terms of their development. Starting at the age of 1, children are beginning to develop sensory-motor skills before their language develops (Piaget, 1965). Within the sensory-motor development, there is a quick development in which children start off with simple reflexes, then begin to form habits, until they eventually can coordinate means and goals. Piaget continues to elaborate on the importance of this stage, in which he speaks about the concept of "schemata of action" (Figure 2). When a child begins to see that there is a cause and effect within their actions, they can see later that similar future situations will have a similar cause and effect. This can be exemplified by the idea of spilling a cup.

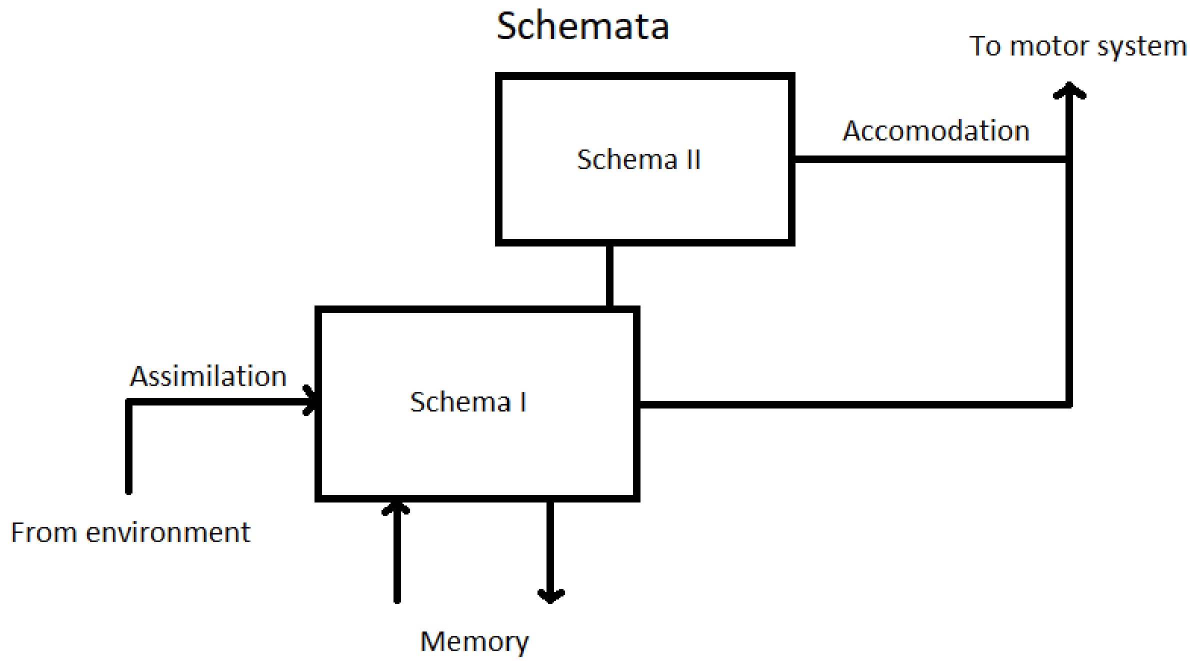

Figure 2: Visual representation of how previous schema will affect the understanding of future similar schema (Kardas, December 1998)

If a child spills a cup with liquid inside, they will later be able to tell that if there is a bowl with liquid inside, that it will also spill. In this case, the cup spilling is "Schema I" and the bowl spilling is "Schema II". Children often will play around with an object, and experiment with it to pick up sensory detail in hopes of connecting it with a previous schema of action. This concept is important to us because the knowledge of the permanent object starts at this point (Piaget, 1965). With schemata of action, toddlers are constructing mental object permanence for time, space, and causality. Therefore, we can focus on developing these basic concepts for children.

While in the process of developing their sensory-motor skills, children tend to play with toys using all their senses. When a child picks up a colorful, wooden block, they may turn it around in their hands, and may even try to put it into their mouth to taste and feel more deeply (Butcher, K., & Pletcher, J. 2016). This is the child using all her senses to understand the qualities of the wooden block. Through sensory play, children develop cognitive skills; they are learning how to problem-solve and create novel ideas from current ideas (Butcher, K., & Pletcher, J. 2016). This connects to the concept of "schemata of action", as mentioned previously. As they child continues to play with different blocks, they will learn new things and remember them, such as the idea that a small block is not as heavy as a light block, or that a red block tastes the same as a blue block. These types of observations are stored into their minds, and they can later apply this knowledge when they view different objects of similar quality, such as later seeing a green block and knowing that it will not taste different from the red or blue blocks.

From one to two years of age, there are certain things that children cannot logically conclude yet. One example is the idea of a class and a subclass. For example, let us consider a situation where we show a child a picture of two apples, one of which is red and one of which is green. If we were to ask a child if there were more red apples or more fruit in the picture, they would not be able to answer correctly because they are unable to distinguish that an apple is a subclass of a fruit. Therefore, we were careful that what we incorporated into our ball wall was not too complex for young children to understand but would still be able to challenge them in ways that they could solve through observation, trial, and error.

2.1.2 Effects of Accessibility on Childhood Education

Because of the sensitivity involved in the early development stages of children, their development must be approached in a very specific way. Ordinary childcare is found to have the smallest initial effects on children's learning and development (Barnett, 2008). This is mainly due to the lack of attention towards interaction with toys, teachers, and peers (Howes et al., 1992). Family day care homes show no effect on cognitive development, while childcare centers produce small short-term effects on cognitive and language development (Barnett, 2008). This implies that children must be taught in a specific way; deviation from careful education can even harm the learning and development of children. This differs from families of higher income that can afford preschool. Most children who are enrolled in preschool attend private programs, for which their parents pay fees. Preschool and center-based care improve young children's early academic skills by providing enriching learning experiences and, sometimes, developmentally appropriate academic instruction (Magnuson, K., & Waldfogel, J. 2016).

Additionally, low-income families may not be able to bring their children to high level early education program due to mobility issues (Vandenbroeck, M., & Lazzari, A, 2014). Specifically, if a low-income family resides in an area where there is no higher education available, they will not be able to bring their children there. Like this, low-income families, in comparison to high income families, often have less access to information regarding early childhood education and care (Vandenbroeck, M., & Lazzari, A, 2014). Thus, they do not know the best program of early childhood education and care to enroll their children in, and they will only be able to enroll their child into a program that is close by and of their knowledge.

For low-income families, there exists programs for child development, which statistically has proven effective for developing children. In Massachusetts, there is a Department of Early Education and Care which can provide 55,000 children from low-income families with opportunities of effective early education (Hart, K. 2018, October 9). These programs are funded by the government to provide low-income families with higher education. "Head Start" or other model programs are a good reference as to how children should be taught. Head Start provides young children with important services such as physical, social, emotional, nutritional, and dental health (Bitler, M. P., Domina, T., & Hoynes, H. I. (2016). As a result of social and emotional development in Head Start, there is positive and larger gains in vocabulary knowledge and receptive language skills during the preschool period within the students. Because early childhood is such an important time of development, if schools are implementing small but effective topics to teach kids at a young age, it would affect their future, and perhaps character and passions. A lot of these services have a long-term impact on the children's growth, mainly on their social and emotional outcomes in early adolescence. Thus, if we are implementing this STEAM wall at the Westborough YWCA, we can expect that some children will develop interest in STEAM concepts in the future, as well as their teamwork and emotional handling with other peers. Higher level child education programs also cause increased high school graduation rates more than a decade later (Barnett, 1995), as well as cut in half the likelihood of kids being held back a grade (Chesloff, 2013).

2.1.3 Effects of Social Development on Childhood Education

Another main task of childcare is to help the children interact with other children in a safe way. Children who have daily contact with stable peer groups from young ages appear most socially competent with peers (Howes et al., 1992). Furthermore, children who feel emotionally secure with adults are positively oriented to peers, and therefore a child's social orientation and attachment behaviors to teachers' security influences their behaviors around other children (Howes et al., 1992). Thus, the YWCA teachers can teach the kids to work together to solve small challenges, and as a result, contribute to the development of social behaviors with classmates.

It is also important to note the significance of adults, mainly parents, and their beliefs in how the child should be raised. Parents have specific influences and hopes such as expectations, goals, and aspirations for their children. These hopes of parents cause behavior inheritances, which shape the cognitive, linguistic, and social-emotional development and thereby influence the acquisition of specific skills or behaviors (Shonkoff, 2000). Because the YWCA and parents of the Westborough community requested the construction of this STEAM ball wall, the encouragement of children playing with educational toys and learning at an early age will influence Pre-K children to enjoy educational activities.

2.1.4 STEAM Education Through Early Childhood Development

Young children and infants have intuitive theories of the physical, biological, and psychological world (Gopnik, A., & Schulz, L. 2004). With these theories, the children can use these intuitive theories to make casual predictions, provide broad explanations, and consider reason (Gopnik, A., & Schulz, L. 2004). It is also a time where they are rapidly learning basic material that will impact their later learning.

Chesloff confirms that the brain is particularly receptive to learning math and logic between the ages of one and four, and that early math skills are the most powerful predictors of later learning (Chesloff, 2013). At the age of three to four, children should have the ability to understand that if they have one apple and get another apple there are now two apples and if one were to be removed it would be back to one apple. Stanberry lists milestones that a child should be reaching by three to four years of age (Stanberry, K. n.d.). One of these milestones says, “Understands that the written numeral “3” means three objects — and the same with numerals 1-5” (Stanberry, K. n.d.).

Like math, physics activities stimulate children’s inquiry and problem-solving skills (Gur, C. 2011). Activities with balls and ramps offer children experiences with their physical world, upon which they can later build more abstract physics knowledge. Thus, through the ball wall, the children at the YWCA can learn about how their movements affect the movement of other objects around them. Specifically, schools should be focusing on the properties of objects, earth and space, and tools and machines when trying to help children understand STEAM in early education (Gur, C. 2011). Similarly, a successful STEAM lesson will involve engineering steps such as observing, comparing, classifying, measuring, communicating, inferring, predicting, and hypothesizing (Gur, C. 2011).

We also aimed for having elements on the ball wall that will allow children to be creative with solutions and teamwork. Allowing children to be creative during their developing years before preschool gives the kids an opportunity to make the activity their own (“PBS”, n.d.). The creative process allows for kids to develop self-expression and the ability to cope with their own feelings. Creative expression also allows to teach the children to not be intimidated by letting creative and artistic expression out (“PBS”, n.d.). We also wanted the ball wall to encourage the idea of multiple solutions, which is common in mainly engineering and all other components of STEAM (Berger, C. 2015, January 30).

As a guideline, we had the Seeds of STEM research group that has a “Framework for Early Childhood STEM Experiences”, in which the report explains some of the current requirements for high-quality STEM education for children (Seeds of STEM, 2018). As mentioned earlier, we had to be sure that our approach was developmentally appropriate for their age group. We also made sure that the ball wall was culturally responsive to every child at the YWCA, and that their gender, ethnic background, and physical abilities were being considered within our design. We did this by making sure we did not make the ball wall too tall, as well made sure the usage of any part of the wall did not depend on the ethnic background or gender of the child. When a person thinks of STEAM, they think of very technical processes that children would never be able to understand at an age. Therefore, one of the guidelines of the article recommended to focus on the process of problem-solving. Specifically, we thought of how we could make our wall have open-ended challenges with multiple solutions to finish the paths within the wall that involves teamwork. This was especially important because if we have one linear solution, it may not be solvable for some children that are fixated on one course of action. Additionally, the children may lose interest if there is only one solution; they are interested in discovering new methods to solve the wall. Thus, we built the wall to encourage their creativity in finding multiple ways to finish the course. Along with this, we planned to incorporate visual and auditory aspects to the wall to encourage learning for both visual and auditory learners.

In addition to looking into STEAM education guidelines for teachers, we also investigated teacher lesson planning for toddlers and Pre-K children. Firstly, teachers need to follow a framework that follows the state's early learning standards (Room 241 Team., 2013). Utilizing this framework, teachers will write down the learning goals for the children, as well as write down any current research on how to effectively implement these topics in a lesson to teach the children those specific learning goals. After this, teachers must define their role within the lesson plan; teachers are responsible for creating engaging interaction and strategies to encourage learning (Room 241 Team., 2013). They also must be aware of how children in the classroom have different learning methods and be able to teach them concepts through multiple methods to accommodate for this. Lastly, teachers are always responsible in thinking about the safety of the children throughout the duration of the lesson (Room 241 Team., 2013). With these three requirements, teachers can safely shape curriculum to accomplish a learning goal for all children, despite their learning differences and backgrounds.

When a teacher introduces a new concept to students, they must make sure that their students are retaining the knowledge that they have been taught. No matter the age, there are ways to determine if the student has learned the intended knowledge, even to some extent. An article by Helen Webb lists criteria that can determine if a student is learning the material or not. One of these points is that they will recreate the material they are taught if they truly understand the concept. For example, if a teacher gives a demonstration, the teacher will search to see if the students are able to recreate their demonstration in some way, or if they are able to talk and teach their peers the new material in some form (Webb, 2017). Knowing this, we knew that there were a lot of ways for teachers to analyze and understand if the students were learning the proper skills or methods to using the wall.

Because we wanted our ball wall to reflect the types of material that the children at the YWCA would be learning, we researched current pre-kindergarten and kindergarten curriculum frameworks. Our team looked for concepts we felt that we could capture through the movement of the plastic balls. Table 1 shows some of the curriculum framework that we felt we could reflect through our ball wall design (Massachusetts science and technology/engineering, n.d.). Examples of pushes or pulls could include a string attached to an object being pulled, a person pushing an object, a person stopping a rolling ball, and two objects colliding and pushing into each other.

Table 1: 2016 Massachusetts Science and Technology/Engineering Curriculum Framework Topics from Pre-Kindergarten and Kindergarten.

PS2. Motion and Stability: Forces and Interactions	PreK-PS2-1(MA). Using evidence, discuss ideas about what is making something move the way it does and how some movements can be controlled.
PS2. Motion and Stability: Forces and Interactions	PreK-PS2-2(MA). Through experience, develop awareness of factors that influence whether things stand or fall.
PS2. Motion and Stability: Forces and Interactions	K-PS2-1. Compare the effects of different strengths or different directions of pushes and pulls on the motion of an object.

2.2 Interactive Learning Models

2.2.1 Current Installations Available to the Public

For the project, a lot of inspiration and information was gathered from looking at some of the current interactive learning models such as the one at the Boston Science Museum or the St Louis Science Museum. These two are prime examples of places that have interactive learning models that are creative, engaging, and educational.

Figure 3: Museum ball structure for children (Go on a Journey of Scientific Discovery, January 2016)

Figure 3 is the exhibit that the St. Louis Science Museum currently has on display. One of the main inspirations that came from this was how open it was, where people could observe the ball go throughout the whole course. This could be incorporated for the kids so that they can understand how the ball travels throughout the course from start to end. Visuals such as these may suggest certain concepts to children, such as how a ball will naturally roll down a ramp. It also suggests the idea that once the ball reaches the bottom of the interactive learning structure, it cannot go back up the ramp and needs to be brought back to the top of the structure in a different way to start doing down the pathways again.

Playgrounds also act as a hands-on structure where kids can learn skills while having fun at the same time, which is like the end goal of our ball wall. Petrova pinpoints some of the goals of interactive play with playgrounds; the spaces are meant to involve varying topography, as well as involve fitness elements that involve the children using their energy (Petrova, 2018). Playgrounds and ball walls both include active play; active play is the incorporation of physical movement into design. Some of the concepts of active play that a ball wall includes are changes in height, development of social needs, and being able to judge risk in a landscape.

2.2.2 Researching Current Children's Toys

Another factor that was examined for the design of the ball wall was the aspect of children's toys (Figure 4 and Figure 5). We observed toys that Kathy Chen, our project advisor and worker in the WPI Precollegiate Outreach Program, had brought in for us to look at.

Figure 4: Child mobile featuring animal characters and sound.

Figure 5: Music toy involving color and sensory play.

Most of these toys have a lot of colors that draw your eyes towards them. This led to us coming to an agreement that the ball wall would need to have a lot of bright colors albeit not overwhelming. In addition to this, a lot of the toys that we looked at had some form of mascot or animal. This was something that the kids could connect to that would provide more interest within the toys. Children tend to connect to characters such that they influence how a child acts and feels. From a paper speaking of children attracted to a food-related character, "[children] develop 'parasocial relationships' with favorite characters, representing emotionally infused friendships based on characters 'attractiveness and the messages they convey that can influence their diet-related outcomes." (Kraak, Story, 2014). While the ball wall does not connect towards eating a healthy diet, some of the same reasoning can be used for the proposal of creating a mascot for the wall. If we were to create a mascot that allows for a parasocial relationship (a relationship where the other party is completely unaware of the other parties existence), it could create a better learning environment for the children because they have something to attach to when learning these STEAM concepts.

Because we had a lot of creative liberty with our wall design, we considered what kinds of colors we wanted to be part of our wall. This involved thinking about what colors affected children, and how they affected them. In a recent study, 12-week-old infants showed preferences for color visual stimuli over white visual stimuli (Read, M. A., & Upington, D., 2009). Many children have emotional reactions to different colors. Children had positive reactions to bright colors (e.g., pink, blue, red) and negative emotions for dark colors (e.g., brown, black, gray) (Boyatzis, C. J., & Varghese, R., 1994). Children prefer blue, yellow, and red, whereas white and black were generally disliked (Meerum Terwogt and Hoeslma 1995). Out of all the bright colors, children mainly preferred by rank: red, purple, and blue (Read, M. A., & Upington, D., 2009). Children also preferred cool colors over warm colors (Read, M. A., & Upington, D., 2009). Thus, we knew to incorporate cooler tones rather than warmer tones on our ball wall. According to (Read, M. A., & Upington, D., 2009), a wall with a subtle purple hue may support children's interest in the space. We also considered how the colors of the wall would be affected due shadows and lights hitting the wall. Environmental color on a plane or wall is quite different visually from a toy or drawing with color (Read, M. A., & Upington, D., 2009).

2.2.3 Research Through Social Media

Another form of inspiration was creating a Pinterest wall. Pinterest, a social media platform designed for "pinning" pictures and creating a wall of similarly themed images, examples that are being used on a smaller scale or have less notoriety than a museum. Some examples of the pictures we used for inspiration can be seen in Figure 6 and Figure 7:

Figure 6: Child playing with textures. (Eureka! The National children's museum, June 2016)

Figure 7: Child ball wall with inspiring design. (Palace Resorts, 2016)

Figure 6 gave us a lot of inspiration towards using texture within our design. Figure 7 made us realize unattainable aspects due to its larger size. Our wall is a lot shorter in height, meaning we could not utilize gravity in the way that many other Pinterest ball walls do.

2.3 Child Safety

2.3.1 Designing for Appropriate Materials Selection and Shapes

One of the top priorities in designing the ball wall was safety of the children at the YWCA. For the children to successfully interact with the wall, the materials that made up the wall needed to be safe for their age. As stated by the teachers at the YWCA, the children love to climb obstacles, chew on toys, and touch objects around them. Since we knew that the children would touch all wall components, the edges and corners of the materials used needed to be rounded. The materials could not cut or injure children in any way. The materials that were used could not splinter apart or corrode such as untreated wood or metal that hasn't been deburred. The materials could not stimulate allergies or sensitivities some children might have. Some allergies or sensitivities to materials that children might have could include nut allergy (walnut wood), latex including rubber or balloons ("What is latex?," n.d.), nickel ("Nickel allergy is a common," n.d.), polyester, etc. (Seladi-Schulman, J. (2018, April 12). Allergy and sensitivity safe materials were investigated to ensure that all children could have access to the ball wall.

Materials like wood must be treated with a polymer or coating that will be smooth enough for the children to touch or chew without being injured. The treated material must also be safe for ingestion (in case a child happens to chew on part of the wall) and not be a choking hazard (based on the choking hazard testing device given by YWCA teachers). Based on (Safe finish for small children 2005, November 28), the forum suggested to let clear coatings such as a polyurethane cure for a month before letting the children use the wooden toy. Another approach suggested on the forum was using a nontoxic food-safe finish such as mineral oil or mineral oil combined with beeswax mix.

A hazard that we took into consideration in a playground is objects that may cause strangulation. Ropes, bars, rails, and nets are examples of components that can catch or strangle ("According to the Consumer," n.d.). The teachers of the YWCA will be monitoring the children during the time that they use the wall. However, it was best to make sure strangulation cannot occur in case the teachers get distracted, and thus we avoided these materials during our building process.

2.3.2 Designing for Cleanliness and Health Safety

Children are not always the cleanest when it comes to toys that several children will be interacting with. Thus, we concluded that smooth surfaces that can be cleaned with cleaning spray or other cleaning methods easily was necessary. To make it easier to clean, the materials are antibacterial and are excellent against germs collecting on the surface. The design of the wall had to have easy to reach areas and the least amount of extruded parts as possible. The more extruded and exposed areas of the wall, the more the kids can touch, and the harder it is to clean. We had to find a balance between ease of cleaning and making sure the requirements of the wall were fulfilled. To make it easier to clean, overcrowding of the wall needs to be mitigated. Different age group classes will be interacting with the wall at different times of the day, meaning this can be monitored and maintained by the YWCA rather easily. A cleaning process that includes the children after they have used the ball wall would help maintain the wall and give the children a sense of ownership and responsibility.

CHAPTER 3: METHODOLOGY

To achieve our objectives for the project, we observed children in multiple settings, gathered funds and low-cost materials, sketched and blueprinted multiple designs, prototyped certain sections of the wall and reiterated these designs until we accomplished a design that best fit the YWCA. We then were able to build the wall and deliver the final project to the Westborough YWCA. Our engineering process is illustrated in the following steps show in Table 2:

Table 2: Engineering Design Process

Explore and Plan:

1. Conduct a preliminary survey for the teachers by asking them about their goals for the ball wall and their involvement with the community.
2. Conduct background research about childcare education and safety.

Communicate:

3. Conduct a preliminary observation of the behaviors of children at the YWCA through social interactions and playing habits.
4. Create a plan for what STEAM concepts the ball wall will include.

Design:

5. Sketch and design our plan for the ball wall.
6. Communicate our plans and designs to the YWCA teachers.

Create:

7. Gather funds and materials.
8. Build prototypes of discrete components of our wall design.

Try it out and make it better:

9. Test these prototypes by learning how the children play with them and survey the teachers about their feedback for these.
10. Reiterate our design by cyclically repeating steps 8 through 10 until satisfied.

Final design:

11. Construct the final ball wall.
12. Test out the final ball wall before implementation.
13. Install the final design in the STEAM room of the Westborough, YWCA.

3.1 Surveys

3.1.1 Institutional Review Board Approval

We had to go through the Institutional Review Board (IRB) in order to conduct surveys at the YWCA. They made sure that our processes were safe for the children, and we would be able to collect data and minimize possible harm. This required us to think carefully about our observation process. We outlined our questions and decided that we would not directly try to interact with the children. We then brought this outline to Ruth McKeogh, the director of Human Subjects Research and Academic Programs at WPI, to make sure that the IRB approved of our observation process. To make sure it was safe for the YWCA staff, we explicitly stated that the surveys were anonymous if chosen to be. Besides this, our questions would not cause any physical or psychological harm that is normally encountered in the daily life of the person being interviewed (Exempt. n.d.). Thus, we received exempt approval from the IRB. Once we received their approval of our process, we were able to proceed with observation and surveying the teachers to collect our necessary data. We received a letter of exemption, listed as Appendix A.

3.1.2 Preliminary Survey for YWCA Child Education Teachers

Our first survey was a preliminary survey sent out by email on August 29th, 2019 where we asked teachers basic questions before we started thinking about designing. These surveys were conducted online using Google Surveys, and the questions were all short answer questions (two questions were leading questions, in which we attached them to their follow up question in Table 3).

Table 3: Preliminary Survey Designated to Teachers to Obtain Background

General questions: 1. What is your name? 2. What age group do you work with? 3. Do any of the children have special needs that need to be accommodated? If yes, please tell us about their special needs. 4. Is there anything else you would like to add? **Goals and ideas:** 5. What kinds of toys do the kids like to play with? 6. Are there any prohibited toys that we should know about? 7. Do you envision separate parts of the wall dedicated towards separate age groups or a wall of all age groups? 8. What type of STEAM (science, technology, engineering, art, math) lesson would you like the wall to help teach the kids? **Effect on community:** 9. How would you describe the relationship between the YWCA and the local community? 10. What do you think the ball wall will bring to the YWCA? 11. What do you hope the ball wall will contribute to the kids, families, and community? 12. To you, why do you think it is significant to have us design the ball wall rather than just purchasing a pre-designed ball wall? 13. Would it be meaningful for teachers, parents, and even students to be involved in ball wall construction? If yes, in what ways would you envision this happening?

Our focus for the survey was focused on their goals and ideals for the ball wall YWCA and how the wall will affect the community. We emailed the survey to Luisa Palladino, the director of the childcare at the Westborough YWCA. She then emailed this survey to the teachers for us. The questions regarding their goals and visions for the YWCA Westborough ball wall aided us in the process of choosing what kinds of concepts to present the children, as well as guide us towards what the children are capable of learning at a young age. On the other hand, community questions were important in leading our group in the right direction before we started trying to brainstorm and design our wall. It also helped us realize how much the project means to the community, and why our work would impact so many people. With this information, we had a strong foundation going into our project about how we could help this specific community in STEAM education. A table of the responses to this survey can be found in Appendix E.

3.1.3 Survey for Informative Feedback on our Design

On November 5th, we reached out to the teachers a second time after we went to the YWCA for our first observations. Like our preliminary survey, we conducted this survey over

Google Surveys, and all the answers were short answers (besides the age group question, which was a multiple-choice question with all the age groups). Unlike the first survey, this survey concentrated on details about our ideas for the wall, as well as asking about specific mechanics that would possibly be implemented in our final design. Additionally, we asked about their current educational STEAM learning goals and lesson plans. These questions are presented in Table 4.

Table 4: Survey to Teachers Asking About Their Teaching and Opinions of Specific Ball Wall Design Ideas

Questions About Their Teaching:

1. What is your age group?
2. What are some of the STEAM concepts that are currently involved in your lesson plans for your age group?

Questions About Specific Possible Design Aspects:

3. Our team is thinking about dividing the ball wall into 3 sections (same dimensions as the 3 bookshelves) for the 3 main age groups. Do you think this is a good approach? If not, please suggest?
4. For your age group do you think the components (tracks, chutes, gears, conveyor belts, teeter-totter, etc.) of the ball wall should be modular (like detachable with magnets) or do you think it would be better if they were mounted permanently? Note: We are thinking the 3 main sections would be separate panels and could be moved if needed.
5. Here are some ideas we have for each section. For each section general objectives: 1. Gravity, balance, shapes 2. Simple math, numbers 3. Gears, linkages (and overall reading, sound, texture). Please let us know what you think of these ideas.
6. What lesson goals would you like to be implemented into the wall? (Some of your lesson plan concepts might utilize a ball wall, and we can try to build a wall that helps implement those lessons.)
7. Are there any other design ideas or requests you have?

Asking these questions were important to determine if our design would educate the children in the STEAM concepts that the Westborough YWCA were hoping to teach. With all these survey results, we were able to consider the teachers' input. The input helped direct our design process, and as we continued to prototype our design, the responses to our ideas directed us towards what the YWCA teachers were envisioning for their age group. A table of the responses to this survey can be found in Appendix E.

3.2 Observations

3.2.1 Preliminary Visit to YWCA

We first visited the Westborough YWCA on August 29th, 2019 to view the STEAM room space, view the back of the shelves that we would be building the ball wall on, and learn about the different age groups of children and their needs through the feedback of the teachers. We specifically met with the teachers during a time where the children were not at school. We had to opportunity to ask directly some of the questions that we created (which were also directly sent to them through email as our “Preliminary Survey”, section 3.3.1 of Methodology) as well as gain an understanding for what teachers of different age groups hoped for the ball wall to teach preschoolers and toddlers. Learning this information early in our project process was crucial in leading us towards our goals of understanding the space and the specific needs of the children that we were building the ball wall for.

3.2.2 Visit to Head Start

We visited the local Head Start in Worcester on October 25th, 2019 to help us visualize more clearly what developed STEAM rooms looked like in other early childcare centers. This gave us a new perspective on how other local child education programs were implementing STEAM concepts within their program. We were also able to directly ask Carlene Sherbourne, the Director of Worcester Head Start program, specific questions about what the children were interested in the room, as well as how the children responded to the Worcester Head Start’s ball wall. We recorded her responses on paper, and we were able to consider these responses as we designed our final version of the ball wall. The questions and responses can be viewed in Table 5:

Table 5: Questions for Carlene Sherbourne at Worcester Head Start

1. What kinds of activities are involved in the STEAM room?
2. What is the most popular activity in the STEAM room?
3. What is the least popular activity in the STEAM room?
4. How do you notice the younger children that do not socialize learn in the STEAM room?
5. How did you receive the materials for the STEAM room?

Carlene Sherbourne showed us different sections of their STEAM themed room and how different elements within the room appealed to the kids. With this information that she provided; we used these observations while we conducted our initial designs for the wall.

Most of the questions that we asked Carlene were directed towards how the students interact with one another and what elements of their STEAM room the children like the most. These questions were important because it gave grounds for similar implementation into our ball wall. A table of Carlene’s responses to each question can be found in Appendix E.

3.2.3 Observing at YWCA for Characteristics

We also visited the Westborough YWCA on November 5th, 2019 to observe the different age groups and their differing characteristics. We focused on four main topics:

- Characteristics of the toys
- How the students interacted with the toys
- How the students interacted with their classmates
- How the students interacted with the teachers

These characteristics allowed us to understand general behaviors of the children. We also specifically looked out for different age groups and how the results of our observations differed from each other.

When looking at the characteristics of the toys, we mainly focused on visual aspects of the toy and the concept that it taught the kids while playing with it. Thus, we looked for color, material, sound, and size of the toys. Then we observed the goal of the toy and what the children were meant to accomplish with the toy. Looking for these aspects of the toys helped direct us towards educational goals for these age groups, as well as gave us ideas for visual and auditory qualities that we could potentially add to our wall.

Next, we observed for children’s interactions with the toys. Mainly, we focused on the amount of collaboration involved when multiple children played with toys, the duration of interest in their toys, and how the children responded to the intended learning goal of the toy. Based on how much the children of each age group collaborated, we decided to try to copy that level of collaboration for each age group section of the wall to reflect our observations.

We also looked out for how the students interacted with each other. Mainly, we looked for natural interactions and collaboration between peers, as well as disagreements that occurred between the students. This allowed us to see the dynamic of interactions for each age group and helped us decided the level of collaboration to be involved in each section of the modular ball wall.

Lastly, we looked at the interactions between students and teachers within the STEAM room at the YWCA. We intended to observe how different age groups were taught within the STEAM room, as well as the level of involvement of the teachers in their education within their allotted time. Thus, we looked out for how much the teachers directed the activities in the room compared to how much free time the students would receive in playing within the STEAM room themselves. This helped us understand how much involvement the teachers should have in playing with the ball wall, as well as their possible impact in helping the students learn and play with the wall.

3.2.4 Observations at YWCA for Prototype Feedback

Once we had a physical prototype of a component of the wall built, we brought it to the YWCA on November 19th, 2019 to observe how preschoolers and toddlers interacted with our prototype. We brought the prototype to the STEAM room and waited for different age groups to enter to introduce our prototype and observe them play with it. During these observations, we were watching for a few different aspects:

- Measurements of our prototype in comparison to the wall
- Level of Interest for different age groups with our prototype
- STEAM concepts are understandable for all age groups

With this information, we would be able to adjust our prototype as necessary for our final ball wall design. The noted adjustments that we would have to make would help us be confident in our final design process.

3.3 Designing the Wall

3.3.1 First Ball Wall Model

The first attempt of designing the ball wall was very important in turning our ideas and research into a physical deliverable. The beginning of this process was brainstorming ideas for functions on the wall. We used different sources to pull inspiration from including Pinterest, museum installations, and other online resources.

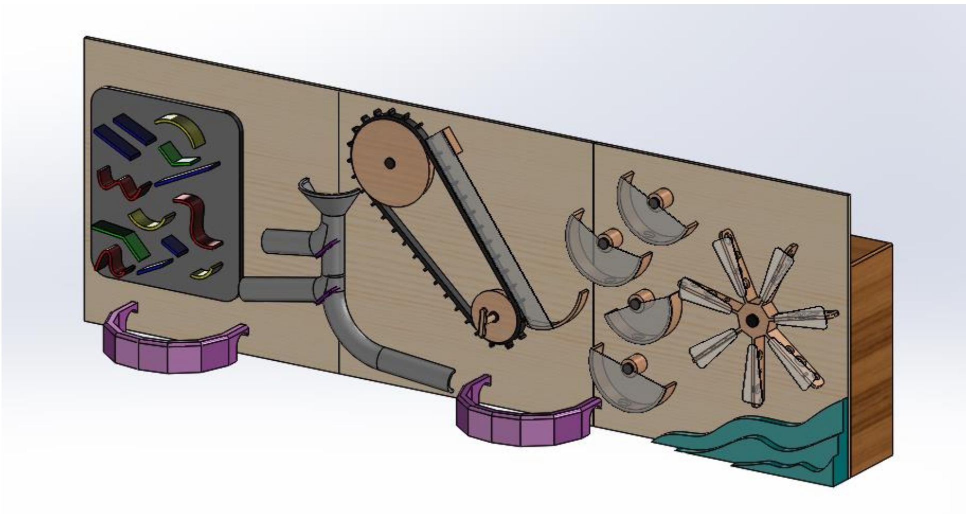

Figure 8: Our first design of the ball wall created in CAD. All sections of the wall are connected as one piece and the components are non-modular.

We were able to use computer aided design (CAD) software to design our first scale 3D model, pictured in Figure 8. While this was a good start for our team to brainstorm ideas, it was never meant to be a final product, and did not include the specific needs and constraints that the Westborough YWCA envisioned for the wall. However, this was useful to the team for many reasons; it included many components that were in our final design, as well as gave a visual during presentations to stakeholders about the direction of the ball wall. It also allowed for our team to think about the appropriate size of components for the wall and think about how to organize sections of the wall together.

3.3.2 Pinterest Wall Inspiration in our Design

After looking at social media and online pictures of inspiring photos, we took a lot of inspiration from photos that contributed to our design process.

Figure 9: Ball wall reference photo from Pinterest that we posted to our Facebook and Instagram pages. (Roof Top Fun Factory, May 2007)

While referring to online pictures, we noticed there were many restrictions for our ball wall design due to the lack of height on the back of the YWCA bookshelf. However, there were still components from multiple pictures that we could take and modify to fulfil our own goals. For example, in Figure 9, we noticed that the ball wall had a pulley system for the children to use. We liked the idea of a pulley because the hands-on play would be unique and unlike most other features that we could add to the wall. Figure 7 also was a picture that we saw on Pinterest, and we were inspired by the corkscrew on the wall because it would be a nice visual of a common function in engineering. Overall, looking at Pinterest photos were helpful in brainstorming ideas whether they ended up in our final design.

3.3.3 Designing the Wall with Key Parameters

After we had brainstormed ideas from our initial design, we approached a new design for the wall. Like the initial design, we used CAD software to build a 3D model of our wall. We used our research from online resources and museum installations to aid our ideas for the wall. A new, additional important step was understanding our key parameters and design constraints we needed to work within, as well as considering costs and materials. After we had a clear picture of what our design would look like and knew its design constraints and objectives, we were able to create sketches of the wall and CAD designs that were more pertained towards the needs of the Westborough YWCA.

3.4 Prototyping

3.4.1 Building Prototypes for Testing

We created separate prototypes for different parts of the ball wall. We approached this by collecting scrap cardboard and (laser cutting) the pieces to our desired shapes. Creating prototypes allowed for us to utilize feedback from teachers and children to create the ball wall. These prototypes ensured that the part itself was fun to play with amongst the kids but also it conveyed the correct STEAM concept through its play. We were able to bring these prototypes to the YWCA to observe how the children interacted with them. From there, we adjusted our prototypes as necessary, as well as redesigned parts of the prototype or the wall as necessary from our visual feedback.

3.4.2 Materials Used

When creating our prototypes and ball wall, we primarily used recycled materials. This was important because it meant not using any of our limited funds on this step of the project. Cardboard was a readily available material that became our main resource for prototyping because it was a cheap and a representative substitute for the plywood that we planned to use in the future. We were able to utilize other scrap materials that we found in various locations around WPI such as the trash disposal area behind Fuller Laboratories and the loading dock of Washburn Shops. Some of these materials include corrugated plastic extrusion (coroplast), PVC piping, and small plywood pieces. Overall, the construction methods of the prototypes varied, but ability to work quickly and get results was prioritized over durability and aesthetics.

3.5 Iteration and Redesign

3.5.1 Adjusting Prototypes to Personalize Design for YWCA

Throughout our process of iterating prototypes and observing the Westborough YWCA, we also received thoughts and feedback from the community through social media. We created a Facebook page and an Instagram page where we posted our progress, which can be located at the links respectively: https://www.facebook.com/wpiballwalliqp/, https://www.instagram.com/ballwall.iqp/. On these pages, we posted pictures of ball walls that inspired us, as well as hand drawings of designs.

Figure 10: Screenshot of a post we made during our counting ramp and number towers prototyping process.

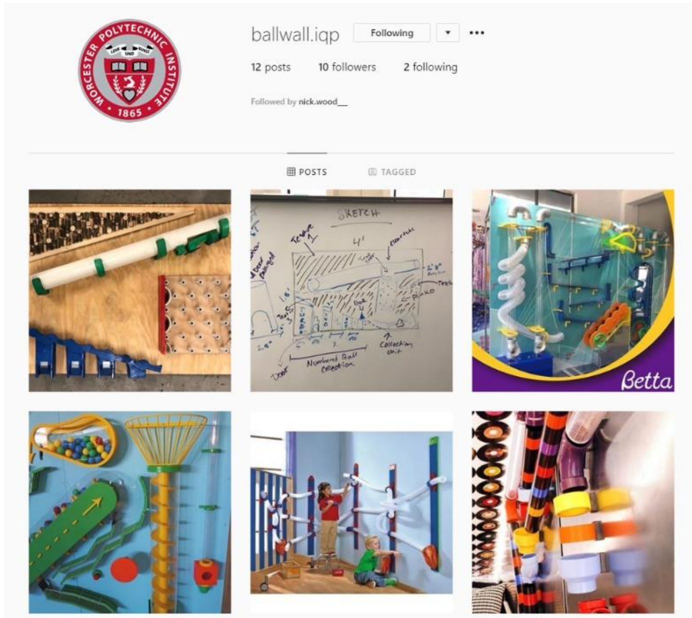

Figure 11: Screenshot of Instagram page we used during our project to interact with the Westborough community.

With these visuals for the community think about, the community was able to respond back to us through liking the photos that they envisioned the Westborough YWCA ball wall to look like. Figure 10, and example of a post we made on our Facebook page, shows that we received some views of our prototype and the community had a chance to see our progress. Figure 11 shows a few of our posts on Instagram, where we mainly received likes instead of comments.

3.5.2 Using Observations of Prototypes to Adjust Components of the Ball Wall

We also observed how the kids interacted with the prototypes to give us a better understanding of how kids would use the ball wall components. Seeing the characteristics and interactions of the children guided us in our process of finding ways to improve our initial ball wall designs. Lastly, we discussed with teachers about how and if our prototypes fulfilled their educational requirements of the ball wall. If certain requirements were not met, further design improvements were made.

3.5.3 Meeting with Luisa for her Input on Our Final Design

Before we started building the final ball wall, we had a meeting with Luisa to get her direct input of our design. Her feedback was important because she knew the most about what the Westborough YWCA children would benefit from. We showed her our CAD design and explained each aspect of the ball wall to her, explaining the functionality of each mechanic. With her feedback, we were able to reiterate the CAD. After this meeting, we were ready to build the final ball wall.

3.5.4 Adjusting our Final CAD Design before Constructing the Ball Wall

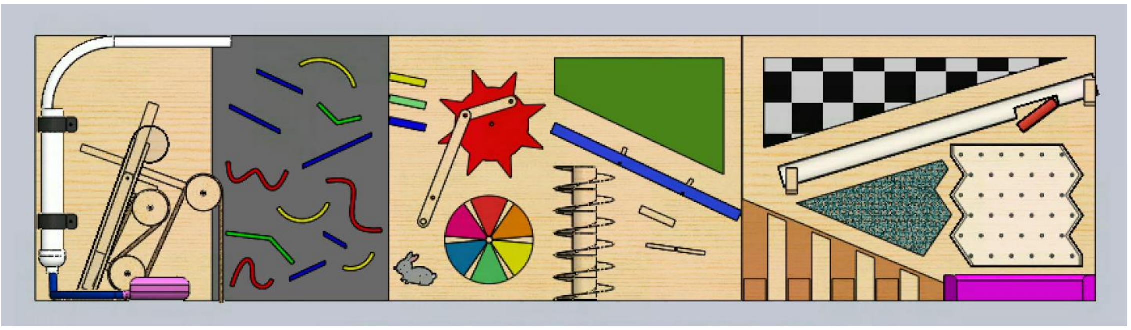

Figure 12: Initial CAD model for our final design before adjustments were made.

The initial CAD model for our final design of the ball wall (Figure 12) was created based on the team's research and design iterations made after considering input for iterations and prototype results. This initial CAD design was able to show a 3D and to scale model of what we intended our ball wall to look like at the end of our project. Many of the modules on the wall were modeled as single solid shapes rather than assemblies of smaller parts that could realistically be created. This meant that we needed to remodel all the CAD components we had previously made so that they could physically be created out of the materials we had.

When using CAD, we needed to ensure that the components redesigned in CAD could be manufactured with our available tools while also considering our time restraint. This meant redesigning components of the wall had to be as simple as possible so that the manufacturing time was reduced. We mainly used the laser cutter, which allowed us to produce parts quickly and accurately. It allowed complex shapes to be cut out of thin plywood in a matter of minutes. To leverage this capability, many of our initial CAD models were redesigned to be assemblies of multiple parts that were planer shapes which could be fitted together with interlocking notches (Figure 13). Knowing we had this tool also played a role in our material sourcing.

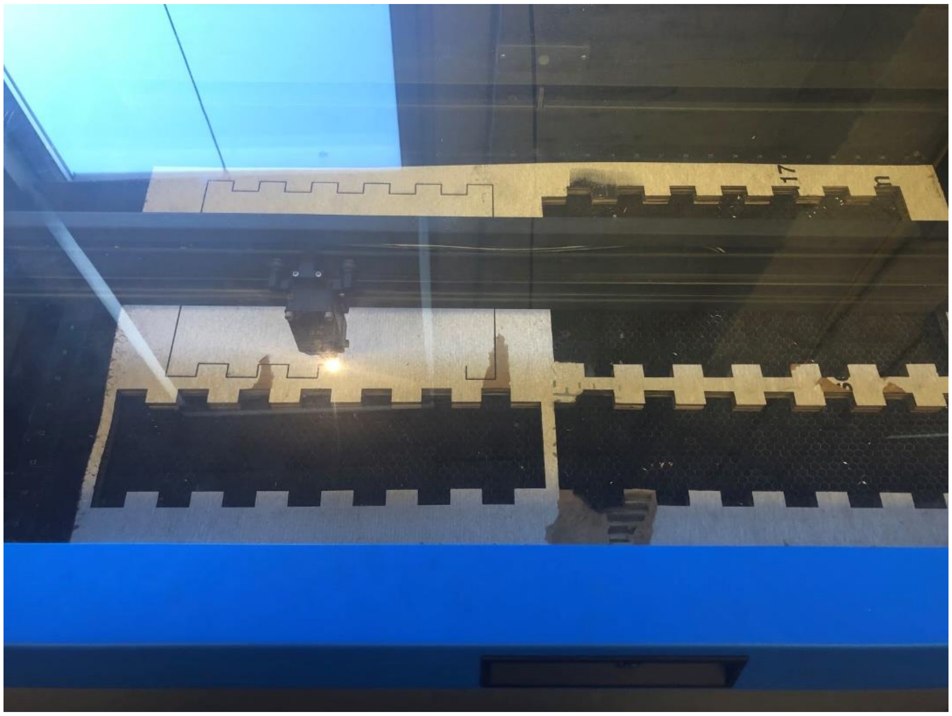

Figure 13: Carbon dioxide laser cutter being used to cut sides out for ball counting ramp in Washburn Shops.

Based on the dimensions of the materials we collected, CAD models were created with the original design in mind but to the specs of what we had to build with. One example of this can be seen in the linear slide assembly where the lower frame is built from two concentric tubes. We initially expected this to be a flat frame built from wood; however, based on the materials we had, the design was reworked to be constructed in a different method that achieved the same function.

Once the team had created an initial CAD component, there was often a redesign process with the CAD model. This redesign process was for making changes to the component that would result in an aesthetically pleasing physical end piece. One example is the ball collection brackets that originally were designed as simple rectangles. Unfortunately, once the team began building the ball wall, they realized the square ball collection design was too square and did not fit with the rest of the wall well. To remedy this issue, a new design was created that had a pentagonal shape and softer curves. All these designs were produced from newly created CAD files or edited previous CAD versions.

The original CAD model created by the team had some unrefined areas that could have posed safety issues. Sharp edges and protrusions were fixed when recreating the CAD models to be manufactured out of our selected materials. In addition, the initial CAD models were reworked to include ways to securely fasten all pieces of the wall.

The team wanted to create a design that would not only function well, but also last for many years. Our initial CAD design did not address this concern. When redesigning many of the parts from the initial CAD design, the team incorporated design elements to prevent issues such as wear and cyclic loading fatigue. One example of a prominent design element on the wall that limits wearing, and fatigue issues are the bearings and ground shafts. These bearings and shafts were included in all the rotational elements on the ball wall for this reason.

3.6 Gathering Funds and Materials

We needed to source materials and funds for the final building process. One of the goals of this STEAM Ball Wall for the YWCA was that it needed to be cost effective because the YWCA is a non-profit organization. With the effort to make it affordable, sourcing materials as donations was important in keeping the wall low budget. Additionally, we needed to make sure that all the materials we collected were safe for the children to be around. Our research concluded that we needed to be mindful of materials that could have sharp edges and corners, cause breathing issues (off gas), decay over time (splinters or rust), or have any other child endangering characteristics. Therefore, our team planned for the types of materials we wanted to include in our wall to be mostly natural materials, non-biohazardous materials, and materials that were inexpensive while being child safe.

3.6.1 Receiving Funds from YWCA

We were given funds through a YWCA fundraiser to have a starting point for the construction of our wall. While these funds were used in the project, we tried to use as little of the donated money as possible to retain the low budget interest of our project. We were offered a maximum of $1000, but with access to materials from Kaven Hall, we were able to cut down on using this fund money, and our team spent a total of $311.47 in purchased materials. Luisa provided our team with a tax-exempt form, which can be viewed in Appendix B.

Another avenue that was a possibility for funding was the YWCA Board Meeting. On November 12th, the team had a proposal presentation to an audience of roughly forty YWCA board members. The connections that the members of the YWCA board had were other options for donated funds or materials that we could use for our project. This was another way which would allow for the project to maintain the low budget that we were striving for. However, after giving the presentation, nobody in the Board of Directors directly reached out to us to aid in our material collection process. Even though we did not receive materials, the attempt was helpful for us to practice pitching our project for help; we later pitched to hardware stores for help in donating materials towards the project.

3.6.2 Reaching Out to WPI Staff for Scrap Materials

We wanted to gather as many scrap materials as possible before purchasing materials to lower the costs of the project as much as possible. Kathy Chen informed the team that she could email the staff for potpourri and the staff and faculty could reply if they had any scrap materials to donate. We compiled a sheet of materials that we needed for the building process, and Kathy sent this list to the WPI staff. While we got a few replies, none of the staff was able to provide us with materials within a time frame that would work with our team's construction schedule. Therefore, while it could have been useful if we had more time to construct the wall, we needed to gather materials elsewhere to manage our time constraint of the project.

Jessica Rosewitz helped us gather many materials from Kaven Hall, a building on WPI campus that has tools and many scrap materials from civil engineering. After looking through the Kaven Hall basement for scraps and recycled materials, we gathered materials such as PVC piping, 2x4s, acrylic tubes. Kathy Chen also was able to direct us toward large steel plates from the potpourri email that were about to be thrown away by the school. These steel plates became the magnet board on the pre-schooler section of the wall.

We also were consistently looking for materials around campus throughout our building process. Pulleys that were used on the linear slide system were found in the trash can in the Washburn machine where we were working. These pulleys were originally used in the elevator in the building (maintenance was being done to the elevator in the building). This was a unique material we needed with a great reuse story behind it. Some other materials we found around campus included polycarbonate sheets, drainage tubes, and steel sheet metal. Polycarbonate would have been an expensive component if we had had to purchase it, but we were able to find a scrap sheet. While looking for a heat gun to bend a PVC pipe, we found a flexible drainage tube. The drainage tube became a replacement for the PVC pipe that we had originally planned on bending for the stomp rocket assembly. All materials we collected around campus were thoroughly cleaned and made safe for children to be around.

3.6.3 Requesting Materials from Hardware Stores

One of the methods that we used to source materials was going to hardware stores and obtain any scrap materials that would be useful for the ball wall. Our group reached out to the local Worcester Home Depot to ask for donations of the main materials used for the wall: plywood backing and plywood for laser cutting. Our group talked to the manager of the Home Depot, and we were able to get plywood donated. We also reached out to a second Home Depot store in Shrewsbury asking for polycarbonate and painting supplies. Unfortunately, this Home Depot had a system in place for giving donations, and they did not contact us further with materials to donate. For materials that we were not able to obtain through donations, we purchased them with the funds provided by the YWCA with tax exempt.

3.6.4 Purchasing Unique Materials Online

Some materials that were more unique needed to be purchased online. Some of these materials included the color pieces on the color wheel, shafts for all the rotational components, bearings for rotating components, shaft collars, and magnets for the magnet board. These materials were more difficult to find around campus or from local stores due to the specific sizes and amounts that were needed. We purchased them on Amazon to help with time efficiency and low costs.

3.7 Final Ball Wall Construction Process

The final construction process started with a deliberation of the three sections into each individual section. The team decided to tackle each section separately based on ease of construction. The construction process took place in the Washburn shops, and the components of the wall were stored in Kaven Hall due to the amount of space it took up. The main tool used was the laser cutter, which was efficient and straightforward to use for our team. We used the laser cutter often because it efficiently cut through many pieces of wood, and the shapes cut from the laser cutter were precise. Other tools included in the process were: welder, drill, drill press, hacksaw, belt sander, miter saw, angle grinder, skilsaw, band saw, 3D printer, sandpaper, and hammers. The team covered the entire ball wall with polyurethane once the construction process was completed to make sure that the children would not get splinters from the uneven surface of the wall. More details of the construction for each part of the ball wall can be found in 4.5 Final Ball Wall Construction Process of our Results section.

3.8 Installation of the Ball Wall in the YWCA STEAM Room

The installation process of the wall involved transporting all three sections to the Westborough YWCA with a truck provided by Jessica Rosewitz. We secured each section of the ball wall to the sides of the truck with bungee cords, then arrived at the Westborough YWCA with all three sections. We brought all three sections to the STEAM room, as well as other tools such as screws and hand drills. We learned that the shelves were not secure enough to hold the weight of all sections of the ball wall, so we visited the local Westborough Lowe's to pick up extra screws, sandpaper, L-brackets, and a final trim piece to finish all three sections of the ball wall. More details of securing the bookshelves and installing the ball wall can be found in 4.6 Installation of the Ball Wall in the YWCA STEAM Room of our Results section.

3.9 Storybook

While constructing our wall, we created a storybook narrative that followed our design and building process of the ball wall. The object of this book was to create a fun way of presenting our engineering process in a way that YWCA staff, children, and parents would be able to follow. All text of the book was written to rhyme while also getting the main points of our project across. Our team created our version of the engineering process that we used during our ball wall construction. This version of the engineering process became the outline of our storybook. The storybook also included pictures of our process. Despite the children being too young to understand a lot of the words we used within the storybook, we hoped that the pictures used would present a visual of how we completed our project.

CHAPTER 4: RESULTS AND ANALYSIS

4.1 Feedback from Teachers

4.1.1 Preliminary Teacher Survey

The survey that we sent out contained a lot of preliminary background questions pertaining to the role of the YWCA with the community and the school's STEAM education goals; these questions can be viewed in Appendix E. We learned that the children at the YWCA were within the age range of one to five years of age. We also learned that children played with multiple types of toys, such as mobile trucks and cars, creative Legos, and ball paths. The main response that influenced our project was the idea of having multiple sections of the wall, each targeted at a different age group. The other response that was important was the connection that the YWCA has with the community of Westborough. The teachers of the YWCA mentioned the good bond that the YWCA has with the Westborough community. This made us decide to find a way to integrate the community into the creation and design of the wall through continuous social media posts and social media comments for feedback.

4.1.2 Survey for Informative Feedback on our Design

From this survey that we conducted at the beginning of November after our behavioral observations, we learned that teachers agreed splitting the wall up by age group was appropriate. Teachers gave us helpful feedback about the STEAM concepts they currently taught in the classroom and what concepts they would like to see implemented into ball wall, such as color mixing, texture experiments, and magnets. Our survey received two responses back from teachers, both who taught older Pre-K students. They agreed that having three modular sections of the wall was a good idea and wanted more involvement with color play and sounds. Thus, we knew to implement color and sounds into the design where possible. The results from this survey were from two teachers of older Pre-K age group teachers. A table of the responses to this survey can be viewed in Appendix E.

Overall, we learned that they were hoping to involve more concepts that aligned with their lesson plans; their list involved may concepts, such as the water cycle, patterns, and weighing objects. While we did not include every suggestion given by the teachers, we focused on these concepts from their responses: color mixing, texture experiments, counting, and magnets. We did this through our design by constructing the color wheel, texture panels, counting ramp, and magnetic wall. They also liked the idea of keeping the ball wall modular and separate for each age group, so we sketched designs that incorporated aspects considering each age group and their development.

4.1.3 Social Media Feedback

After posting on social media for feedback from the community, we mainly received likes and encouraging comments. While our main goal was to have more direct opinions and involvement from the community, the social media page instead acted as a medium for updating the community with our progress. Comments on social media were not constructive feedback, but rather compliments about our progress. Despite the lack of feedback, we could still update the community by posting each section of the ball wall we completed. We also received a question about the safety of the ball wall (Figure 14). The team responded by explaining the tests we did with children and the safety precautions taken. Even though the social media aspect was not used for constructive feedback for the wall, we were happy to answer questions from the Donna Bullock Taylor, an employee at the STEM Education Center regarding the engineering process; one of our goals for the project was to educate the community about the engineering process, and social media allowed us to do so.

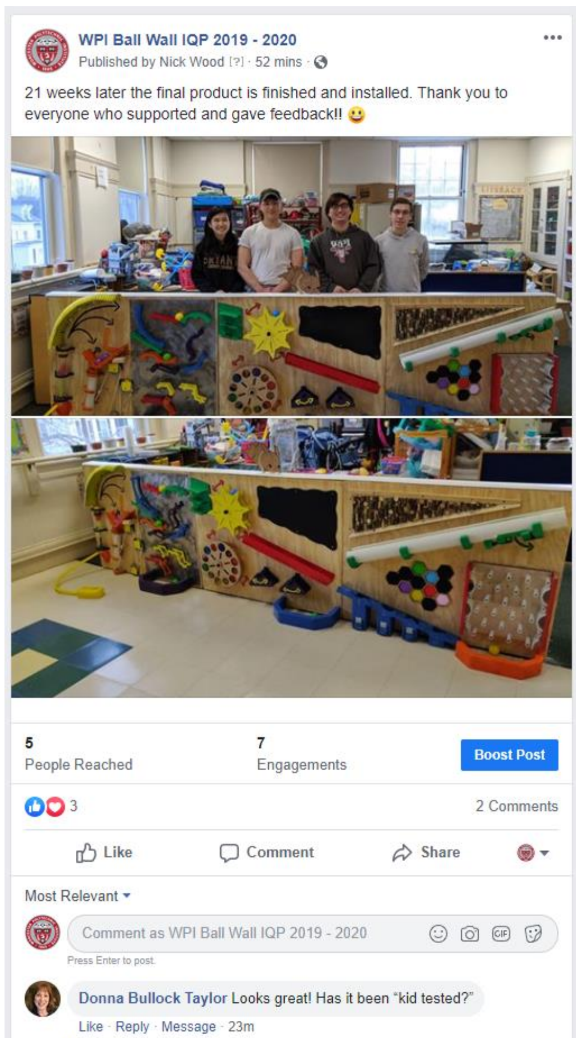

Figure 14: Photo we posted of the final ball wall, where a commenter asks about our engineering process.

4.2 Observations at Preschools

4.2.1 Worcester Head Start STEAM Room

Our group visited Worcester Head Start to observe the ball walls they created for similar age groups as the YWCA. Head Start created an overall theme to each STEAM room. The room we visited was based on nature-related STEAM topics. Since the room was focused on nature, activities for the kids included fossil digging, water stations, a tree-themed ball wall, live animals, a color mixing station, and a sand station. Surprisingly, the ball wall was the least used station of the nature themed room. The ball wall had multiple ramps that could be connected based on the magnetic backing, shown in Figure 15:

Figure 15: Magnetic ball wall located at the Worcester Head Start nature STEAM room.

We also noted that their ball wall was made of low-cost materials that were either supplied by parents or recycled materials. We learned that the water station was the most popular station to the children because they could connect and disconnect tubes to create a flow of water. This water station is pictured in Figure 16:

Figure 16: Water station located at the Worcester Head Start nature STEAM room.

The water station was also convenient for educators because they could easily clean the parts each day. This station is where the educators used the term “parallel play”. Parallel play is where two kids are standing next to each other and are watching each other. When one kid becomes interested in what another kid is doing, that kid would try to replicate or help the other kids. This way, the children learn how to do new things based on what their peers are doing. We found this to be a crucial part of education for children that are not ready to directly socialize with classmates, so parallel play was one of the most important topics that we concluded to implement into our own YWCA ball wall.

4.2.2 Westborough YWCA Classes and Classrooms

For our observations of preschool social interaction, we saw most of the kids find small groups to play with while they were all using the same toy. Some of these interactions were collaborative with the purpose of meeting a shared end goal, whereas some of these were more independent goals for individual students. Some kids took inspiration from watching other kids play with the toys and learned through parallel play. These findings influenced our design by inspiring collaborative elements on the wall because we learned from observations that the preschoolers would learn from both collaborative and parallel play environments.

In contrast to preschool children, the toddlers were more independent in collaborative and parallel play. With social interaction being something that the toddlers have not developed yet everything they were doing was a lot more independent and at most only with another teacher guiding them what to do. This information aided in our design by showing us that for the toddler-focused parts of the wall, they would have to be more independent because they lack collaboration at their age due to their lack of communication development.

For our student to teacher observations amongst the preschoolers, the most crucial observation was that the teachers did not have a concrete lesson plan for the time in the STEAM room. The time teachers spent with the kids were instead focused on safety, allowing the kids to be independent when interacting with one another and playing with their toys. These observations influenced our design by giving the option of creating things that allow the kids to learn independently but can involve the teachers as well when necessary, such as our section of the wall that involves the color wheels or the magnetic board. Contrarily to the preschooler observations, the toddlers were independent due to developing social skills and language. This was an important observation to us because it also affected the student to teacher interactions. Most of the toddlers received help from teachers to properly use the toys. In addition to this, we noticed many of the teachers were demonstrating how to use the toy first. After this, they watched the toddler try to use the toy, then explained the outcome verbally while clapping or praising them as encouragement.

Figure 17: Picture of heat-sensitive color changing boards that YWCA children played with in STEAM room. (Lakeshore Learning Product, n.d.)

For example, the toddlers would put their hands-on heat-sensitive boards that changed colors based on how much heat emitted through the child's hand onto the board. This toy is picture in Figure 17. When the children did not keep their hands on the board long enough, it would not change color as intended. Teachers would use the heat-sensitive boards to demonstrate to the kids what colors could be made based on how much length of time and pressure they put into the board. Then, once the kids tried to use the board again, they learned to hold their hands-on for longer. These teaching moments influenced our design by showing us that we should create parts designated for the toddlers that provide a teaching moment for the teachers.

For student interactions with their toys, we noticed that most preschoolers used the toys for their intended use, but some found other creative ways to use the toys. One example of this was a child using a rod-shaped toy as a sword, despite it intending to be a geometric puzzle piece. This information was useful for us because it meant that the children may create new ways to play with the ball wall in ways we did not initially plan.

The toddlers' interactions with the toys were different than the preschooler interactions. While the toys were meant to be educational, the kids did not understand how to use some of the toys as marketed or intended. The teachers had to show the toddlers how to use the toys, as mentioned above. Without teacher intervention, the toddlers mostly just picked up and swung around the toys or poked at them. Most toys consisting of color or counting were not used necessarily for their intended purpose but were just something for the toddlers to grab onto and feel. It was mostly the teachers that would teach the toddlers to use them for the intended purposes.

As for the qualities of the preschooler toys, most of them were solid colors and very vibrant to grab a preschooler's attention. In addition, they were mostly all plastic or wooden with smoothed edges. This influenced our design by showing us what colors were common among their current toys, allowing us to think of how we might want to match colors on our ball wall. Along with our research that children prefer bright colors such as red and blue over basic colors such as white and gray, we decided to aim for solid, bright colors for our components of the wall.

The toys that the toddlers used were a lot simpler in design and larger compared to the preschooler toys. The toys were also of few solid colors and portrayed everyday objects that a person might see throughout their day. These everyday objects include toys such as trucks, cars, and house sets. These toys were different from many of the preschooler toys, which were often creative puzzle play and building toys.

4.3 Design

To start the design phase, we first conducted functional requirements based on requests from our sponsor, our observations at the YWCA, and our background research. From these functional requirements, our group brainstormed and put together hand drawing sketches of each ball wall section. These hand drawings were later translated into CAD drawings to give a three-dimensional aspect to the drawings. From these drawings, we built prototypes of certain parts of the wall to test and made further changes to the design. After these design iterations, we had a final design for each section of the ball wall.

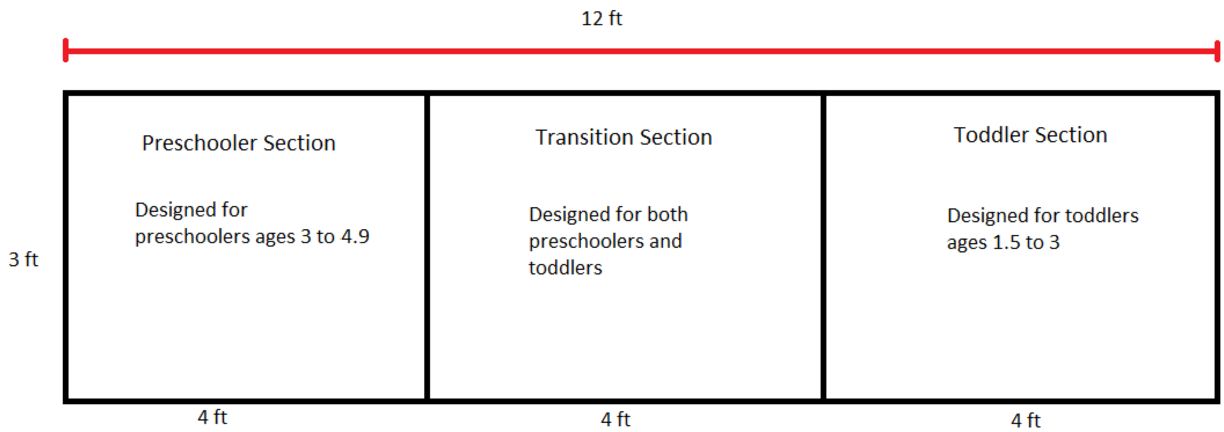

Figure 18: The ball wall was composed of three sections, each designed for different age groups. From left to right: Preschool Section, Transition section, Toddler section.

The leftmost and rightmost sections of the ball wall were created to pertain to the preschoolers and toddlers separately, whereas the middle section is meant to include educational aspects from both age groups (Figure 18). We planned for teachers to help the toddler students learn about the parts of the preschooler wall that may be more difficult for toddlers to understand. All the sections of the ball wall cohesively work together by several entry and exit points for the balls, and thus the wall is interconnected through multiple pathways. Thus, the ball wall allows the YWCA preschool age groups to use all sections of the wall despite certain sections being focused on specific age groups. We also made the dimensions match the dimensions of the bookcase to make sure we could easily attach the ball wall once we implemented the final design at the YWCA. Having exact measurements meant that no parts of the wall would be protruding from the sides of the walls.

4.3.1 Toddler Section – Functional Requirements and Initial Plans

For the toddler section, we noticed from our research and our YWCA STEAM room observations that texture, sound, and color was important for the younger toddler kids. The toddlers are just learning how to speak and interact with one another. They are trying to understand what is around them, and therefore are easily stimulated by sensory elements. Some of the STEAM concepts we determined to introduce to this age group included simple ideas of cause and effect, gravity, counting, and language (both English and Spanish). Based on our observation that the toddlers were too young to understand how to use most toys as was most likely intended by the toy makers, we made sure that all parts of the wall were mounted and unable to be modified in position. Mounting the paths of the wall will allow most of the children to be able to use the wall effectively through experimentation. Thus, the backboard acted as a base wall design for the kids to learn from instead of creating their own wall designs. From our observations of our prototypes, we expect that children of all age groups will find new creative ways to utilize the wall, so creativity will not be lost in the decision of mounting all parts of this section. We also expect that toddlers will be able to express creativity in later sections of the wall with guidance from teachers. A summary of the functional requirements for the toddler section are listed below in Table 6:

Table 6: Brainstorming Functional Requirements for Toddler Section of the Ball Wall

- Texture → Paint, Material, Wood?
- Sound → Bell, Drum, Chimes
- Lights → Hand Crank?
- Bright Color → Cool Tones (Red, Purple, Blue), Keep them Solid
- Words/Letters/Numbers
- Character?

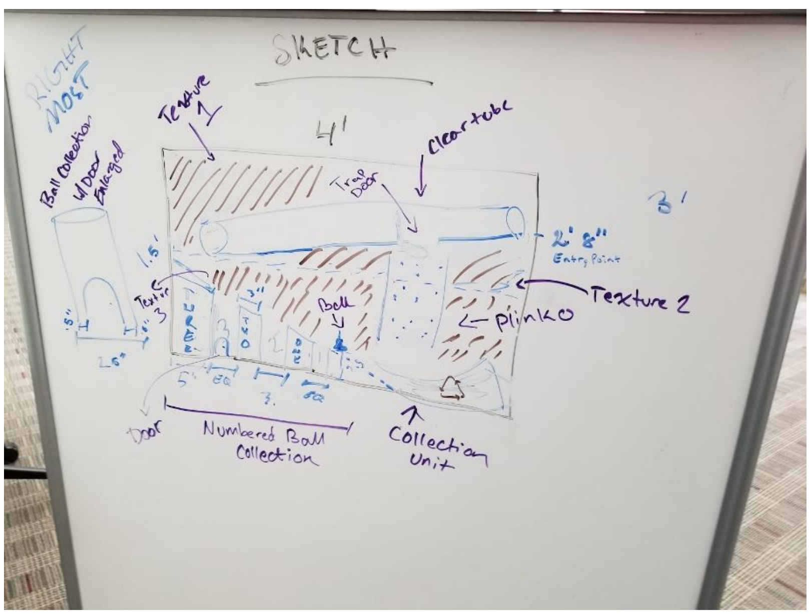

Figure 19: Whiteboard hand drawing of toddler section.

With these functional requirements established, the focus of the toddler section was simple, age-appropriate apparatuses that would be easy for the toddlers at YWCA to understand. We sketched out a design that incorporated the functional requirements that we made (Figure 19). This section has a tube starting in the top right-hand corner that connects about midway on the left-hand side. This tube introduces the concept of an object moving in motion until something changes its direction. For instance, about one-third of the way into the tube, there is a hinged door that can open to allow a ball to fall into a Plinko section of the wall. Plinko is a wall with multiple, evenly spaced pegs that randomizes the path of an object falling down the wall, or a random motion peg board (Figure 20).

Figure 20: Example picture of a Plinko board (Fun Carnival, n.d.)

The hinged door in the beginning allows the kids to change the path of where the ball goes next into the Plinko. When the ball falls from the hinged door and into the Plinko, it exemplifies a basic example of randomness of path that the ball can take.

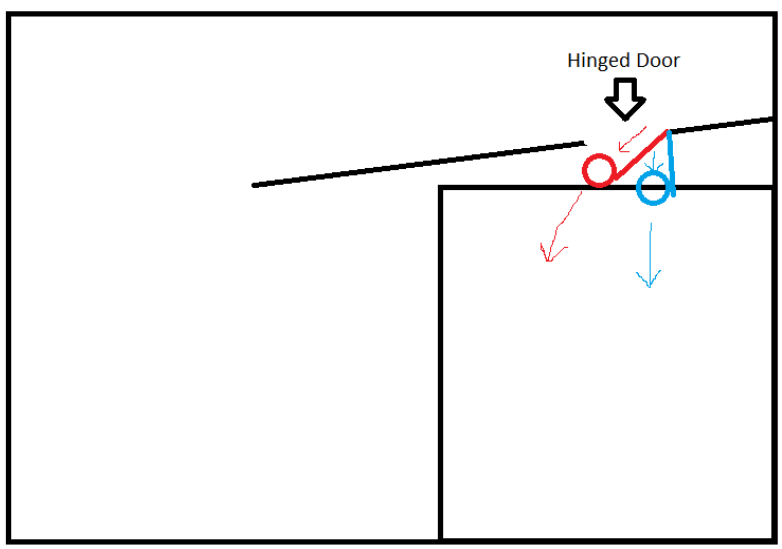

Figure 21: Diagram of how hinged door changes the angle of the ball falling into Plinko

By changing the angle of the hinged door, the ball can fall into different starting points of the Plinko (Figure 21). The Plinko will exemplify a factor that influences the fall of the ball. Adding Plinko to our ball wall is in reference to the preschool curriculum framework that encourages the STEAM concept of multiple end goals.

In the bottom left-hand corner of the toddler section is the counting ramp.

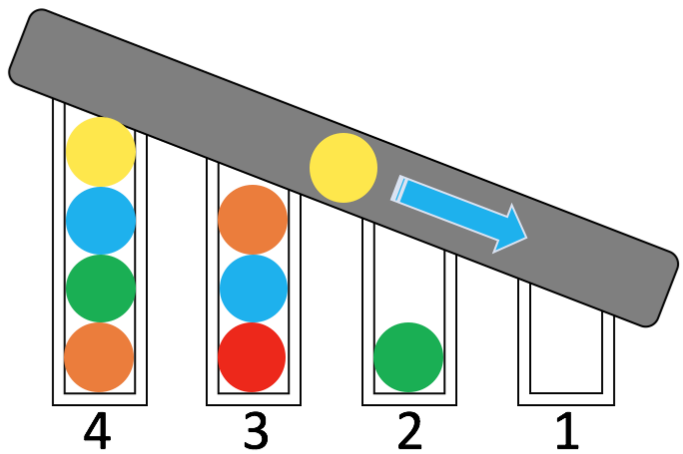

Figure 22: Example of counting ramp. The yellow ball rolling down the counting ramp will pass over tube four and three on the right but fall into tube two.

This mechanism has four tubes which holds according amount of balls (the fourth tube on the left holds four balls, the third tube holds three, and so on). If all tubes are filled with the correct number of balls, then a ball that rolls down this ramp should be able to roll over these tubes and fall into a collection unit that we had placed in the right-hand bottom corner of this section (Figure 22). These tubes were supposed to have each respective number spelled out in English and Spanish vertically along the front onf the tube, but this has been changed in 4.3.3 Toddler Section – Design Iterations. We wanted to add this feature because the YWCA tries to involve both languages in their early development, and we found English and Spanish around classrooms during our observations. A bell is placed at the end of the counting ramp to indicate that the tubes are full, and to indicate achievement of reaching a goal. Lastly, the open spaces of the wall were replaced with texture to let the toddlers observe and feel different materials. A summary of the basic elements of the toddler section of the ball wall are listed below in Table 7:

Table 7: Summary of Components for Toddler Section of Ball Wall

- Entry tube and hinged door
- Plinko
- Counting Ramp
- Textured Panels

4.3.2 Toddler Section – CAD Drawing and Design Iterations

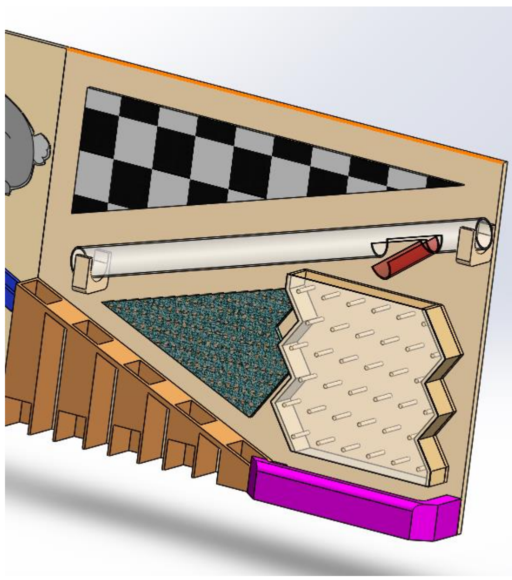

Figure 23: Our CAD Drawing of Toddler Section which includes translucent full tube with a hinged door, Plinko, counting ball ramp, textures, and ball collection.

A Solidworks CAD drawing is shown in Figure 23 and is meant to give a three-dimensional aspect of the toddler section. For spaces that were not occupied by the Plinko, entry tube and hinged door, and the counting ramp, we decided to add textures that the kids could touch and feel with. We decided to add a natural texture section, where we used locally found wood and painted a finish for the children to touch. This would be located where the checkered texture section of the picture is in Figure 23. For the green texture section on the wall, we were going to add artificial grass, but this changed to 3D printed textural hexagon shapes and cut out pieces of rubber trivets to attach to the wall. Lastly, we added a ball collection at the bottom of the counting ramp and the Plinko to make the cleaning process for the YWCA easier.

As part of the engineering design process, we made design iterations based on prototypes and suggestions. From our counting ramp prototype, we were able to see that five tubes would take up too much room and would not leave enough room for the balls to collect at the end. Thus, we decided to instead have only four tubes for the counting ramp to shorten the width of the overall ramp. Based on suggestions given from YWCA members, we planned to make the tubes painted brightly to make the section more engaging for the toddlers. Through feedback, we also learned that the ball might get stuck in the PVC pipe, so we decided to change it to a half-tube so that balls can easily be removed in the case that it does not roll down the tube ramp. This tube was going to be clear, but we found a large recyclable tube that could be used in place of the clear tube, so our final design used an opaque half-pipe.

As we were building this section with our final materials, we had other changes we needed to make. We realized that the plastic balls were very light and did not provide much weight. Therefore, due to our budget and this observation, we removed the bell from the design. Additionally, we were unable to use clear tubing for the material for the towers due to a difficulty in making the hinged doors on the clear tubes, so we made the towers out of wood instead. The tower of the counting ramp that is meant to contain only one ball was too short to add a hinged door. Therefore, we changed the placement of the words and numbers; we put the numbers on the face of the ramp where the balls roll over, and we wrote the English and Spanish for each number of the face of the doors of the counting ramp (except for the smallest tower, in which we wrote the English and Spanish on the face of the tower). Additionally, we drew a small diagram of how the balls were to be stacked on the rail of the counting ramp so that the children could visualize the way that the balls were supposed to be stacked in each tower. This is pictured in Figure 24:

Figure 24: Counting ramp with visual of how plastic balls inside ball tower is supposed to be stacked.

4.3.4 Transition Section – Functional Requirements and Initial Plans

After visiting the YWCA multiple times and Worcester Head Start, we were able to observe that many children are transitioning from the toddler age group to the preschooler age group. This section is designed as a transition between toddler and preschool. Because this section is located between the toddler section and the preschooler section, we wanted the transition section of the wall to be usable for both preschoolers and toddlers. We decided that modularity in terms of multiple entry and exit points was an important design element. We determined that it was best for the toddlers to not only play with the toddler section, but also change the path to continue into other destinations on the ball wall. Because we observed parallel play at the Worcester Head Start, we wanted to add parallel play as a main theme for the transition section of the wall. Sound and color were still an integral part for toddlers mainly, but also for preschoolers. We expected the apparatuses to make their own noises and planned to color multiple parts of this section to involve these sensory details. A summary of these functional requires is listed below in Table 8:

Table 8: Brainstorming Functional Requirements for Transition Section of the Ball Wall

- Multiple entry and exit points → Need to connect toddler and preschooler sections of the wall
- Parallel Play → Can add something with balance? Will need separate activities to include so that the children can watch each other as they are also playing with the wall
- Sound → Natural sounds will come from gadgetries that we add to this section
- Color
- Character? → Maybe Thumper? We will design the character for the YWCA

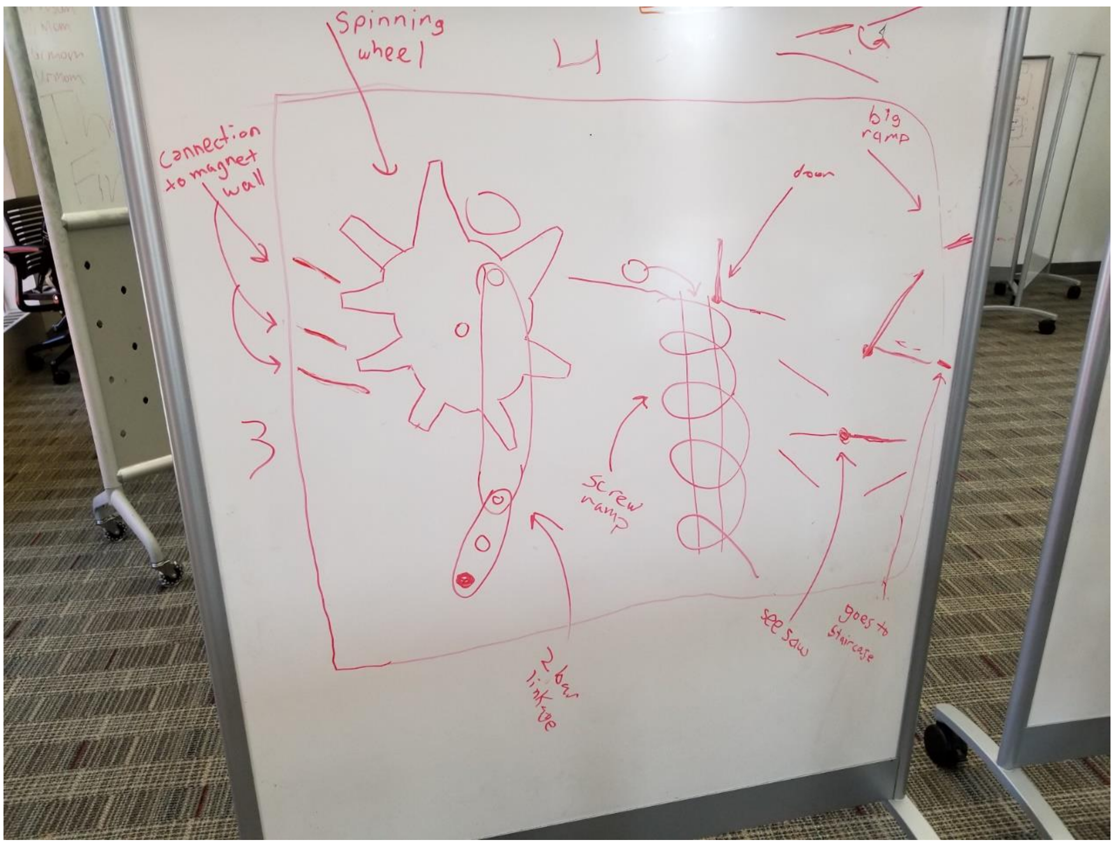

Figure 25: Whiteboard Hand Drawing of Transition Section including a spinning wheel that will turn the balls onto a ramp by a two-bar linkage, a corkscrew path, and balancing teeter totters.

In the top left-hand corner of Figure 25, there is a spinning wheel powered by a two-bar linkage. The spinning wheel holds one ball per cutout, and the children can control this linkage by rotating a crank located at the bottom of the lower bar. The linkage and spinning wheel introduce the YWCA kids to rotational motion. To the left of the spinning wheel are ramps that will allow balls to come from the preschooler section. However, the children also have the option of placing the balls manually into the spinning wheel as a starting point. This spinning wheel is controlled by a two-bar linkage that will rotate the spinning wheel as the children move the crank in a circular motion. The balls rotate clockwise on the spinning wheel toward the right of the wheel, where the balls will fall down a ramp. The ramp includes two drop down locations from the trap doors along the path of the ramp. The first trap door feeds into a corkscrew ramp. The corkscrew ramp is a fun mechanism for the kids to interact with and see how long paths can be changed into rotating vertical motion to get from the top of the ramp to the bottom of the ramp. The second trap door leads into teeter totters, allowing for the children to witness an aspect of gravity and balance. The end of the ramp later connects to the toddler section counting ramp.

<u>4.3.5 Transition Section – CAD Drawing and Design Iterations</u>

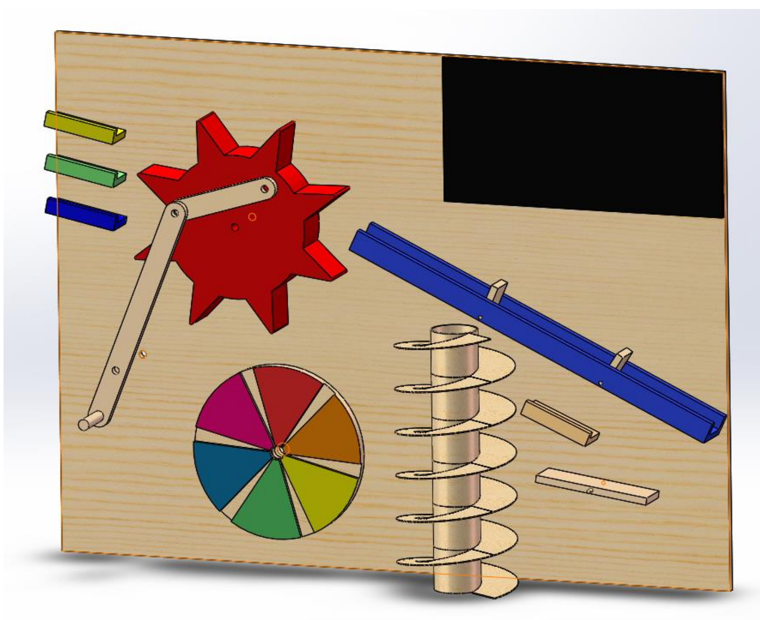

Figure 26: An earlier CAD drawing of Transition Section, including a spinning wheel with two-point linkage rotational motion, a corkscrew, teeter totters, a blackboard, and a color wheel.

After completing the hand drawing for the transition section, we transported the ideas into CAD drawings (Figure 26). Some minor changes that were added into this design includes having the trap doors built into the ramp itself allowing for easier manufacturing. We also noticed we could add additional teeter totters in the path coming from the second trap door due to the extra space in the bottom right corner of the transition section. This will be discussed in the following section.

For the design iterations, we talked to Luisa and educators and the YWCA. Since our design process was agile, it was important for us to relook open spaces of the design. They suggested that we added something to the open spaces of the wall. In the open space in the bottom left-hand corner, we came up with the idea of adding a spinning color wheel. This wheel is not be directly attached to a path or hold balls. This will allow for the children to combine colors together by layering the translucent colors together. Behind the layering of these color wheels, we will have a push button flashlight which would illuminate the translucent section that has the layered color wheels.

In the top right-hand corner, we discussed adding a whiteboard or chalkboard to allow the kids to draw creative art pieces. After speaking with Luisa about this idea, she suggested a chalkboard as a preference for the YWCA. Thus, the upper right-hand corner of this section would contain a blackboard section for all children to draw and be creative on. Lastly, Luisa was hoping to see a connection to toddler section for our wall, so we added a component to the wall that will allow the toddlers to choose to either go to the teeter totter balance blocks or the counting ramp after going down the clear tube. As we built the final wall, we had to make additional changes. The two-point linkage system was removed due to the lack of space. Instead, the wheel can be spun by simply rotating the wheel by hand. We removed the corkscrew due to time constraints and difficulties finding suitable materials to build this component. Lastly, we decided to add a laser cutout of Thumper on top of the transition section of the wall so that the cutout would be on display. A summary of design elements can be viewed in Table 9 below:

Table 9: Summary of Components for Transition Section of the Ball Wall

• Spinning wheel with hand crank • Ramp to teeter totters and toddler section • Teeter totters • Chalk Board • Color Wheels and Light • Thumper Cut-out

4.3.7 Preschooler Section – Functional Requirements and Initial Plans

For the preschool section of the ball wall, we researched and observed that collaboration between peers is a key part of social development for preschoolers. We saw a lot of collaborative construction and play through our preliminary observations when the kids were playing with Legos. Thus, we wanted to focus on collaboration and inspiring creativity. Worcester Head Start did an excellent job inspiring creativity with their magnetic ramps and backboard. We wanted to build off this idea for this section of the ball wall, and thus we created a magnetic board section for the right side of this preschooler section. We envisioned that the children would use the magnetic pathways to create their own paths to the bottom of the preschooler section or create entry points into the transition section. Entry and exit points to the middle section would be important for the kids to be creative with their own paths.

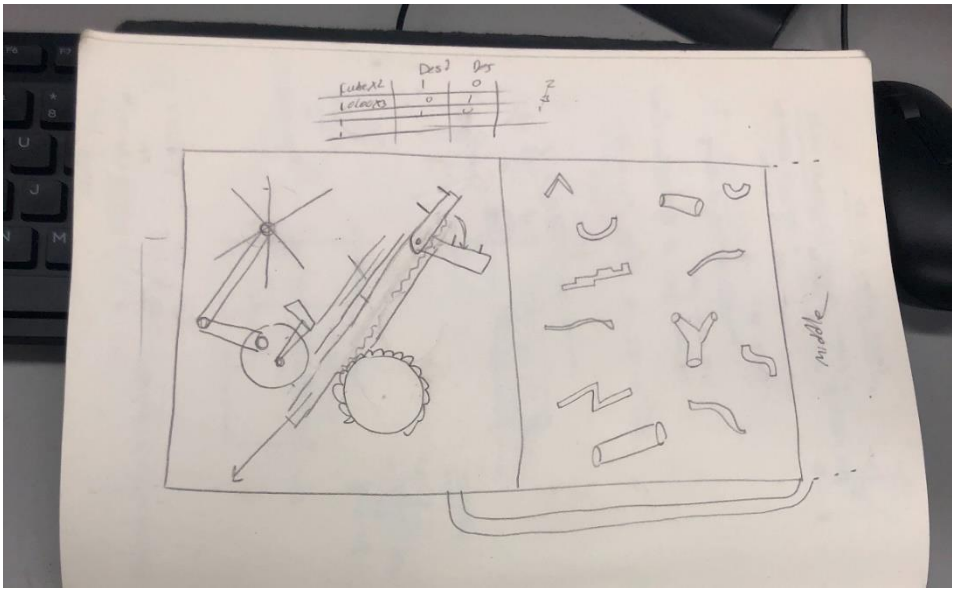

Figure 27: Paper sketch of preschooler section of the ball wall.

We were able to put together hand drawings from our functional requirements for the preschooler section (Figure 27). On the top left-hand side, we designed a spinning wheel with a two-bar linkage. This would give the kids a chance to have hands-on play with cranks to control the spinning wheel. We wanted the children to have a hands-on experience with rotational motion because most parts of the wall involved linear motion. Below the spinning wheel is a rack and pinion track to raise the balls to the top of the wall. Once the balls reach the top, they would dispense on the right side. We hoped that the children would see that the rack would be cranked up and would fall, and they had control of this through the gear. We also hoped that this rack and pinion would be a sound aspect to this section of the wall because there would be a wood clacking noise as pinion fell back to the bottom. The right-hand side of this section is where the creative aspect comes into play. The right-hand side has a magnetic back piece with smaller individual magnetic pieces that can be moved around and will create a path for the balls to be rolled down. These smaller pieces can be put together in several configurations allowing the kids to create their own paths. Our functional requirements for the preschooler section are in Table 10:

Table 10: Brainstorming Functional Requirements for Preschooler Section of the Ball Wall

• Lots of Options to Make Own Path → Magnetic like Head Start? • Gears and machinery → more complexity than previous sections • Natural sounds from ball wall • Wheel

4.3.8 Preschooler Section – CAD Drawings and Design Iterations

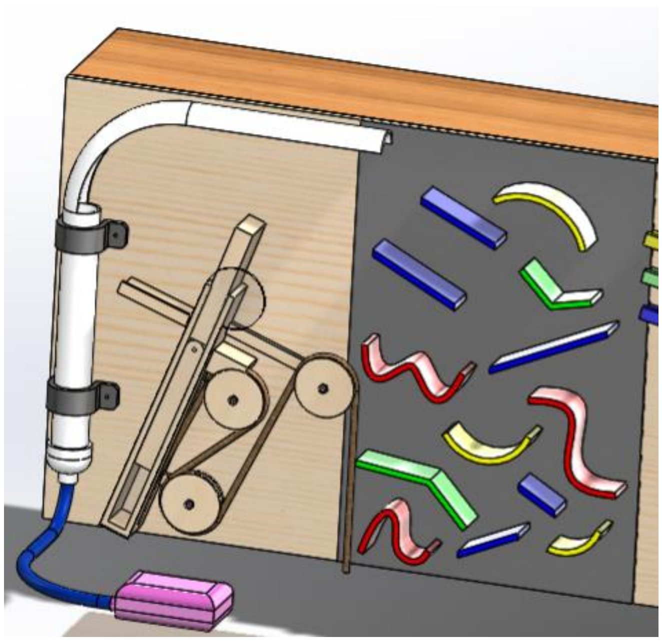

Figure 28: CAD drawing for preschooler section, including a pulley linkage system, a stomp rocket, and a magnetic board.

Figure 28 shows the CAD design that resulted from our sketch and functional requirements. We decided to move the spinning wheel to the transition section to free up space for the linear slide. After discussing as a group and talking with educators at the YWCA, we realized that there is a possibility for pinching points that may hurt the children, and thus would not be safe for them to use. Additionally, we found that it may be too difficult to create in the allotted time of our project. Therefore, we decided it would be best to change the functionality of how the linear slide operated. Instead of having the linear slide power by a rack and pinion, we thought it may be better to have it powered by ropes and pulleys because ropes and pulleys avoid pinch points and will be easier to build. Three pulleys would be attached sequentially to wall with having tie offs at the upper part of the slide and after the last pulley. Changing to a slide operated by ropes and pulleys should help with the wear and tear of the materials and make the concept of lifting the ball to magnet wall easier for the YWCA kids to understand. We also included a stomp rocket, where children can press their food against the pedal, and the ball would launch out of the vertical tube. Additionally, a plastic half-pipe was placed on top to direct the motion of the ball coming from the stomp rocket.

Where the stomp rocket was placed, we originally had a spinning wheel with a two-bar linkage (this is now in the transition section). We realized the spinning wheel would take up too much space and later moved it to the middle section for the CAD drawing. Instead of the spinning wheel, we decided to add a rocket stomper for the children to use their feet. We were inspired by an air pump that we found in Foisie Innovation Studios at the WPI campus. The children will be able to put balls inside of the tube, then stomp on the rocket stomper to launch the balls out of the tube and towards the magnetic board. Because we were aware that the children may load the rocket stomper tube with too many balls, we made the tube removable so that it could be unloaded easily.

4.4 Prototyping Process

4.4.1 Construction Methods

Figure 29: Spencer using the bandsaw in Washburn Shops to break down large sections of cardboard to fit into the laser cutter.

To build our prototypes, we took advantage of the Washburn Shops lab space located at WPI. The cardboard we used for the prototypes was able to be laser cut to get relatively exact shapes quickly based on CAD models that we converted to vector images. In order to use the laser cutter, large cardboard sheets where broken down using band saw so that they would fit into the laser cutter (Figure 29). We found that the thick, multi-layered cardboard would catch fire while being cut on the edge perpendicular to the corrugations. To solve this, we tested multiple settings to reduce the dwell time of the laser to a minimum. Increasing cut speed helped, but we found the best method to prevent burning was dampening susceptible edges of the cardboard prior to cutting as well as orienting our cut layout on the stock to reduce cuts parallel to corrugations. We used other tools such as hacksaws, drills, X-acto knives, and sandpaper to create prototypes. Once pieces of the prototype were created, we used simple methods such as tape and zip ties to join pieces quickly.

4.4.2 Prototype Construction for the Counting Ramp

Building a physical model of the counting ramp helped us learn about how our final counting ramp would function (Figure 30). When creating the counting ramp, the first thing we had to do was model specific parts that were manufacturable to any community. The initial CAD model we created was good to display our concept but was not built in a way that was possible to manufacture for most communities. This made us reconsider and create other CAD models to make our counting ramp possible to create for other communities. Another learning experience we had while building the counting ramps was the importance of details in our designs to ensure the intended ball behaviors. Specifically, this meant that the angle of the was critical. The ramp had to be angled such that the plastic balls from the YWCA would roll down the ramp with enough speed to pass over our full counting cylinders without getting stuck (Figure 22). The balls also had to move slow enough that they would fall into the opening of the empty counting cylinders.

Figure 30: Nick and Spencer determining the best angle for counting ramp for correct function and trail of balls.

4.4.3 Prototype Results for Counting Ramp

After creating the counting ramp cardboard prototype, we observed the separate groups of preschoolers and toddlers interact with the prototype. When the preschoolers came into the room to try our prototype, the teacher in the STEAM room first explained to the children what our prototype was meant to do, and the preschoolers understood the counting concept that we were aiming for with this prototype. Their understanding was exemplified when they were able to do addition to solve for how many balls could be contained in each tube. After the preschoolers learned about what the counting ramp was intended to do, the children started to play with the prototype with the balls that will be used for the final ball wall. At first, four to five children were all playing with the ramp at once, working together to put the balls down the ramp. They also learned to lift the ramp to empty the balls, then they would start over to play with it again. The children did not get bored with the prototype despite it being intended for the younger age group. They also took actions that we did not predict at first, such as filling the tubes manually by placing them in by hand rather than rolling the balls down the ramp to fill the tubes. Over time, the number of children playing with the wall dissipated and only one to two kids remained playing with the counting ramp. These two children creatively played with our prototype by completely fill the ramp will balls before releasing them all at once, as pictured in Figure 31:

Figure 31: Preschooler creatively uses our prototype by trying to collect as many balls as possible before releasing them down the ramp.

With the toddler group, the teachers first started with directly showing the toddlers how to roll the ball down the ramp. They repeated this process multiple times before the kids tried to play with the wall. With a lot of encouragement from teachers, the toddlers approached our prototype and began to use it after they were handed a ball from the teachers. The teacher commented that they were more shy than usual because we were strangers in the room. However, over time, more of the children began to play with our prototype as we anticipated. We concluded from the toddlers playing with the prototype that the toddlers would be able to use the counting ramp with guidance from teachers and is what we initially predicted from our first observations.

Lastly, we needed to compare our prototype to the actual size of the wall (Figure 32). We found that the prototype was too big and would not be able to leave enough space for the Plinko, so we took note of this for our actual building process.

Figure 32: Picture of our prototype compared to toddler section of the wall.

4.4.4 Prototype Construction for Plinko

Figure 33: Plinko prototype we created with scrape plastic pipes and cardboard.

Another prototype we built was the Plinko pegboard (Figure 33). This prototype was constructed using cardboard and 5/8 inch diameter PVC pipe. We decided to produce this prototype to test the spacing between pegs in order to get randomized ball paths from the top while still allowing free movement without getting jammed. Our first attempt at this prototype presented an issue: the first holes we created did not hold the pegs tightly enough. To solve this, we made a test piece that had a variety of holes with varying diameters to determine a hole size that would provide a tight press fit (Figure 34). Although the materials changed significantly when building the final part, we implemented tolerance tests with the cardboard to find the best diameter size. These tests proved to be important to get part measurements correct the first time and produce low scrap rates.

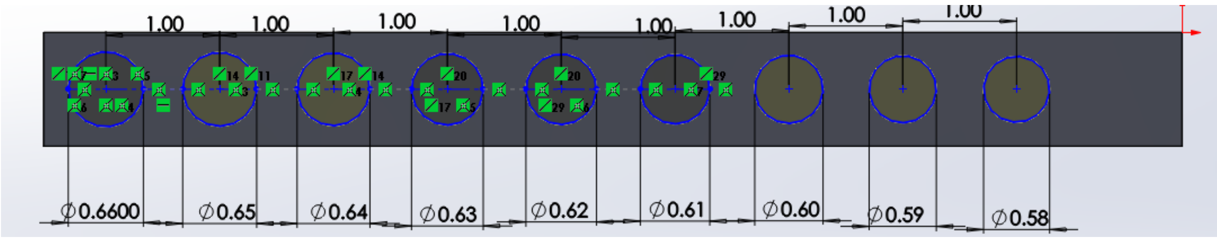

Figure 34: CAD sketch used to laser cut different diameters to test which best fit our Plinko dowel size. Each diameter decreases in size by 0.01 inches going from left to right.

A piece of cardboard was cut out with a row of circles, each one smaller than the other by 0.01 inches. This allowed for the plastic dowels to be inserted into each hole so the best pressure fit could be determined. Once we determined which size fit best, we created a Plinko pattern on a piece of cardboard to test function of the prototype.

4.4.5 Prototype Results for Plinko

We tested to prototype by ourselves in the lab instead of bringing it to the YWCA. When testing the tolerances of the Plinko prototype, we found that a 0.63-inch diameter worked best for fitting all the PVC dowels into the Plinko board. This information was useful because it told us what tolerance we could use to pressure fit all the dowels for the final Plinko board. We found that once we had the correct hole size for the pegs, we evenly spaced out the PVC pipe pegs and dropped the ball multiple times to observe the pathing. Even when dropping the ball from the same starting point, we found that the ball would take different paths each time. These different paths provided the randomness that we were hoping the ball wall to have. The spacing between the pegs in each row were wide enough for the ball to fall through with ease, but we found that the distance between the rows of pegs from each other was a little too small. While the distance between the rows didn’t change the fact that the Plinko prototype worked, we found the impact between each row too abrupt. Therefore, we took this into consideration for our final Plinko construction.

4.5 Final Ball Wall Construction Process

4.5.1 Toddler Section Construction

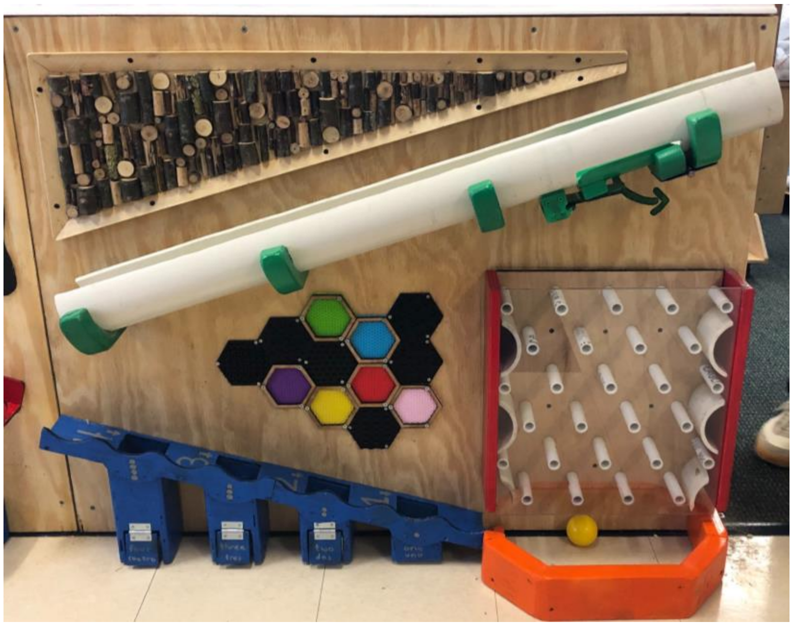

Figure 35: The final toddler section of the ball wall including the PVC pipe with the hinged door, Plinko, the counting ramp, and the textured panels.

For the toddler section, there were a lot of parts that needed to be created to support the tube and for the numbered ball ramp. Through the acquisition of PVC piping from WPI, the top of the tube was cut out and sanded down to emulate a ramp for a ball to roll down. Close to the top of the ramp, a hole was cut out for a ball to fall through; the hole had a hinged door to open or close the hold as desired, which is pictured in Figure 35 as the green door along the bottom of the pipe. If the hinged door was open, the ball could fall into the Plinko piece of the toddler section. To support this ramp on the wall, we created some circular cutouts to hold the ramp in place. Figure 35 pictures the PVC pipe held up by the green circular cutouts. The toddler section also has a Plinko board that has a laser cut plywood backpiece alongside some PVC pipes cut to act as the pegs within the board and a piece of clear plastic to contain the board. The Plinko board is pictured in Figure 35 with the red walls.

The toddler section also contained texture pieces. These pieces were created with multiple materials and designs to create different textures within the two texture pieces. The upper piece exemplified natural material, created with circular pieces of wood that varied in size and orientation to vary the texture. The lower texture piece is made up of 3D printed hexagons with different shapes on them to invoke different textures when touching them. In addition to these hexagonal pieces, rubber silicone trivets were cut to the same shape to add a contrasting rubbery feel compared to the hard, plastic hexagonal pieces.

Lastly, Figure 35 shows the blue counting ramp. This piece was made from laser cut wood that was glued together to make each of the four towers. Each tower has small door holes cut out of the bottom. The doors were mounted with a hinge to both ensure the ball stays within the tower but also is openable to retrieve the balls when needed. On top of these towers was a 2x4 piece of wood that has cutouts for each tower. This ramp was glued onto the pieces and mounted to the wall with an attached side rail to make sure the ball stays on the ramp. On the face of the ramp, we wrote the number of balls for each hole needed for a ball to successfully roll down the ramp. Additionally, we drew a small diagram of how the balls needed to be stacked for a ball to successfully roll down the ramp. This diagram was drawn on the side rail. The wooden supports on the half-pipe ramp and the numbered ball collection were spray painted green and blue, respectively, to add distinct colors on this section of the wall. Once all these pieces were created, they were bolted down to a larger piece of 2x4 wood.

4.5.2 Transition Section Construction

Figure 36: The final transition section of the ball wall including the transition piece from the preschooler section, spinning wheel, color wheel, teeter totters, red trap door ramp, and chalkboard.

We created the spinning color wheel, the teeter totter pieces, and the ramps for the transition section (Figure 36). The spinning color wheel was comprised of two wheels made from laser cut wood with twelve smaller holes. In an alternating order, six of the twelve circles ended up with a color to fill to hole, representing the color wheel of red, orange, yellow, green, blue, and purple (Figure 37). Each of these colored tabs was glued down onto the wooden piece using epoxy and weighed down for compression. The spaces between each colored tab allowed a space to turn on the light. These lights could be manually turned on by pressing the face of the light. The lights are battery powered and can be replaced with three triple A batteries. The middle of each circle has an offset wooden piece screwed into it with a hole in the middle so a metal rod can fit through it.

Figure 37: Final product for color wheel on transition section. It contains two panels and lights, which can be rotated to combine different colors.

The teeter totter pieces were made from laser cut wood with a small wooden piece used as a storage bay below it for the ball (Figure 38). Walls of the teeter totter had slots cut out of the bottom for the floor of the teeter totter to be pressure fit into to create the piece. Each of these pieces has a circular mounting piece that is screwed into the teeter totter walls and has a hole in the middle for a rod to be passed through so it can sway back and forth. The circular mounting piece is made up of three smaller laser cut wooden circles with holes in the middle of each. These pieces are then glued and screwed together and mounted to the teeter totter on the inner faces to prevent the teeter totter from being rotated too quickly.

Figure 38: Final teeter totters fastened with circular mounting pieces and metal rods.

Creating the ramp for this section was very similar to other parts on the wall. It started with a laser cut piece of wood that had cutouts in the bottom for the base of the ramp to be slotted into with wood glue and a pressure fit. Within the two cutouts of this ramp, there were wooden pieces that were sanded smooth and screwed into the ramp in such a way that they can be rotated so they can act as doors for the teeter totter pieces below it.

The spinning wheel was made in a similar way to the color wheel. Two identical pieces were laser cut out of wood to look like gears with teeth. Each of these sections had a hole cut out in the middle for a bearing to be attached so it could rotate. The metal rod that the piece rotated on was a metal backplate with a rod welded on and cut down to size. It was attached to the wall with wood screws. With the rod attached, the spinning piece needed to be assembled. Rectangular pieces of wood the same size of the diameter of the ball were cut out to go onto each "spoke" of the circle in order to ensure the two wooden cutouts were of the right spacing. The circular bearings were attached to the inside of each wooden piece with wood glue and screws. The wooden pieces and the spaces were glued together with wood glue. This piece was slid onto the metal rod, and finished with a shaft collar to create friction and a 3D printed safety cap.

The green transition piece pictured in the top left corner of Figure 35 was made from a wooden back piece that had cutouts smaller than the width of the platforms that would be glued, and pressure fit into it. The platforms were three identical pieces laser cut out of plywood. These pieces were fit into the slots that were on the backpiece. Installing this onto the wall consisted of screwing each corner of the backpiece into the wall. Lastly, the chalkboard was laser cut down to size and shape and installed with screws into the wall.

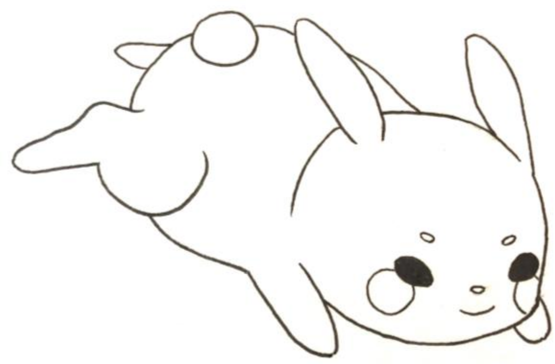

Figure 39: Design of Thumper that was put into CAD and laser cut into wood.

On top of the transition section of the wall, we designed a drawing of Thumper (Figure 39). This drawing was transferred from paper to CAD, then the outline was laser cut into wood.

The outline of Thumper was colored with black marker, and the dark brown of Thumper was colored in with a light brown alcohol-based marker to give a wood-stained look.

4.5.3 Preschooler Section Construction

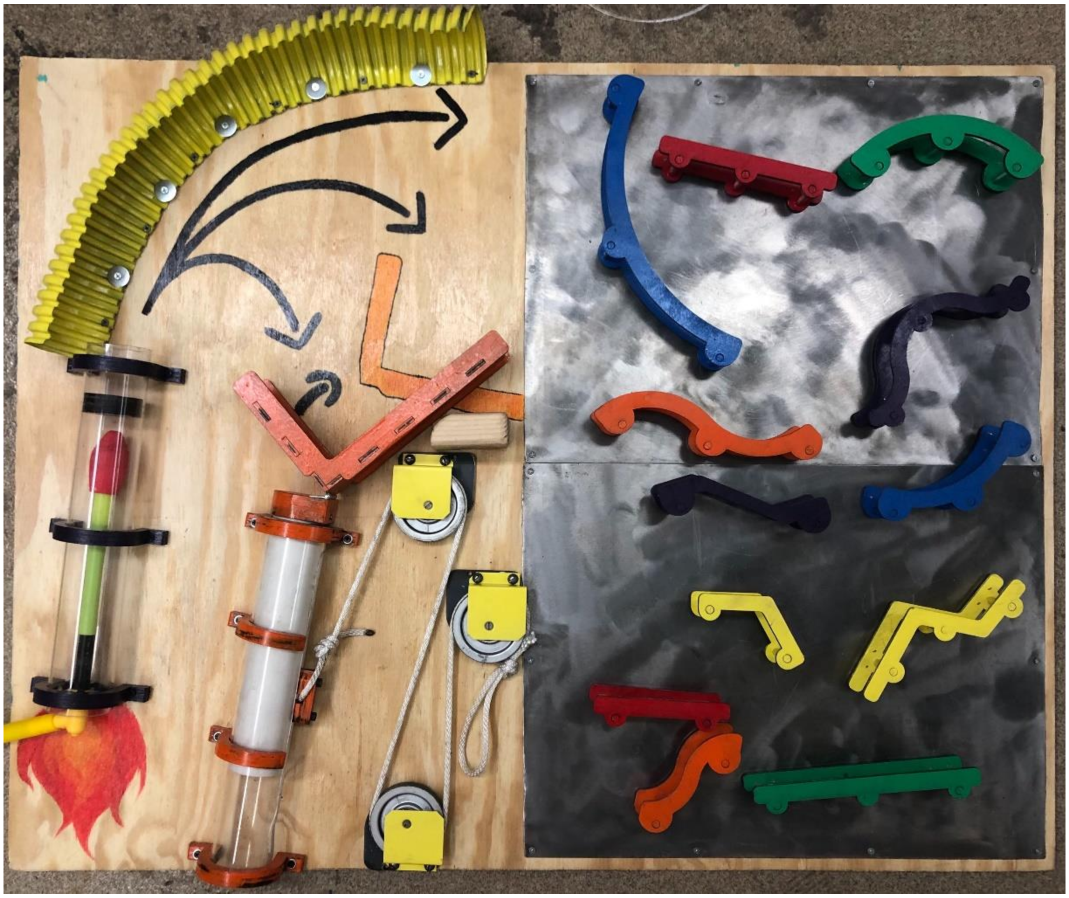

Figure 40: The final preschooler section of the ball wall including the stomp rocket, pulley linkage system, and the magnetic wall.

The preschooler section construction involved cleaning the magnet board, installing the pre-purchased rocket ball launcher, and attaching the pulley linkage system (Figure 40). We obtained and cleaned two steel plates that would be used as the magnet board for this section of the wall. The steel was cut down using a plasma cutter and then cleaned with both an angled wire brush and a grinder to get rid of the rust and to make it usable for the magnet board. This board was mounted to the plywood backing by using eight screws per board. Mounting the board to the plywood backing was necessary to ensure that the magnet wall would not strip away from the plywood backing in any way while the kids used it.

The pulley linkage system was made up of an acrylic tube that was cut to a size that could hold PVC piping. The PVC piping was covered on top with a laser cut wooden piece which is meant to stop the piping from falling completely into the acrylic tube. The top of this pipe contained a laser cut wooden bed that was attached with a hinge. This part also has a smoothed-out ledge that the bed rests on so that when mechanized, the wooden bed will tilt over the wooden ledge and dispense the ball into the magnetic ball section. The acrylic tube also has a slotted cut out from it so a stopper attached to the PVC piping can run up the tube. The stopper that is attached to the PVC piping is used to the limit the height the inner tube can go so it never leaves the outer tube. This stopper is also attached to a rope that is linked to a pulley system. The pulley system is comprised of three pulleys that were from an elevator. They were cut out larger pieces of metal and washed down with acetone and painted to look new. These three pulleys were mounted in a formation that allowed for the rope to be pulled at a multitude of angels without disrupting the integrity of the piece. The rope is attached to the small stopper so that when pulled, it moves the linkage piece out of the acrylic tube. The tubing was bolted down by laser cut wooden supports that were glued together to have a stronger piece then bolted down onto the backing plywood piece as a pressure fit.

The magnet wall pieces were constructed by laser cutting wood of different shapes and sizes into rail pieces out and connecting them with a wooden dowel in between the two identical pieces allowing a rail to be formed, slightly smaller than the diameter of the ball so it can go across the magnetic piece. These rail pieces then had magnets attached to the back of them so they can be attached to the magnet wall. The pieces were painted different colors to add some diversity to the magnet wall.

The stomp rocket piece was assembled with laser cut brackets that were glued together to create a stronger hold when screwed to the board. These brackets were secured around the circumference of the acrylic tube that was cut down to house the rocket. The acrylic was cut down using a hacksaw and smoothened with sandpaper. For mounting the rocket, a custom 3D bottom was printed, and pressure fit into the acrylic tube with the base of the rocket attached. Along the topside of the tube, there was a laser cut circular base that would be used to fit in the top to ensure the rocket can go up and down its air shaft. The stepping piece was attached to the base of the 3D printed piece so air can knock the rocket into the stopper and launch the ball out. This piece was mounted to the wall by using three of the brackets, fitting and screwing them to the wall. The guiding piece above the acrylic tube is made of a larger air tube that was found as scrap. The air tube was painted and cut in half and attached with washers to create a curve to guide the movement of the ball.

A picture of the completed ball wall can be viewed in Figure 41.

Figure 41: The final ball wall to be implemented in YWCA STEAM room.

4.5.4 Testing the Final Ball Wall Before Implementation

Once the ball wall was mostly constructed, we were able to test the wall with Jessica Rosewitz's son, two year old Ethan. While the wall was missing some very minor features, we were able to get a grasp of how children might interact with the wall, as well as ensure the safety of the product. Jess needed to demonstrate how to use the sections of the wall to get Ethan to understand how different components worked. Most of his time was spent on the preschooler section; the rocket stomper and the pulley system seemed to attract him in the most. After a few attempts with Jess showing Ethan how both of those parts worked on the wall, Ethan was able to replicate them without being shown by an adult.

Ethan also took interest in the color wheel because the lights attracted him, and he enjoyed the ability to spin the wheel. During his interaction with the color wheel, he attempted to do things that we did not anticipate, such as trying to push out the colored pieces within the wheel. Ethan also enjoyed rotating the yellow spinning wheel above the color wheel was. Overall, Ethan was attracted to parts of the wall that contained movement.

In the toddler section of the wall, Ethan would hide the balls behind the hinged doors on the counting ramp and find them later. In addition to this, he spent a lot of time just playing with the doors themselves, flipping them up and down without any ball in sight. We did not anticipate this, and we expected that children would find ways to use the wall in ways we did not expect. Ethan playing with the doors without the plastic balls helped support our expectation. Additionally, despite Ethan being a two year old toddler, he liked all sections of the wall, which mean that other toddlers could be interested in other sections of the wall.

4.6 Installation of the Ball Wall in the YWCA STEAM Room

Figure 42: Picture of the ball wall IQP team with the fully implemented STEAM ball wall.

With all sections of the ball wall ready to be attached to the bookshelves, we added support 2x4 beams onto the top of each of the three bookshelves so that the top of each section had something to mount to. These 2x4 pieces had wood glue spread across the bottom and later were screwed into the top of the bookshelves. These wooden blocks on top made the bookshelves the same height as the wooden back pieces of each section of the wall. This would allow for flushed mounting onto the wall. For each section of the wall, a layer of wood glue was applied onto the side of the wooden 2x4 above the bookshelf and the section of the ball wall was pressed against and screwed into the 2x4 wood at the top left and right corners of the piece. To ensure maximum support, screws were put into the structural frame of the bookshelf as well along the outside of each section. Then, a final white trim piece was attached above all 2x4 wood blocks to give the ball wall a cohesive look. Once all parts of the wall were mounted onto the bookshelves, we used sandpaper to round the edges of the ball wall to ensure the safety of the children. We attached the laser cut Thumper above of the transition section of the wall, using L brackets and screws to mount Thumper onto the trim. The final piece of the installation was a plaque that was attached onto the side of the bookshelf with pilot holes and screws. The final ball wall implemented in the Westborough YWCA STEAM room is pictured in Figure 42.

4.7 Storybook

We initially had the idea of creating an instructable to go with our building process, but we changed this idea into a storybook. We could physically deliver the storybook to the YWCA community and have an age-friendly visual and explanation of our design process for the community to remember. With each page, there is a rhyming narrative that the teachers can read to the students. Additionally, the narrative also follows steps of the engineering process that we took during this project. The main character of the story is Thumper, a class pet bunny that the YWCA cares for. We hope that this storybook can be a guide for the YWCA to understand more about the engineering process while being fun and a good memory for the childcare center. The final storybook can be viewed in Appendix C.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Reflection of our Project

5.1.1 How We Approached the Project

The project started with a lot of background research; most of this research consisted of how children pertaining to the YWCA age range would learn with different elements of STEAM. We also researched what could be taught at different stages of development when trying to teach a young, developing child. It was important to look at a lot at current STEAM focused lesson plans and frameworks catered towards toddlers and preschoolers. We tried to use these preschool curriculum frameworks to influence what we designed for our final ball wall. We designed our wall after thinking of functional requirements we wanted in each section of the ball wall. To test out our ideas, we created prototypes for the counting ramp and Plinko. Testing these prototypes aided in the final design because it allowed us analyze issues with our initial designs and make crucial changes. The goal of this research, designing process, and prototype testing was to inform our decisions on each part of our final design.

5.1.2 What the Final Product Looked like

The ball wall consisted of three sections: the toddler section, the transition section, and the preschooler section. These sections were catered towards a different age group based on their learning ability and capability at completing the tasks on the wall. While each section had a targeted age group, all sections are available for the students to play with. In addition to the final design, we wanted to incorporate elements that made it unique to the YWCA such as their bunny Thumper. We aimed for a ball wall that targeted the requests of the YWCA and tried to make the wall as personal as possible.

5.1.3 Things that Went Well

We were able to incorporate the YWCA and its community into our design; this allowed the design to be unique towards the YWCA and meet the needs they wanted. Another thing that went well was the creation of prototypes; there weren't as many issues when designing or constructing than was initially assumed, on the Plinko or Counting Ramp prototype. One of the issues that occurred was determining the tolerances for the dowel pressure fits. The observations that followed the construction of the prototypes also went very well, yielding a lot of very useful data for us. Sourcing materials ended up being good for the project as well. With a completed Bill of Materials (BOM) going into C-Term it was very easy to approach stores and try to get donated materials for the project. The Worcester Home Depot donating materials and WPI having extra materials allowed us to keep the cost of the wall very low, hitting one of our initial goals for the project.

5.1.4 Things that Went Wrong

Because we started our building process rather late in our allotted project time, we struggled completing the wall in seven weeks. This meant many long nights building the ball wall. We also noticed that our design process would not turn out as expected during our construction process. During the design process, there were a lot of things that we wanted to implement as a group, but complexity and time limited the complex ideas we had in mind. Thus, there were a few last minute changes that had to be taken out of our final design. Overall, we kept most of the original design.

5.1.5 Lessons Learned

There are a lot of things that we can take away from this project. What we have learned as a group was how to incorporate the community into the engineering process. We did this by consulting various social media platforms to better engage the community to provide feedback. While this did not work out as well as we hoped, we used YWCA teacher and staff feedback to guide our design process. Another way we engaged the community was trying to get materials donated for the project to keep the cost as low as possible. We also learned proper ways of research by courtesy of Laura Robinson, as well as how to source the research we found.

For those interested in attempting a similar project to our ball wall project, we would advise to tackle the process before building as early as possible. The building process of the final ball wall took a lot of time to complete. There was a lot of preplanning that had to go into creating the ball wall with educational intentions. Moreover, when doing a project like this for a community, it is important to remember that you are designing the project for the specific needs of the community. It was easy to get attached to our own ideas even if it was not ideal for the YWCA's personal needs.

The advice that we would want to give for anyone to do this project in the future would be to take their time with proper research and design steps in order to create the most ideal design. Our project was time consuming. Therefore, it is important to plan early in the project how time will be managed and when specific tasks will be completed. This will allow for a smoother building process, and a schedule that you can follow to distribute time as evenly as possible.

5.2 Final Conclusions

Our final design incorporated educational and community-oriented qualities that reflected the needs of the YWCA: cost friendly materials, safety for children, useable for all age groups, fun and educational learning, and fitting for the bookshelves in the YWCA STEAM room. During the process of the IQP, we conducted research and utilized prototypes to help guide us and make decisions towards our end goal. With this research, we were able to gain a lot of knowledge about the child development process. Throughout our design process, we had consultations with the YWCA staff to show them some of our preliminary ideas. We asked for their feedback, asking for any concerns that they might have had with the design; surveys were taken to get an understanding of what the YWCA staff wanted to see with this project. We had many struggles through our project, such as receiving feedback through social media and obtaining donations to make our ball wall cost friendly. We are thankful to the local businesses that donated larger materials for our project. Using these donated materials allowed us to start the construction process as soon as possible. However, for future projects of the same degree as the ball wall project, starting even earlier would be ideal because we needed to spend many long hours each day to complete the ball wall in time; each section took roughly two weeks to fully build, and installation was completed in one day during the last week of our project. In the end, the project was successful due to the hours of dedication put into the ball wall to ensure a quality build job that considered research, community, and the satisfaction of the YWCA.

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APPENDIX A: EXEMPT APPROVAL LETTER FROM INSTITUTIONAL REVIEW BOARD (IRB)

WORCESTER POLYTECHNIC INSTITUTE

100 INSTITUTE ROAD, WORCESTER MA 01609 USA

Institutional Review Board
FWA #00015024 - HHS #00007374

Notification of IRB Approval

Date:	29-Oct-2019
PI:	Ellis-Rech, David Shlomo
Protocol Number:	IRB-20-0143
Protocol Title:	Westborough YWCA Student Observations
Approved Study Personnel:	Ellis-Rech, David Shlomo~Lee, Erica~Gregg, Spencer~Wood, Nicholas~Chen, Katherine C~
Effective Date:	29-Oct-2019
Exemption Category:	2
Sponsor*:	

The WPI Institutional Review Board (IRB) has reviewed the materials submitted with regard to the above-mentioned protocol.We have determined that this research is exempt from further IRB review under 45 CFR § 46.104 (d). For a detailed description of the categories of exempt research, please refer to the IRB website.

The study is approved indefinitely unless terminated sooner (in writing) by yourself or the WPI IRB. Amendments or changes to the research that might alter this specific approval must be submitted to the WPI IRB for review and may require a full IRB application in order for the research to continue. You are also required to report any adverse events with regard to your study subjects or their data.

Changes to the research which might affect its exempt status must be submitted to the WPI IRB for review and approval before such changes are put into practice. A full IRB application may be required in order for the research to continue.

Please contact the IRB at irb@wpi.edu if you have any questions.

*if blank, the IRB has not reviewed any funding proposal for this protocol

APPENDIX B: TAX EXEMPT FORM FROM YWCA

Rev. 6/09
Massachusetts Department of Revenue

Form ST-5
Sales Tax Exempt Purchaser Certificate

Part 1. Exempt taxpayer information. To be completed by exempt government or 501(c)(3) organization.

Name: YWCA of Central Massachusetts Inc.

Address: 1 Salem Square

City: Worcester State: MA Zip: 01608

Exemption number: 04-2105873

Issue date: 1/4/19 Date of expiration of certificate: 1/3/29

Certification is hereby made that the organization named above is an exempt purchaser under Massachusetts General Laws, Chapter 64H, sections 6(d) or 6(e). All purchases of tangible personal property or services by this organization are exempt from taxation under said chapter to the extent that such property or services are used in the conduct of the business of the purchaser. Any abuse or misuse of this certificate by any tax-exempt organization or any unauthorized use of this certificate by any individual constitutes a serious violation and will lead to revocation.

Signature: [signature] Title: Assoc. Exec. Dir. Finance + Adm. Date: 12/4/18

Warning: Willful misuse of this certificate may result in criminal tax evasion sanctions of up to one year in prison and $10,000 ($50,000 for corporations) in fines.

Part 2. Agent information. To be completed by agent of exempt government or 501(c)(3) organization.

Name of agent's organization

Address

City State Zip

Agent's name

Address

City State Zip

I certify that in making this purchase, I am acting as an agent for the exempt organization named above (select one):

☐ Government organization (local public school, city/town government, state agency, etc.).
Attach Form ST-2, if available. If Form ST-2 is not available, enter exemption number, if known: ______

☐ 501(c)(3) organization (parochial school, Scout troop, etc.). Form ST-2 must be attached.

Signature Title Date

Part 3. Vendor information

Vendor's name

Check applicable box:

☐ Single purchase certificate (attach detailed receipts or complete Part 4, on reverse)

☐ Blanket certificate

This form is approved by the Commissioner of Revenue and may be reproduced.

Commonwealth of Massachusetts
Department of Revenue
Christopher C. Harding, Commissioner

mass.gov/dor

Letter ID: L0655910528
Notice Date: December 3, 2018
MA Taxpayer ID: 12110907

CERTIFICATE OF EXEMPTION

YWCA OF CENTRAL MASSACHUSETTS INC
1 SALEM SQ
WORCESTER MA 01608-2015

Attached below is your Certificate of Exemption (Form ST-2). Cut along the dotted line and display at your place of business. You must report any change of name or address to us so that a revised ST-2 can be issued.

DETACH HERE

MASSACHUSETTS DEPARTMENT OF REVENUE — Form ST-2

Certificate of Exemption

YWCA OF CENTRAL MASSACHUSETTS INC
1 SALEM SQ
WORCESTER MA 01608-2015

MA Taxpayer ID: 12110907
Certificate Number: 1568927744

This certifies that the organization named above is an exempt purchaser under Chapter 64H, section 6(d) or (e) of the Massachusetts General Laws. All purchases of tangible personal property by this organization are exempt from taxation to the extent that such property is used in the conduct of the business of the purchaser. Misuse of this certificate by any tax-exempt organization or unauthorized use of this certificate by any individual will lead to revocation. Willful misuse of this certificate is subject to criminal sanctions of up to one year in prison and $10,000 ($50,000 for corporations) in fines. This certificate is non-transferable and may be suspended or revoked for failure to comply with state laws and regulations.

Effective Date: January 4, 2019

Expiration Date: January 3, 2029

APPENDIX C: "THUMPER'S BALL WALL ADVENTURE!" STORYBOOK FOR YWCA

Thumper's Ball Wall Adventure!

By WPI Ball Wall IQP Team

We dedicate this book to Luisa Palladino, Kathy Chen, Jessica Rosewitz, and the YWCA community.

2

Every day is so lively at the YWCA,

A non-profit organization where children learn and play.

Teachers help the children to achieve their dreams,

Through topics such as friendship, language, and STEAM.

YWCA

3

One quiet morning, Thumper laid resting in bed,

Until chatter of a brand new ball wall was said.

Teachers and staff gathered around, agreeing the idea was a fit,

“We will need some help, let’s call Jessica Rosewitz!”

4

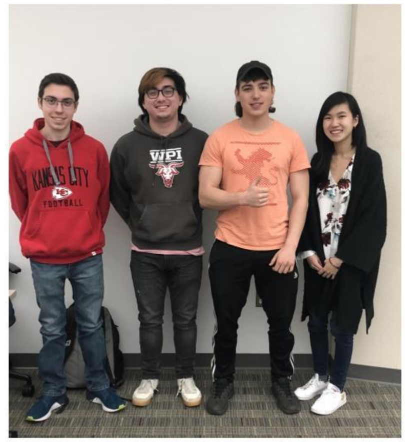
Later that day, Jessica Rosewitz came,

And Thumper overheard a specific school name.

Jessica Rosewitz exclaims,

“Hey how about those students from WPI!”

“Oh yes they’ll do it for a piece of pie!”



WPI

5

The WPI students were excited to begin,

But the project was too hard to dive right in.

They thought long and hard to make the project a success,

The WPI students used the engineering design process.

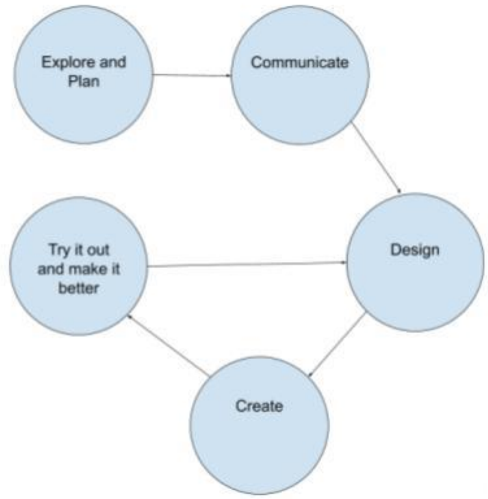
6

The team first must explore and plan,

Then communicate their ideas as best as they can.

After this matter, they will design, then create,

And try out their product to reiterate.



7

The (WPI) students searched online as a guide,

Only to find out that their design options are wide.

But a plan was formed with long and hard thought,

Of a ball wall with STEAM concepts to be taught

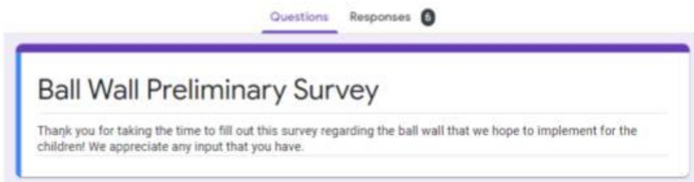
8

The (WPI) Students surveyed all the YWCA teachers

To ensure they considered all the right features

Counting, colors, and creativity alike,

Soon their ball wall would be coming to life!



9

Finding a design for the wall was hard to start

It had to incorporate STEAM, creativity, and heart.

But with all their sketches, the team at last decided,

Which ball wall design would be the one they provided.

10

After selecting their design, they needed to craft,

A ball wall brought to life from what once was a draft.

The team gathered materials, used teamwork and tools,

And built the ball wall for the YWCA preschool.

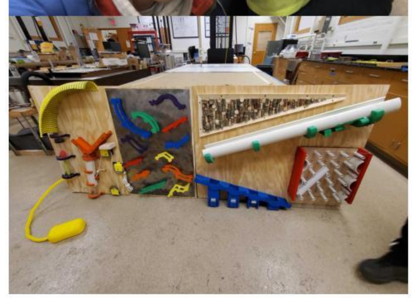
11

The ball wall once built was (then) brought to a test

To ensure the safety and function were at its best.

They tested until no more could be done,

And what was left was a ball wall full of fun.



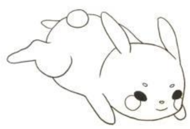
12

With the wall completed, all that was left was to install,

So in the STEAM room, there now houses a STEAM ball wall.

With the ball wall established, the children could finally play,

And the community was happy on this joyous day!



13

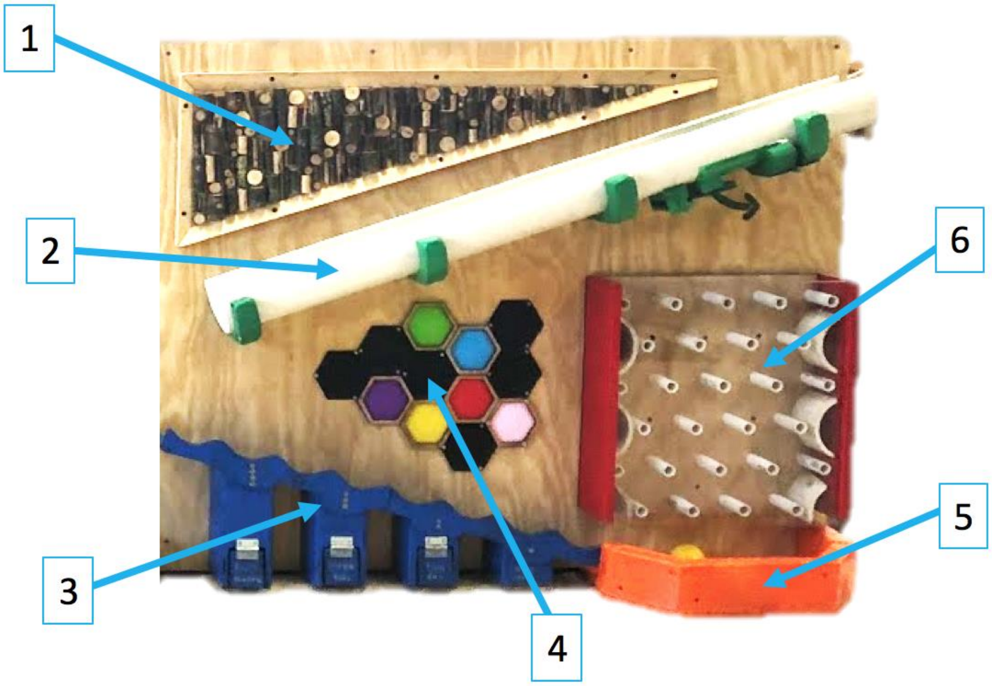
On behalf of WPI and the Ball Wall team, we wanted to thank Luisa Palladino, Jessica Rosewitz, Danielle Scanlon, and the YWCA for this opportunity to build the STEAM ball wall for the YWCA. Our efforts would not have been fruitful without your input throughout the entire process. We worked very hard on this project, and we hope that the children can have a fun and educational experience playing with the wall!

-Ball Wall IQP Team

14

APPENDIX D: ANNONTATED ASSEMBLY OF THE BALL WALL

Section 1



1. Natural Texture Piece

Materials Used:

- Recycled pieces of wood
- Plywood
- 2 by 4 cut down for trim

Assembled and Mounted by: 10 wood screws along the perimeter and wood glue on the matting surfaces.

2. PVC ramp

Materials Used:

- 4in PVC pipe cut lengthwise

- 4 2x4 mounts made by hand
- Latch holder: multiple laser cut 0.25 in pieces with notches for mounting
- 4in door hinge, pvc door, hand made 2x4 piece

Assembled and Mounted by: 2 wood screws from the back side for every green colored hand cut 2x4 wood mount and wood glue on the mating surfaces. Construction adhesive and 2 wood screws were used to secure the PVC pipe to each 2x4 wood mount. The door hinge is mounted by 2 screws into one of the mounts. A ¼ bolt is used to allow the swinging latch to rotate into place.

3. Numbered Ball Collection

Materials Used:

- 11/32in laser cut wood,
- 2in hinges

Assembled and Mounted by: The laser cut wood has notches to make the rectangular tubes. Wood glue was used to hold the sides of each tube together. The hinges were mounted with the screws that they came with. Wood screws and wood glue were used to mount the wavy fence onto the side. The top ramp has 2 wood screws per tube piece. The piece is mounted to the plywood backer with wood glue on all the mating surfaces and wood screws from the backside into both the ramp and the square tubes.

4. Hexagonal Texture Pieces

Materials Used:

- 3d printed hexagons
- silicone pieces
- laser cut perimeters for the silicone pieces

Assembled and Mounted by: 3 wood screws mount each hexagon onto the 3ftx4ft back piece.

5. Ball collection

Materials Used:

- 5 individual 2x4s parts
- wood glue
- spray paint

Assembled and Mounted by: The 2x4s were cut at an angle to be attached together by wood glue and wood screws. The 2x4 piece that goes beneath the numbered ball collection is unique in comparison to the other ball collections. The ball collection is not mounted to the 3ftx4ft back piece.

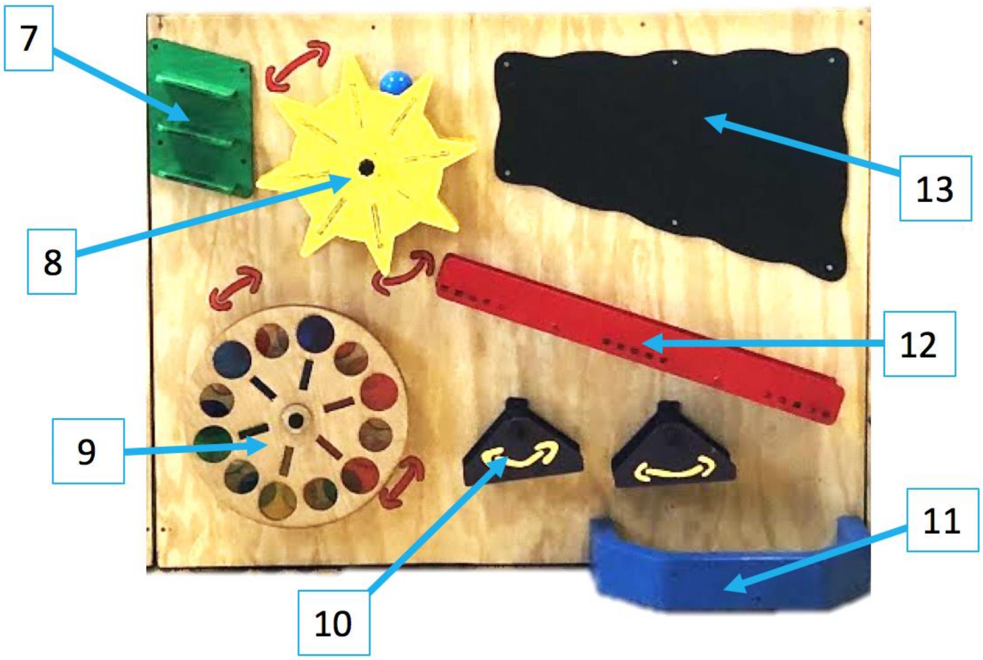
6. Plinko

Materials Used:

- 3 hardwood plywood pieces (2 sides and one backpiece)
- 7/8in pvc pipes
- ¼ section of 4in pvc pipes for the outer parts
- 1/4in thick polycarbonate sheet

Assembled and Mounted by: Wood screws from the backside mount the 2 side pieces. Both side pieces have slots to hold the polycarbonate sheet. A screw on the top right side holds the polycarbonate sheet and two wood pieces hold it from the bottom. The screw on top of the polycarbonate sheet can be unscrewed to remove the polycarbonate sheet (for cleaning and other purposes). The larger ¼ section of pvc pipes are mounted into the hardwood back piece by 2 wood screws. Each of the 7/8in pvc pipes are press fit into the holes in the hardwood backpiece. The hardwood backpiece of the plinko is mounted by 7 wood screws into the 3ftx4ft back piece and wood glue on the mating faces.

<u>Section 2</u>



7. Connecting ramps

Materials Used:

- 4 11/32 laser cut wood plates

Assembled and Mounted by: Each ramp has individual notches going into the mounting plate. These notches are glued to the back plate. The back plate is screwed into the 4ftx3ft section with wood screws and wood glue.

8. Spinning wheel

Materials Used:

- 2 ¼ in thick star pattern outer plates
- 8 inbetween 11/32in posts
- 2 8mm bearings
- 1 8mm shaft and mount (welded)
- Laser cut bearing holders

- 3d printed end cap
- 8mm shaft collar

Assembled and Mounted by: The two plates are connected by the 8 standoff posts. The posts have notches that stick out of the 2 outer plates. The 8 standoff posts are glued into the two plates. The two bearings are held to the outer wheel pieces by laser cut press fit bearing holders. The 8mm shaft and welded mount is attached with 2 wood screws into the 3ftx4ft back piece. The shaft is extended to where it extrudes into the 3ftx4ft section (the shaft goes into the back piece). The spinning wheel is put onto this shaft where it is held on by an 8mm shaft collar and a 3d printed end cap.

9. Color Wheel

Materials Used:

- 0.25 inch plywood
- Colored acrylic pieces
- 2 8mm bearings
- 1 8mm shaft and mount (welded)
- Laser cut bearing holders
- 3d printed End cap
- 8mm shaft collar
- Push button LED lights

Assembled and Mounted by: The two bearings are held in place by laser cut press fit bearing holders that are glued and screwed to the large wheels. The 8mm shaft and welded mount is attached with 2 wood screws into the 3ftx4ft back piece. The shaft is extended to where it extrudes into the 3ftx4ft section (the shaft goes into the back piece). The color wheels are put onto this shaft with spacers. They are held on the shafts by an 8mm shaft collar and a 3d printed end cap.

10. Teeter Totters

Materials Used:

- 0.25 inch plywood
- 2 8mm bearings
- 1 8mm shaft and mount (welded)
- Laser cut bearing holders
- 3d printed End cap
- 8mm shaft collar

Assembled and Mounted by: The two bearings are held in place by laser cut press fit bearing holders that are glued and screwed to the teeter totter sides. The 8mm shaft and welded mount is attached with 2 wood screws into the 3ftx4ft back piece. The shaft is extended to where it extrudes into the 3ftx4ft section (the shaft goes into the back piece). The teeter totters are put onto the shafts and held on by an 8mm shaft collar and a 3d printed end cap.

11. Ball Collection

Materials Used:

- 5 individual 2x4s parts
- wood glue
- spray paint

Assembled and Mounted by: The 2x4s were cut at an angle to be attached together by wood glue and wood screws. The ball collection is not mounted to the 3ftx4ft back piece.

12. Ramp with doors

Materials Used:

- 0.25 inch plywood
- 11/32 plywood
- 6mm bolts

Assembled and Mounted by: The base is made of laser cut 11/32 inch plywood pieces that are notched and fit into the two laser cut 0.25 inch plywood sides. They are secured together with wood glue and a tight press fit. The doors are held in place by 6mm bolts that run through the entire ramp and into the back plywood 3ft by 4ft section. The entire ramp assembly is held to the wall with wood glue on the matting faces and 6 wood screws that run from the back into the lower base and 4 wood screws from the front through the ramps back wall.

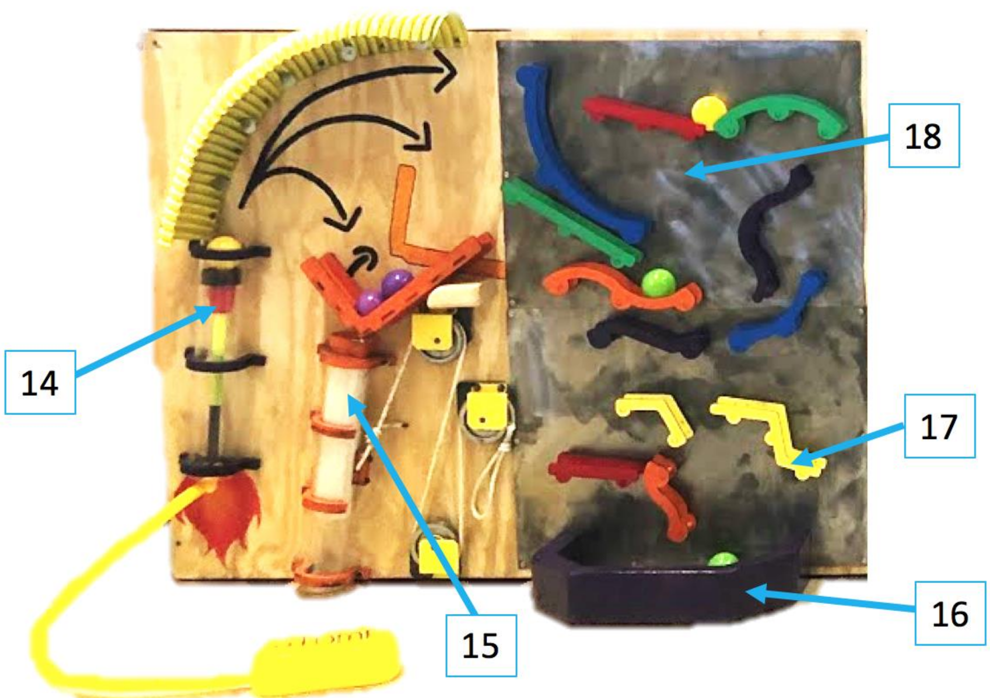
13. Chalkboard

Materials Used:

- Chalkboard MDF

Assembled and Mounted by: Six wood screws from the front face and wood glue on the matting faces.

<u>Section 3</u>



14. Stomp Rocket

Materials Used:

- Acrylic tube
- 3 laser cut plywood mounts
- 1 stomp rocket
- 1 stomp rocket pump
- 1 3d printed ball holder at the top
- 1 3d printed holder for the stomping pump
- cut drainage tube for redirecting the balls.

Assembled and Mounted By: The two 3d printed parts are pressure fitted into either end of the acrylic tube. The bottom 3d printed part can be pulled out in case the rocket needs to be replaced. The acrylic tube is clamped onto the wall with the 3 laser cut plywood mounts. The 3 laser cut plywood mounts each have 2 screws going into the 3ftx4ft back piece. The drainage tube to redirect the balls has 6 screws without washers and 5 with washers. The washers help secure the tube more firmly and not flex as much.

15. Linear Slide

Materials Used:

- Acrylic tube on the outside
- pvc tube on the inside
- 4 laser cut mounts (2 of which are cut to clear the slot)
- laser cut end cap on the pvc pipe
- 4 laser cut notched pieces for the ball holder
- 3 elevator pulleys
- 1 2x4 piece of wood to direct the ball holder.

Assembled and Mounted by: The two tubes are fitted together. The end cap on the pvc pipe is glued on with construction adhesive and bolted in from the sides. The acrylic tube that also holds the pvc pipe is mounted to the 4ftx3ft section by 4 laser cut mounts, 2 of which have 2 wood screws and the 2 inner pieces have one. The 4 notched laser cut but pieces that hold the balls are glued together. The hinge is mounted by 2 screws going into the ball holder and another 2 going into the end cap. The rope is attached to the pvc pipe by a layered piece of wood (attached with 2 machine screws and nuts on the inside) with a hole in the middle. The rope is tied off to this hole with a double figure 8 knot. Each elevator pulley is attached by 3 wood screws going into the 4ftx3ft section. The cover for the elevator pulleys is held in by 2 machine screws into threads in the back plate of the pulley. A second double figure eight is used to make the looped handle at the other end of the rope.

16. Ball collection

Materials Used:

- 5 individual 2x4s parts
- wood glue
- spray paint

Assembled and Mounted by: The 2x4s were cut at an angle to be attached together by wood glue and wood screws. The ball collection is not mounted to the 3ftx4ft back piece.

17. Magnetic rail ramps

Materials Used:

- 2 uniquely laser cut rails for each ramp
- 2 or 3 3/8in diameter oak wooden dowels for each ramp
- Magnets
- 3dprinted magnet holders

Assembled and Mounted by: Each ramp was uniquely laser cut with different patterns. 2 or 3 3/8in wooden dowels are press fit (and glued) into each of 2 rails. 2 magnets are attached to the backside of each ramp by using the 3d printed magnet holders. Each 3d printed magnet holder is screwed in with 2 machine screws into one rail.

18. Magnet board

Materials Used:

- 2 18inx24in sanded steel plates

Assembled and Mounted by: Along the perimeter, wood screws hold the 2 steel plates onto the 3ftx4ft section. Construction adhesive was also used to adhere the plates onto the wood and applied on each mating face.

Notes:

Paints and finishes are used on many of the components but have not been listed in the materials list. For paint, Rustoleum spray paint was used and for finishing, polyurethane was used.

APPENDIX E: SURVEY QUESTIONS AND RESPONSES

Questions with Carlene Sherbourne:

Questions for Carlene Sherbourne	**Responses from Carlene Sherbourne**
What kinds of activities are involved in the STEAM room?	Live animals, comparison of natural versus artificial materials, color mixing and art, sand station, water station, fossil/digging station, ball wall, and books.
What is the most popular activity in the STEAM room?	The water station because the children get to build the paths for the water with tubes.
What is the least popular activity in the STEAM room?	The ball wall because there are multiple ball walls around the childcare center. The children became much more interested in the ball wall when a protruding tree stump was added at the bottom of the ball wall.
How do you notice the younger children that do not socialize learn in the STEAM room?	Parallel play: they watch each other without directly interacting and learn from what they see others doing.
How did you receive the materials for the STEAM room?	Many of the materials were used from recyclable materials. Parents volunteered to help build the room as well as gave scrap materials from their home.

Preliminary Survey taken on August 29th:

Question	Response 1	Response 2	Response 3	Response 4	Response 5	Response 6
What is your name?	Teacher A	Teacher B	Teacher C	Teacher D	Teacher E	Teacher F
What age group do you work with?	2-2.9	1-2 year olds	Toddler 1 (one to two years)	Pre- K	Toddler 1	Pre-K (4 and 5 years)
What kinds of toys do the kids like to play with?	Cars, magnets, blocks, babies, phones	blocks things that stick	Trucks, balls, and farm animals (toddler safe)	blocks, trucks, coloring, dramatic play	Push cars, sensory toys, balls,animals	Balls, legos, beads, connecting toys, ramps, magnets, water, dirt and sand, bowls and spoons, cars, dinosaurs
Are there any prohibited toys that we should know about?	Chocking hazard toys	sharp toys	Beads, sharp toys,	not sure yet, I am still new	Extra small toys that may cause choking	

Do you envision separate parts of the wall dedicated towards separate age groups or a wall for all age groups?	All ages	yes	Yes (height restriction)	either way would be fine!	Yes, because of the difference in their heights	No, but I would children to be able to modify various parts to help them learn. I envision a general wall with parts that can be added or taken away depending on ages.
What type of STEAM (science, technology, engineering, art, math) lesson would you like the wall to help teach the kids?	All	all	All	Art and Engineering	All	Teamwork, problem solving, cause and effect, hand eye coordination, confidence.
Do any of the children have special needs that need to be accommodated? If yes, please tell us about their special needs.	No	No	No	No	No	No
How would you describe the relationship between the YWCA and the local community?	Welcoming	good	YWCA is the heart of every community	The Ywca helps families in the community	YWCA has been very helpful in providing childcare and education	Community is welcoming and engaging as necessary

What do you think the ball wall will bring to the YWCA?	Attraction to the steam room	learnig and growth and developement	Fun way of learning for children	A fun and exciting new way to learn	It’s going to be educational and fun	Exciting experiences for children and families
What do you hope the ball wall will contribute to the kids, families, and community?	Education	gross moter	Fun way of learning for children and the family	A fun and exciting way to learn with teachers, friends, and family.	Aid in learning and more motivation in learning	An exciting experience with the ability to help children make educated guesses and have discussions
To you, why do you think it is significant to have us design the ball wall rather than just purchasing a pre-designed ball wall?	Learning experience, creativity	(No response)	Designing for the age appropriate	You will be able to cater to what our children need	It’s more personalized and more meaningful and most importantly, made by heart.	(Please view “**Response 6 full answer 1” below)
Would it be meaningful for teachers, parents, and even students to be involved in the ball wall construction? If yes, in what ways would you envision this happening?	Yes. Each of us having an idea and collaborating it into one.	Yes	Yes. Involving them while designing the wall	Yes. Asking the teachers what they think.	Yes. Team work.	(Please view “**Response 6 full answer 2” below)

**Response 6 full answer 1: As engineers, it is important to help design something with hands on trial and error processes. If it was just bought, it would take away the steps of planning and engineering something that will be unique to our students. It will be a great learning experience to say you designed something that is bringing such joy to children and families, along with having the experience of knowing what worked well and what did not. Working together as a team will help bring in many ideas and background knowledge that might not have been known or thought of before.

**Response 6 full answer 2: Yes. Assisting in drawing "blue prints", helping to decide on colors and some ideas of how the balls should move on the walls. Letting children assist in the process will help with many parts of creating something meaningful. Plus children will feel good about having helped to create the ball wall and the older children will most likely carry that memory with them.

Informative Design Feedback Survey taken on November 5th:

Question	Response 1	Response 2
What is your age group?	Older Pre-K	Older Pre-K
Our team is thinking about dividing the ball wall into 3 sections (same dimensions as the 3 bookshelves) for the 3 main age groups. Do you think this is a good approach? If not please suggest?	Yes	Yes
For your age group do you think the components (tracks, chutes, gears, conveyor belts, teeter-totter, etc.) of the ball wall should be modular (like detachable with magnets) or do you think it would be better if they were mounted permanently? Note: We are thinking the 3 main sections would be separate panels and could be moved if needed.	Moveable only for the children who are ready to explore and create their own	Having movable pieces will allow for more engagement and planning
Here are some ideas we have for each section. For each section general objectives: 1. Gravity, balance, shapes 2. Simple math, numbers 3. Gears, linkages (and overall reading, sound, texture). Please let us know what you think of these ideas.	Love it	Children will love sound effects and they enjoy ramps, slopes and when items pick up speed going slow to fast.

What are some of the STEAM concepts that are currently involved in your lesson plans for your age group?	Water cycle and sensory toys along with being able engineer whatever they would like to make	Science experiments, color mixing, texture experiments, stacking and building with various materials, counting, measuring, graphing and charts, patterns, color sorts, heights, weighing objects, building with different blocks, nuts and bolts, magnets, reactions such as baking soda and vinegar, building chutes for marbles
What lesson goals would you like to be implemented into the wall? (Some of your lesson plan concepts might utilize a ball wall, and we can try to build a wall that helps implement those lessons.)	Working together and learn	Colors, textures, problem solving, cause and effects, magnets, measuring, patterns, weights, counting
Are there any other design ideas or requests you have?	(No response)	(No response)

WORCESTER POLYTECHNIC INSTITUTE

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Institutional Review Board

FWA #00015024 - HHS #00007374

Notification of IRB Approval

Date:	29-Oct-2019
PI:	Ellis-Rech, David Shlomo
Protocol Number:	IRB-20-0143
Protocol Title:	Westborough YWCA Student Observations
Approved Study Personnel:	Ellis-Rech, David Shlomo~Lee, Erica~Gregg, Spencer~Wood, Nicholas~Chen, Katherine C~
Effective Date:	29-Oct-2019
Exemption Category:	2
Sponsor*:	

The WPI Institutional Review Board (IRB) has reviewed the materials submitted with regard to the above-mentioned protocol.We have determined that this research is exempt from further IRB review under 45 CFR § 46.104 (d). For a detailed description of the categories of exempt research, please refer to the IRB website.

The study is approved indefinitely unless terminated sooner (in writing) by yourself or the WPI IRB. Amendments or changes to the research that might alter this specific approval must be submitted to the WPI IRB for review and may require a full IRB application in order for the research to continue. You are also required to report any adverse events with regard to your study subjects or their data.

Changes to the research which might affect its exempt status must be submitted to the WPI IRB for review and approval before such changes are put into practice. A full IRB application may be required in order for the research to continue.

Please contact the IRB at irb@wpi.edu if you have any questions.

*if blank, the IRB has not reviewed any funding proposal for this protocol