Designing and Building Simple Machines for STEAM Education for a YWCA Preschool

An Interactive Qualifying Project

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by

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Abstract

The non-profit organization, YWCA of Central Massachusetts, hosts a preschool educational center for children ages two to five. The goal of the center is to better the futures of the children they instruct and prepare them for the world they live in. In particular, they work to educate children in science, technology, engineering, art, and mathematics (STEAM) literacy. This project provided a piece of playground equipment to aid the YWCA in their ability to educate their students in STEAM concepts (in particular simple machines). The IQP team analyzed current methods and tools used in STEAM education, government standards, interviewed YWCA instructors, and observed students to develop a device consisting of several interactive simple machines that was installed in the YWCA playground.

Acknowledgements

This project could not have been accomplished without the help of the YWCA CM staff and faculty members, in particular Luisa Palladino, Elizabeth Scanton, Deanne St. Pierre, Taylor Cullen, and Kayla O'Brien. These individuals donated their valuable time and knowledge to guide the project throughout the development process. The teacher's insight and experience as educators dramatically changed our personal expectations and perceived designs of the project and assisted in shaping it into a more effective system.

We express our thanks to Professor Katherine Foo and Paige Neumann for their assistance in the review of literature and background research that established the scope of the project. They provided access to resources and services that allowed for a more thorough understanding of the project's requirements and the applicable regulations that governed it.

The team would also like to thank our wonderful advisor, Professor Jessica Rosewitz. She went well beyond the duties of a standard project advisor and provided us with any and every tool we needed to successfully accomplish this project. Without her knowledge as an engineer, a parent, and an educator, the team would not have been able to understand the vast number of design considerations and physical constraints a project like this entails.

Executive Summary

Introduction:

Organizations such as the YWCA of Central Massachusetts (YWCA CM) promote early childhood STEAM education work to create and expose children to these positive experiences. They aim to encourage all interested children to pursue STEAM regardless of background or externally perceived identities. However, there are stumbling blocks to every good mission. At present, few items exist for children to utilize in an outdoor setting that are both engaging and educate on foundational STEAM principles (i.e. simple machines).

This project produced an educational toy capable of demonstrating rudimentary physics and engineering principles in an engaging and accessible manner. The toy, coupled with a set of educational activities created around the Massachusetts Department of Elementary and Secondary Education Curriculum Framework, is capable of reaching PreK students from any background to assist in their development and understanding of the world around them.

Methodology:

The IQP team employed the engineering development process to design, construct, and install the playground equipment at the YWCA of Central Massachusetts. We observed the children at play in the preexisting playground and interviewed teachers to establish the baseline behavior of the children and the goals of their educators to identify attributes that both groups would value in the final implementation. After generating and assessing designs internally, the team presented them to the instructors for final approval and then constructed the playground equipment. We installed it at the YWCA for their use for both recess and class time.

Results

The communication with the teachers and observations of the students shifted our preconceived ideas of the design to focus on a more cooperative model that prioritized teamwork on the part of the students to operate. The team developed eight initial designs and then presented three refined designs for considerations by the YWCA CM faculty. Once the final design was selected, the design was further developed, constructed, and installed in the playground. The children of the YWCA CM appeared to thoroughly enjoy the toy and the teachers likewise enjoyed the opportunities the new toy provided, albeit with some safety concerns.

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1. Introduction

Children have always sought to learn and understand the world around them until they are satisfied with the amount of information they have gathered. Yet, children do not instinctually form complex hypotheses that rival Nobel laureates, nor do they conduct double-blind studies. Children the world over learn through play, and it is through play, educators can best give their students the tools to discover concepts about the world around them (The British Association of Early Childhood Education). Chief among these concepts are abstract constructs that are difficult to verbally explain, especially to an audience with limited communication abilities. Science, in particular physics, has several foundational laws and theories that are difficult to comprehend through pure verbal explanation, such as work, required force, and mechanical advantage. Children at play do not require complex explanations to derive an intuitive understanding of how things—such as levers—work. This project will create a group play structure for young children that will assist with their education in teamwork, foundational physics and engineering, and promote a mindset of curiosity and exploration.

Science, technology, engineering, and mathematics (STEM) education is of vital importance in early education. A foundational principle of STEM education is student-led discovery and exploration of conceptual principles (Bencze, 2008). This system, coupled with play, provides instructors powerful tools to inspire children to investigate and question everything—the ultimate goal of science. Additionally, early introduction of STEM can "set the stage for their college curriculum later. Besides scoring higher in the SAT and needing less remedial classes when they start college, these children are most likely to pursue a career in STEM with confidence" (MandLabs, 2020).

Beyond the understanding of theorems and postulates, STEAM (science, technology, engineering, arts, and mathematics) education provides children opportunities to investigate, collaborate, design, and solve challenges across a multitude of fields and disciplines (Alacapinar, 2008). These social (or soft) skills provide all children the ability to interact more effectively with the society around them and work with others to solve the great problems of their world.

In addition to the intangibility of the subjects, the world may influence children in unnecessary ways. Even at a young age, children are exposed to racial and gendered stereotypes that influence their self-perception and may sway the directions of their lives. This is especially true in the sciences, where there are a significant majority of homogenous groups. The National Center for Science and Engineering Statistics (2019) reported that approximately 74% of all science and engineering positions in the United States were held by male-identifying individuals. Of all STEAM occupations, 64% were held by white employees. In particular, Asian, African American, Hispanic, and other underrepresented women make up less than 10% of all science and technology occupations despite being over 50% of the population.

In central Massachusetts, “more than 40 percent of all employment in the Commonwealth revolves around innovative industries such as clean energy, information technology, defense and advanced manufacturing” (The Commonwealth of Massachusetts, 2021). While the state government has provided numerous programs and opportunities for post-early-childhood education, few resources are made available to support similar programs at the pre-kindergarten or kindergarten level.

Organizations attempt to alleviate these lapses in education through their own independent programs to empower children to be who they want to be in life without socio-economic status or societal prejudice diverting their interests. The YWCA (Young Women’s Christian Association) is one such organization that works to provide resources and programs to eliminate racism and gender biases. In addition, this organization is moving to bolster its’ youth education program that works with preschool-aged children (ages two to five years). However, few resources currently exist to effectively teach physics or other STEAM subjects to such a young age group, especially within the price range of a nonprofit. Additionally, little research exists to evaluate gender or racial equity of education at this age range.

This project will work with the YWCA of Central Massachusetts (YWCA CM) to produce a set of educational lesson plans and a set of playground equipment to educate young children (ages two to five years) about physics and STEAM concepts, specifically those that pertain to simple machines. The lesson plans will be used to not only further explain the scientific ideas but to begin the education of related skills—problem-solving, communication, teamwork— and to encourage gender and racial neutrality amongst the children interested in STEAM. The playground equipment will allow children the ability to learn through play and experiment with the physical concepts at play in a semi-structured environment—such as recess—and during directed lessons.

The development process of this project will employ an iterative engineering design model in which designs and macro concepts will be developed using a mixture of archival research, intended-user interviews, and field observations to establish baseline requirements. The designs will be developed and prototyped digitally, go through several phases of redesign, and then presented to stakeholders for critiques before finalizing. Through feedback, the team will deploy the solutions and evaluate via observation and instructor assessment the effectiveness of the products.

1. Background

This project aims to develop an educational system for young children that enables and empowers them to explore, think, and create regardless of their background. To do so, one needs to understand how young children learn, how they traditionally develop the ability to explore and create, what factors can discourage children from doing so, and what research is being conducted to encourage similar growth.

The following preliminary review of the literature provides an overview of the current studies and related perspectives on those foundational aspects of this project. The chapter is broken down into six primary sections: Play, STEM Education and Physics, Gender Discrepancies in STEM, Racial Inequalities, YWCA Central Massachusetts, and Simple Machines.

2.1 Play

Play, a word traditionally associated with the movements and activities of children untethered from their responsibilities and assigned duties, has undergone a radical redefinition. Over the last fifty years, developments in neuroscience and developmental theory have recategorized play as a critical tool of education. Dr. Frost of the University of Texas in Austin has described the ongoing renaissance in the study of play as scientists realizing that “play is indeed serious business and is perhaps equally important as other basic drives of sleep, rest, and food” (1998). Additionally, Education Professor David Whitebread of the University of Cambridge states that “Play in all its rich variety is one of the highest achievements of the human species, alongside language, culture, and technology” (Whitebread et al, 2012). Play’s necessity in children’s lives has gone so far as to be declared a right of all children. Article 31 of the United Nations Convention on the Rights of the Child states that all members recognize the right for children to ”engage in play and recreational activities appropriate to the age of the child” (1989).

Why does play merit such high regard by modern developmental researchers? During the first few years of human life, the brain makes rapid developments and is highly influenced by its environment. As the brain develops during this period of life, play has been shown to affect its structure and functions on a molecular and neuronal level that result in increased connectivity and activity levels. It has even been shown that play can affect the length and density of neurons in the brain which can increase the speed at which electrical signals move across regions of the brain, and it promotes the production of hormones that are important for long-term memory and social learning (Yogman, 2018).

Beyond physiological improvements, children given opportunities to play have also been shown to have improved executive functioning. Executive functions (also called executive control or cognitive control) are mental processes used when one concentrates and pays attention. Primary executive functions are inhibition control, working memory (information that is held and consciously processed or manipulated), logical reasoning, and problem-solving (Diamond, 2013). The improvement of executive function allows for increases in early math skills such as numerosity and spatial concepts. Panksepp has also suggested that children deprived of play experience a degradation of executive functioning, which could be associated with the increasing prevalence of attention-deficit/hyperactivity disorder (2012).

Play allows for children to engage with and interact with their peers and develop necessary social skills that they will use throughout their lives. Activities performed during play, such as sharing toys, coordinating with others, and taking turns, are necessary to develop complex social behaviors (Bruder & Chen, 2007). Social competency development is heavily impacted by children's ability to play, especially in pretend play—in which children act out situations that demonstrate their understanding of their world (Moore & Russ, 2006). Socially competent children apply developed behaviors, cognitive skills, and effective methods developed during play to unfamiliar and diverse social situations (Bruder & Chen, 2007).

As stated elegantly by Michael Yogman, "to encourage learning, we need to talk to children, let them play, and let them watch what we do as we go about our everyday lives" (2018). Play is quintessential to well-developed and well-rounded children equipped to traverse the large and dynamic world in which they will have to live.

The focus of this project is to design, implement, and evaluate a piece of equipment conducive to play behavior in children as a means to educate them on identifying and using simple machines.

2.2 STEM Education

The use of play as an educational tool tends to be weaned from children as they age. When they move to higher levels of education, society seems to believe we must lose our sense of wonder and curiosity in exchange for being taken seriously. However, the recent boom of STEM (Science, Technology, Engineering, and Mathematics) education is working to help engage children in the creativity and wonder traditionally lost in post-primary education.

This focus on STEM education, on the surface, is to prepare children for technical careers and fields that have been rapidly expanding in the last few decades. For example, the Smithsonian Science Education Center (2016) reports that the development of STEM-related jobs was three times higher than other jobs from 2000 to 2010. In addition, the U.S. Bureau of Labor Statistics (2021) estimates that STEM occupations will continue to grow at about 10.5% from 2020 to 2030. With such high demand and a positive outlook for the fields, it is imperative that STEM education at the early-childhood and secondary levels familiarize children with the associated careers and provide support for interested children to pursue these occupations.

Beyond the capitalist viewpoint of STEM education, research suggests that all children should participate in STEM education to at least some degree, as this form of education typically incorporates project-based learning (PBL). PBL gives children structured independence to develop their own solutions based on the project's criteria. It enables the learner to self-pace, define the problem, generate objectives to answer the problem, plan to achieve the goals, organize information, coordinate with team members, and acquire valuable skills (Alacapinar, 2008). An additional study conducted in Thailand showed that exposure to STEM education activities and curriculum increases the children' creative problem-solving ability (Sangngam, 2021). This form of education allows children to be exposed to a variety of projects and concepts that necessitate the development of a wide array of problem-solving techniques. Regardless of the child's field of interest, they will be faced with problems that need to be solved, and the foundational skills developed from STEAM education will assist in their ability to accomplish it.

Of the many topics that fall under the wide umbrella of STEAM, physics is an essential and underrepresented subject matter at nearly all levels of education. It is particularly missed in early childhood education as the vast majority of physics education does not take place until secondary level education. Introducing physics from an early age is a necessity (Nasrudin et al., 2021). The study strongly associates future student STEAM success with an early understanding of physics principles. Young children have seen an increased capacity to learn media, logic, language, and physics literacy when the proper approach is utilized. The method suggested by Nasrudin (2021) uses a Focus Group Discussion (FGD), including (1) more straightforward physics logic that is easy to understand, (2) omission of symbols of language, (3) through the right approach, method, and media, delivering learning by the teacher. This research concludes that physics is possible to be taught in early childhood and recommends that early childhood teachers implement cross-disciplinary collaboration with physics teachers in planning, implementing, and evaluating physics learning (Nasrudin et al., 2021). Although the study focuses on physics, the fundamental concepts of problem-solving, collaboration, sequential planning, and discussion of results are applicable across the board regardless of discipline.

STEAM lessons like physics are able to be taught in early childhood. We believe that if we lead children to explore STEAM with the right approaches and media, children will benefit from it. The project will provide an interactive tool for teachers to introduce their classes to physics starting from the *simplest* concepts of force, work, and movement via a direct lesson and allow the children to derive the conceptual relationship between these foundational ideas independently by using the toy at recess and during their varying forms of play.

2.3 Massachusetts Department of Elementary and Secondary Education

The U.S. Department of Education identified the Massachusetts Department of Elementary and Secondary Education (DESE) as the state education agency for the Commonwealth of Massachusetts. The program was started in 1991 by the Early Education Department, who still runs and funds this grant today.

Massachusetts DESE continuously publishes, evaluates, and corrects several curriculum frameworks including common courses such as English Language Arts, History, Art, Mathematics, Science, Technology, and Engineering.

The purpose of the Massachusetts Curriculum Frameworks is to codify expectations for what all children should know and be able to do at the end of each school year. The frameworks “represent a promise of equitable education for all children. They formalize the expectation that all children in the Commonwealth have access to the same academic content, with no prejudice” (Massachusetts Department of Elementary and Secondary Education, n.d.).

As preschool students, the frameworks lay out a series of standards necessary for teachers to address throughout the academic year as a means to prepare the children for success. As a whole the standards aim to provide the children with the means to operate in the very new-to-them world around them. Learning to socialize, communicate, and collaborate are key tools for any child’s future success. Additionally, many standards articulate the necessity of the children moving and becoming more effective in manipulating their environment.

In the study of Arts, children at the Pre-Kindergarten (PreK) level explore topics such as dance, music, theater, visual and media arts. Dance, music, and theater work to develop the children’s fine and gross motor skills and their ability to differentiate between different parts of their bodies and use them as a means of expression. Visual and media arts work on a more conceptual level to encourage the creation of artistic thoughts or works (Massachusetts Curriculum Framework for Arts, 2019, p 24, 32, 40, 50, 59).

The English Language Arts (ELA) standards encourage the PreK children to expand their means of communication and their comprehension of written or verbal information. Written information is omnipresent in society and the children will need to have the means to read, comprehend, and respond to the information they encounter in everyday life. The ELA framework also delves into the way information is distributed digitally by instructing on the uses of mobile devices and internet enabled devices that can send media nearly instantaneously (Massachusetts Curriculum Framework for English Language Arts and Literacy, 2017, p26-29).

Social Sciences and History introduce the children to the general rules of society and motivate the students to ask questions about why people act the way they do and why our society works the way it does. By exploring civics and history on a very personal level, the framework allows for children to develop habits that promote fairness, friendship, and respect amongst their peers. Studies in geography begin the process of the children understanding their place in the world and what is in the environment around them (Massachusetts Curriculum Framework for History and Social Science, 2018, 27-32).

The framework for mathematics wants the children to look out into their world and have the capacity to quantify what they see. The curriculum standards do so by expanding the children's understanding of numbers into the double digits, and increase their knowledge of simple shapes. The children will also take time to exercise their spatial reasoning and learn to characterize objects they see using comparative adjectives such as "this one is longer than that one", "this is heavier", etc. It is a necessity for children to learn to differentiate aspects of their environment as a means to communicate mathematical ideas and express their ideas (Massachusetts Curriculum Framework for Mathematics, 2017, 22-24).

Science, Technology, and Engineering are interwoven into a single collaborative form in the curriculum standards to highlight their interdependence in today's society. At the PreK level, children continue the work from their history and social sciences by exploring the environments around them. The children observe the plants, animals, and weather in their everyday life. They explore natural phenomenons like the sun and moon, their movements, why they occur, and the effects of the sun's light. The primary focus of this scientific observation is to help establish the cause and effect relationships that the physical world exhibits, provide the children with the tools and language to express this relationship, and instill the sense of curiosity for children to question what is causing these strange patterns they experience (Massachusetts Curriculum Framework for Mathematics, 2017, 22-24).

The scope of this project will be to enhance the preschool teacher's ability to instruct the science, technology, and engineering standards by creating an intuitive system for children to interact with during play and explore the mechanisms that can cause change in their environments. This will allow teachers to begin discussions that challenge the students to identify why the actions occur. Secondary to the science and engineering standards, the ability to coordinate and discuss actions with their peers will provide a means for the children to explore the social behaviors described in the civic curriculum.

2.4 Gender Discrepancies in STEAM

Given the universal importance of STEAM education, the vast gender discrepancies in those that pursue STEAM are shocking. The National Science Foundation reported that in 2019 approximately 74% of all science and engineering positions in the United States were held by male-identifying individuals.

The most prominent theory behind the wide gap in gender discrepancies is due to perceived stereotypes of the engineering field. In the article, "When preschool girls Engineer", the author observed whether preschool girls were actively participating in engineering-related activities and then interviewed the children regarding their future goals and aspirations. The author believes that most preschool girls find it difficult to actively participate in engineering education activities due to a bias in the material presented that tends to cater towards male individuals. These materials often portray engineers as males and utilize examples that are perceived as excluding women from technical fields. This makes it difficult for preschool girls to imagine that they will become engineers in the future. Therefore, it is vital to redesign engineering courses to include women, which can directly increase the proportion of female engineers by reducing the stereotypical view of STEAM fields as being male dominated (Fleer, 2019).

To reduce the perception of the male-dominated field, it has been proposed to intentionally use materials and examples that incorporate women and other minority groups in equal proportion to the number of male examples. Sapna Cheryan (2009) conducted a series of experiments to show that by replacing some traditional materials which are considered engineering or science-related with examples amplifying women's roles in those fields, it increased the overall reception of the content by women. Additionally, it was noted that the utilization of primarily male examples hindered women's interest in engineering and science, even if a class consists entirely of women (Cheryan, 2009).

Fleer from Monash University in Australia researched a cultural-historical study investigating how a "Conceptual PlayWorld" changed the traditional Froebelian play—a form of educational play characterized by Freidrich Froebelian that viewed play as "play is the highest expression of human development" (The British Association of Early Childhood Education)—to support girls' play and motives in STEAM. Classrooms that taught subjects traditionally difficult for girls to engage in were transformed and afforded entirely new ways of playing, shown to be inclusive of girls, and disrupted gendered interactions and divergence. Researchers designed a "Conceptual PlayWorld" over 12 weeks in the educational experiment focusing on role-playing engineers and scientists. The study's findings provide evidence to suggest that children that feel welcomed and included in an area are more likely to engage in that subject regardless of the established norms (Fleer, 2021).

Fleer asserts that "society as a whole is likely to benefit as girls gain equal access to STEAM knowledge, changing the future course of STEAM fields where more ways of solving STEAM problems can become the new normal" (Fleer, 2021). As a girl gains equal access to STEAM knowledge, it will become more beneficial for STEAM education and society.

People need to diversify the image of computer scientists and engineers to attract all groups of people and to stifle these preconceived notions of belonging to a career or discipline simply due to your gender. Through interventions in the environment and the media, and through the diversification of the types of people who represent these fields, children's cultural stereotypes can be changed (Cheryan, 2015).

The development of a child's toy necessitates that we as the developers take stride to avoid unconscious bias towards or against any subset of the population. To this end, we intend to avoid developing any structure that overly resembles structures, concepts, tools, or other items that have become unnecessarily gendered. Additionally, we will ensure that the toy incorporates colors and patterns that do not appeal to one particular group. It will also be crucial that any diagrams, images, or descriptions that are made available to the children, educators, or their parents avoid depicting only a small part of the population.

2.5 YWCA of Central Massachusetts

Working to bridge the gaps of society and demolish the barriers that inhibit gender or racial equality, the YWCA is dedicated to eliminating racism, empowering women, and promoting peace, justice, freedom, and dignity for all. (YWCA USA, 2021). During the industrial period of the late 19th century, young women started to come to Worcester searching for jobs and education. The YWCA was founded for the needs of these women and provided services from educational and job-training resources to safe, affordable housing and health-promoting programs. These services and programs empower young women to become self-reliant and financially independent when many of them are not (YWCA CM, 2018).

Today, there are over 20,000 local YWCA branches located in more than 120 countries, such as the United States, Canada, and the United Kingdom (YWCA USA, 2021). Our local YWCA chapter, the YWCA Central Massachusetts (YWCA CM), was founded in 1885 and is the longest-serving agency in Central Massachusetts. YWCA CM serves more than 13,000 individuals annually from 64 cities and towns (YWCA CM, 2018). The operating site of YWCA CM in Westborough, MA provides early-childhood education and care and youth development programs for the surrounding communities in order to promote their mission of helping early-childhood education, promoting racial and social justice, and improving women's health and wellness (YWCA CM, 2018).

YWCA CM provides four different programs for children from one month to five years old. These programs include the Infant Program for children from 1 month to 15 months, the Toddler Program for children from 15 months to 36 months, the Preschool Program for children from 2 years, 9 months to 4 years old, and the Pre-Kindergarten Program for children from 4 to 5 years old. The goal of these programs is to develop children's language skills such as reading and writing, athletic skills such as swimming, social skills such as cooking, learning skills such as STEAM activities, and creative skills. YWCA hopes to stimulate each child's curiosity and encourage them to learn through these programs (YWCA CM, 2018).

To support the YWCA CM in the promotion of the educational and societal welfare of young children, this project aims to provide a set of educational activities to accompany the toy that promotes the children's abilities to explore and investigate their surroundings. The activities can either be used on their own as individual experiences to challenge the children to converse and interact with each other during a structured play session or used as a series aimed to engage children in scientific learning and collaboration through related activities.

2.6 Simple Machines

To better educate children regarding engineering and physics, the children need to develop an intuition regarding the fundamental tools used in these fields. The most basic tools upon which almost all mechanical devices are derived from are the set of devices called simple machines. This set consists of levers, inclined planes (or wedges), pulleys, wheels and axles, and screws (Victoria State Government, 2019). Understanding how simple machines work can provoke curiosity for children, which leads to further interest in the topic (Lucas, 2018). Once a child learns the usage and application of simple machines, they gain the ability to recognize the machines in their everyday lives.

Simple machines in preschool classrooms provide an opportunity to develop fine motor skills along with the engineering reasoning. Fine motor skills are defined as “the movements and coordination of the small muscles of the body, typically thought of as the movements that involve the fingers and the hands” (Rodil, 2020). It becomes imperative for children to develop fine motor skills for usage in daily life. “These types of movements are important for young children to practice as they develop because they help a child lay the foundation to do such everyday tasks as buttoning a shirt, tying shoe laces, grasping a pencil, using utensils, typing on a keyboard and much more” (Moyses, 2016). Asking children to balance two sides of a lever, raising a pulley to specific heights, screwing in a screw, or turning a wheel are all activities to promote fine motor development.

This introduction to simple machines at the preschool level will enable better recognition of the material when reinforced with mathematical formulas later in education coupled with the physical benefits of fine motor development. To this end, we will incorporate as many simple machines as possible, but give preference to those with the most visible mechanism (pulleys, wheel and axle, and levers) as visual information will provide a simpler method of conveying information to the young children.

2.7 Summary

It is evident that play provides a quintessential area for young people to investigate, discover, create, and reinforce thoughts on how the world around them operates. When they are given these opportunities to develop a practical understanding of scientific concepts and theories, they are better prepared to excel in these fields later in life.

To provide the best environment and circumstances possible for a wide audience of students to explore these fields, it is imperative that children are provided with positively affirming (or at the bare minimum, not negatively affecting) examples of these fields that they can connect with so as to not deter the children. The ability for children to develop positive experiences related to these fields has been shown to encourage children (especially those in traditionally underrepresented populations in STEAM) to pursue and take interest in these fields.

Organizations (such as YWCA CM) that promote early childhood STEAM education work to create and expose children to these positive experiences. They aim to encourage all interested children to pursue STEAM regardless of background or externally perceived identities. However, there are stumbling blocks to every good mission. At present, few items exist for children to utilize in an outdoor setting that are both engaging and educate on foundational STEAM principles (i.e. simple machines).

This project seeks to produce an educational toy capable of demonstrating rudimentary physics and engineering principles in an engaging and accessible manner. The toy, coupled with a set of educational activities created around the Massachusetts Department of Elementary and Secondary Education Curriculum Framework, will be able to reach PreK students from any background to assist in their development and understanding of the world around them.

3. Methodology

The goal of our project is to make an outdoor toy for preschoolers aged two to five years old that can help them learn about simple machines and work with the simple machines in a team setting. To accomplish this goal, this IQP team will:

- Analyze playstyles of children to deduce common traits and patterns of behavior
- Determine the current methods of teaching STEAM to children (2-5 years old)
- Develop designs for the toy and educational lesson plans to accompany the toy using an iterative feedback system (see Figure 1)
- Construct and deploy the toy and lesson plans to preschool children
- Analyze the successes and shortcomings of solution

These steps are visualized in Figure 1, below.

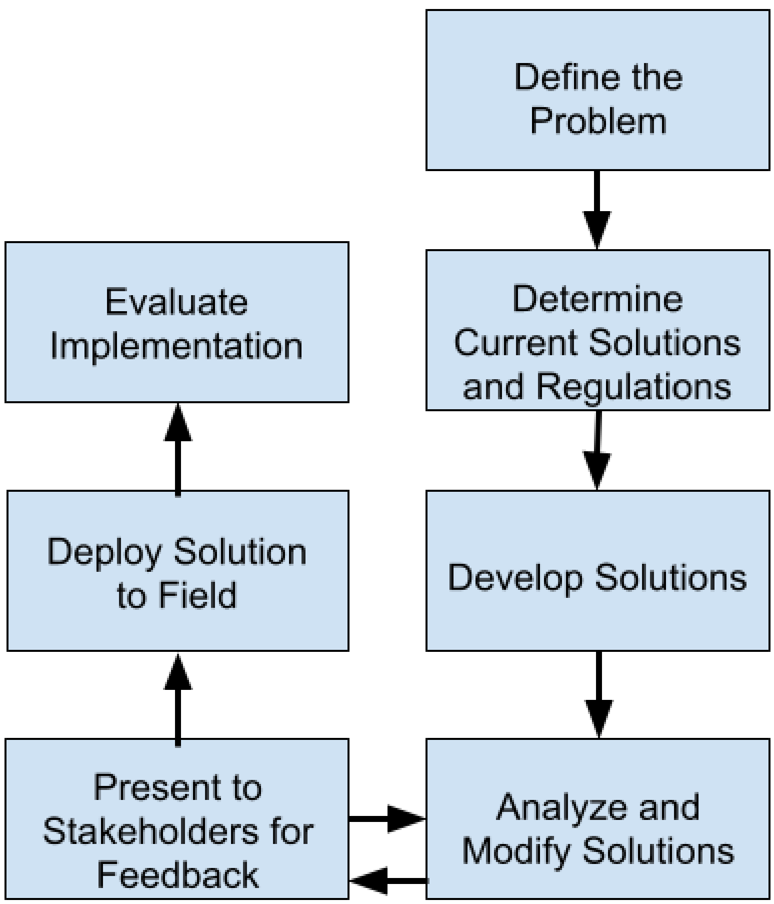

Figure 1: Iterative style that is implemented to develop and test the lesson plans and physical structure

3.1 Preliminary Observations and Interview

When they play with toys, children can learn many different things such as shapes, colors, and numbers, as well as abstract concepts like cause and effect, forces, and teamwork. Therefore, it is very important to observe what children are interested in and how they learn. At the same time, interviewing preschool teachers can provide a better perspective on structuring and tailoring education to best fit this age demographic. We will combine interviews with teachers and observations of children to make an engaging toy that will allow children to freely learn about simple machines and teamwork.

3.1.1 Observations:

Before we conducted interviews and observations, our team needed to identify an ideal set of metrics to identify play behaviors in children for the observations. The team reviewed current literature via educational databases—such as the Education Resource Information Center (ERIC)—to firmly cement the metrics for observation. The entire list of observation criteria is included in Appendix D. However, the primary considerations during observation will be:

- Which pieces of playground equipment are most popular
- What are common characteristics between the most popular pieces
- How do most students interact with the available equipment
- Is there an observable bias for certain demographics of children and their playground equipment interests/interactions

To ensure proper observation of the children, the team held two observation sessions (Nock, Kurtz, 2005). Each session lasted approximately one hour during the afternoon when children at the YWCA played at recess . The team documented all observations on the synchronous notes platform Google Docs so the data was available to all members and secure from unauthorized access.

3.1.2 Initial Interviews:

Adjacent to characterizing the play styles of the YWCA CM children that will be using the final product, a focus group style interview with four YWCA CM teachers helped to establish the learning styles of the YWCA CM children and ideal approaches to instructing technical and abstract information in an unbiased way.The interview involved four YWCA teacher who volunteered to have the IQP team interview them via Zoom video conferencing for about one hour. The IQP team members took turns asking questions and used an auto-transcription program through the Zoom video conferencing service to record the answers the teachers provided. The team followed the same procedure for data storage as described for the observations. The formal interview involved a range of skills: directing the interviewee to the information required, minimizing defensiveness and anxiety, overcoming people's natural tendency to suppress information, avoiding the introduction of information that has not yet been established, and encouraging accurate, coherent, and elaborate detail (Powell & Brubacher, 2020). The review of appropriate literature suggested that the interview questions should be mainly open-ended questions because such questions can give teachers better opportunities to articulate their exact thoughts. The interview questions are listed in Appendix E.

The main questions of the interview will revolve around what methods are needed for the children to learn a variety of different topics and subjects. Minimizing misunderstanding and potential contamination of the memory process is the key to getting the best evidence. Questions must be non-leading and without coercion (Powell & Brubacher, 2020). We avoided some wording deviations that would have affected the answers by the interviewee. Leading questions often carry personal opinions, provide negative or positive information, and force respondents to make distorted or wrong judgments. Further, the team framed questions to encourage elaboration and allow interviewees to report what happened in their own words and at their own pace; these elements comprise open-ended questions (Powell & Brubacher, 2020).

Additionally, the IQP team also consulted the teacher for some simple data. These data will include the number of children and the height of the children. This information can help us design a toy suitable for children. However, to ensure the privacy of the students and teachers being interviewed, we will gather no personally identifying information such as names, birth dates, or home addresses.

The information gathered from the interviews and observation was used to drive the more hands-on portions of this project — i.e. the building of the playground toys and development of lesson plans.

3.2 Initial Designs and Selection:

All group members developed a list of conceptual designs of the playground toy during three primary brainstorming sessions. Each session was separated by about two days to allow members time to develop new ideas or improve upon previously discussed concepts. Prior to these sessions, the team established ground rules to the session that followed a procedure similar to Tom Kelley's and Jonathan Littman's work on discussing proper brainstorming practice (2001). An initial goal was established to guide ideas towards the purpose of the session, no ideas were criticized, all ideas were sketched on a communal whiteboard so all team members could be involved in discussion and all designs were easily seen. The team recorded the designs by creating a diagram-like drawing and a written description of a design idea. Each of these concepts were generated to provide the team with as many different concepts as possible to consider. A list of the designs and their descriptions can be found in Appendix B.

To determine the best design, the team implemented a design matrix. A design matrix is a list of candidate designs and characteristics we wish to achieve, such as number of simple machines, repairability, resistance to child damage, etc (Complete list of characteristics and descriptions in Appendix C). Each design was ranked in those categories by giving points from 1 to 5 and adding up all points to see which design receives the highest score—indicating the preferable design. Once scored, the highest ranked design will be selected to continue through the design process.

Table 1 below lists the criteria included in the design matrix, the considered designs, and their respective rankings for those criteria. The sums of those columns was used to select the three highest designs used for further consideration.

Criterion	Weight	Designs											
		Shovel on Wheels	Bucket Pulley on A-Frame	Moving platform with pulley bucket	Rotating Post with digging tools	Model Crane	Auger	High Rise Crane	3-D Printer	Adv. Big Dig	Giant Excavator	Box Dirt Mover	Stationary Dirt Loader
Safety	10	4	4	3	4	4	3	4	4	4	2	4	3
Number of Students Required to Operate	8	1	2	2	2	1	2	2	4	1	2	1	4
Number of Unique Simple Machines	7	3	3	3	3	3	3	3	4	2	3	3	2
Number of Simple Machines	6	3	3	3	4	2	3	3	5	3	3	3	2
Fun	3	4	3	3	3	4	4	4	5	3	4	4	4
Resistant to Student Damage	5	3	3	3	3	3	4	4	3	4	3	3	2
Obstructs dig pit use	1	5	4	5	4	3	2	5	5	3	3	5	3
Repairability	2	4	3	2	4	2	3	3	2	2	2	4	4
Installation ease	1	4	3	2	4	2	3	3	1	4	2	4	4
Total:		131	132	120	141	117	128	141	170	120	111	131	125

Table 1: Design matrix used to evaluated design concepts

3.3 Modeling:

The three initial designs (3-D Printer, Rotating Pole with Digging Tools, and Bucket Pulley on A-Frame) allowed the team to develop a set of computer-aided design (CAD) models using engineering modeling software, like Solidworks ©. Digital modeling enables the team to make quick changes and measure all dimensions, mass, and volumes. It also provides a 3-D visual appearance, structural analysis, and motion animations. As a result, digital modeling saves money and time as well as provides opportunities to improve the design before it is built and installed. Digital modeling also presents an easier way for non-engineers as compared to a complex blueprint or other standard technical drawings as it eliminates the need for the individual to project a 2D design into 3-D space as the CAD model does so already. Krigsman et al. (2021) performed a similar methodology on the development of an interactive cart as a family-friendly mobile exhibit. In designing the cart, the group members each sketched out their initial ideas on paper, in Microsoft Paint © and in SolidWorks ©, and compiled them into a document. CAD programming allows them to develop a scaled prototype, get better visualization, and aid in the cart fabrication.

This project will take a similar approach by first creating digital 3-D models of the selected toy structures. The digital model will be true to size and include realistic finishes, and moving parts. The digital models will be scaled down to 1:18 scale and 3-D printed to a small-scale working physical model. This 3-D printed model will be presented to the YWCA CM teachers and stakeholders for their input.

3.4 Material Selection:

During the modeling phase, the team must closely consider the material choices. The playground set needs to be highly resistant to not only the wear and tear of children playing but also prevent chemical reaction and natural corrosion. Dr. Kate Cronan (2019) reports that “more than 200,000 kids are treated in hospital ERs for playground-related injuries.” Ensuring the equipment we produce for the YWCA CM is safe and will remain safe is of the utmost priority.

The team will conduct a review of materials commonly used in playground equipment to determine an ideal set of material properties to ensure strength, durability, financially feasibility, and environmental resistance along with the appropriate material standards. We will then apply this research to generate a list of appropriate materials, apply them in different combinations to the selected designs, and analyze the cost of the final product. There are several material properties we are going to focus on such as anti-mold, moisture and UV-resistant, non-toxic, lightweight, and touch-friendly. The intent of this process is to identify the ideal cost and material property tradeoff to maximize the economic feasibility of the design.

The material selection will also allow for a complete rendering of the CAD model with all of the colors and features of the design. A full model—which involves adding material appearance, physical constraints, and animations—makes communication of the designs to the teachers much easier on both our end and theirs.

In addition to enhancing the CAD models, the selection of materials and parts will enable the team to generate an initial bill of materials to present. The bill of materials will be used to estimate the cost of the designs as the final cost is a factor of the design.

3.5 Lesson Plans:

The development of the playground toy will be coinciding with the development of lesson plans that utilize the toy design. The goal of these lesson plans is to encourage the teachers to utilize the playground toy in formal lessons and not just as recreational equipment for their children and as a demonstration of play-based learning. In the state of Massachusetts, teachers are required to present information relevant to the state educational standards—specifically, the State of Massachusetts Curriculum Framework for Science and Technology (2016). We need to ensure that the lesson plans developed to accompany the playground equipment provide teachers with a way of enhancing the material they already present. Therefore, generating a set of lessons that cover material required by the state provides the teachers an additional method to explain information.

3.6 Final Review of Design:

With the full models in hand, the team will perform a focus group analysis of our design to gauge the interests of the educators and gather feedback about the playground toy's design, accessibility features, and perceived educational value. To conduct the focus group, we will invite the same teachers that participated in the initial teacher interviews to meet in-person to view an approximately 15 minute presentation given by all four members of the team that highlights the three designs of the toy. After the presentation, we will ask a series of questions to engage the teachers in discussion about the design qualities, their preference in design, and features they believed were missing. The teachers' responses will be recorded via manual transcription to Google Docs. We view this set of opinions and focus groups with the utmost importance as this group of primary stakeholders will be using the proposed designs to educate students and therefore need to have their concerns and thoughts incorporated.

3.7 Acquisition of Materials:

We will modify our design based on the feedback they provided and then produce a final computer design model with full rendering. We will determine at this time if it is necessary to conduct another focus group or to proceed to construction. Additionally, this rendering will enable the team to be able to generate a final bill of materials (BOM). This rendering is necessary to construct as it provides a more detailed version to provide exact quantities of each material we will need for construction of the playground toy. The BOM that contains these quantities of all rough materials will streamline the ordering of materials and the building process.

The materials will be sourced by using the funds provided by WPI Worcester Project Center funds and from money raised by the YWCA CM.

3.8 Installation and Review:

Once the parts have been processed and built, the team will install the toy in the YWCA CM playground for the children to access during recess and guided exploration classes. We intend to identify how intuitive the design is for students to use. To achieve this, we performed another round of observation following the same format as the initial observation. The group will observe the children's behavior. In particular, the team will note how the children use the toy, the number of times children use the toys, particular biases towards using or not using the toy, student difficulties in manipulating the toys, etc. The Center for Early Childhood Education research group has found that leaving kids to explore and form discussions among themselves without formal lead by an educator leads to more engaged play, especially for students who are 3 years old (DeLapp, 2021). This information brought the most direct feedback to the IQP team as to whether the children like the toy and if the toy meets the physical design demands to resist the rough environment of a playground.

Once we are assured of the safety and proper design of the playground equipment; the team will provide the teachers at the YWCA CM who participated in all teacher interviews and focus groups with our set of developed lesson plans to implement in their classes. After reviewing the lessons, the instructors provided written feedback on the strengths and weaknesses of the lesson plans. This methodology and similarly described instruments have been utilized by others in educational researchers — e.g. Putnam et al. 2006.

The successful completion of this project will enable the YWCA CM not just another toy to entertain the children they care for, but a tool to spark the interests of students and engage them with the foundational concepts of physics, collaboration, and problem solving. We intend for all students to approach the toy wondering how it works and to leave the toy with the desire to ask questions about the mechanics of the world around them.

4. Results

4.1 Initial Teacher Focus Group:

The initial teacher focus group was conducted on November 11, 2021, and lasted for 48 minutes. During this time, four YWCA CM preschool teachers (Elizabeth Scanton, Deanne St. Pierre, Taylor Cullen, and Kayla O'Brien) discussed topics ranging from curriculum, STEAM teaching methods, play habits of students, and expectations for the final design of the playground equipment.

The YWCA at Westborough uses a curriculum design tool called Teaching Strategies that complies with the Massachusetts Educational Frameworks. At the preschool level, this curriculum calls for each day to have the following dedicated time periods: free playtime, an overarching question for the day's lesson, a large group activity, a reading passage, hands-on activity representative of the day's topic, art project, tactile engagement, dramatic play, small group sessions, outdoor activity, and handouts for students to work on with a family member. This system provides structure for each day's class but allows flexibility for teachers to employ varying activities that fit into each.

The goal of the lessons is not to necessarily provide the most minute level of detail regarding the day's topic, but to instill a more abstracted sense of operation for how a concept works. An example activity the teachers described involves students constructing ramps for toy cars. The children develop the general understanding that the higher the ramp, the further the car will travel after the release from the peak. The children grow to understand the cause-and-effect systems in place at this level of education, especially during STEAM activities.

The teachers discussed design concerns and criteria they were most interested in seeing for the final product. There was discussion regarding the teachers' concern for safety as the young children rarely treat things gently, especially on a playground. The safety concerns revolved around the ability to tip the equipment or climb on it. Both of these potential accidents should be avoided at all costs to prevent injury and ensure compliance with state regulations. The focus group additionally recommended avoiding small pieces or anything detachable because, as Deanne St. Pierre stated, “if it’s small enough to go in their mouth, it’s gonna go in their mouths.”

While the anticipated safety and maintenance concerns were discussed, the focus group provided a vast amount of information that the development team had not previously considered in the preliminary discussions about possible designs. A primary concept the teachers wanted to have integrated into the design involved mechanisms that required more than one student to operate, a.k.a. teamwork. Systems that involved teamwork were desired by the teachers as a way to improve their students’ communication and problem-solving skills. A collaborative system would also partially negate kids attempting to ‘hog’ the toy or arguing over who should use the equipment. Teacher Elizabeth Scanton described this issue by saying “The problem with a lot of outside toys is if it’s ‘one’ toy, they’re going to fight over it. So there needs to be different components of something out there…”.

The interview highlighted the need for the play equipment to be complex enough to necessitate multiple students operating it for the development of critical social skills. However, it needs to have systems that control clear cause-and-effect relationships for children to grasp the physical forces and concepts at work.

4.2 IQP Student Observations of YWCA Children at Play:

Our observation period of an hour consisted of two distinct phases. Due to the class sizes and age differences, the recess area was divided into two sections: a blacktop with bikes, scooters, and other similar toys and a playground area with slides, climbing equipment, and the dig pit. We focused our observations on the latter area as this is where the dig pit resided, and it is intended that the toy structure will be installed in the dig pit.

Two age groups each used one area while the other age group played on the other. At approximately 30 minutes, the two groups rotated so they could use the other area. Initially, the younger group (up to 2.5 years old) played in the playground area with the dig pit.

The younger group consisted of about approximately 13 children. During their thirty minutes on the playground, they primarily utilized the slide/platform equipment, the stationary car, the green climbable frog, the scattering of balls, and a doll stroller.

Most notably absent from this list of activities that the students participated in was the dig pit. None of the students in this age group interacted with this area for any substantial period of time. The teachers reported that the dig pit is more popular when it has a higher level of soil, and it has not been refilled recently.

Realizing we could not observe without creating a noticeable distraction to normal play, we capitalized on the opportunity by asking the children a few questions about their favorite toys and colors to determine what they would like to see in a new piece of playground equipment. Unfortunately, for every child we asked, a new color and favorite playground piece was named showing no consistent answer.

When the classes rotated, the older children entered the play area. These children ranged between about 3 to 5 years old. There were approximately 14 children in this group.

These children were much more timid and uneasy around us. They played close to their teachers, but once again did not appear to show any preference for playing in specific groups.

The older children were much more interested in the dig pit. However, the teachers were actively encouraging the children to play in the dig pit. The children used rakes and handheld shovels to remove leaves and manipulate soil. The teachers claimed that the dig pit is very popular, but as soon as the teachers left the area and stopped actively encouraging, the children left the area and moved to the slides and climbing equipment.

4.2.1 Analysis:

The students observed during this time period seemed mostly uninterested in the dig pit in its current form. Although some interacted with it. It was clear that it was primarily due to encouragement from their instructors that they played with the Dig Pit. This may be due to the IQP Teams presence in the playground or from the low level of soil as the teachers only refill it a few times per year.

Beyond the Dig Pit, the students showed no gender or racial preference for any of the toys nor did they appear to group together following any pattern. This provides further evidence to earlier works that point to external pressures later in life causing the development of the gender bias observed in STEM workers.

4.3 Initial Designs:

Eight unique designs were generated for consideration of the project (each design is listed in Appendix B). The designs were analyzed using a decision matrix (Table 1) to identify the most effective designs for further development. The decision matrix was created with a heavy emphasis on safety and teamwork as these were the properties most highly desired by the YWCA CM teachers.

Designs 2, 7, and 8 (the Bucket Pulley on A-Frame, High Rise Crane, and 3-D Printer respectively) were selected with the highest scores on the decision matrix.

The 3-D printer (seen in Figure 2) had the highest overall score of 171. The team identified this design as having the most number of unique simple machines as it incorporates pulleys, wheels and axles, a gear system, and a series of screws for the students to operate. Additionally, It would require the most number of students to operate. It would require one child to move the carriage along the X-axis, one child to move it along the Y-axis, one child for the Z-axis, and one student to operate the digging tool. In a more subjective matter, the design appeared the most difficult to operate and would require more teamwork than the other designs. A concern was raised involving the installation of the design as it was the most complex design presented.

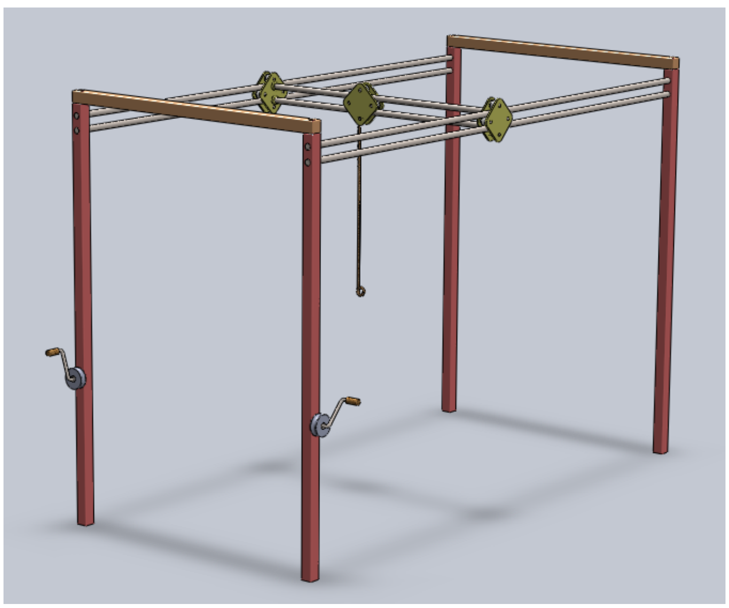

Figure 2: 3-D Printer

The second highest design was the High Rise Crane (seen in Figure 3) with a score of 141. This design required fewer students to operate the design as it would only require one child to position the digging tool and one child to operate the tool. It required a total of three unique simple machines (pulleys, wheel and axle, and a lever). It was considered more resistant to student damage than the 3-D printer as it required fewer parts and less overall moving pieces. For this same reason, it was deemed easier to repair and install.

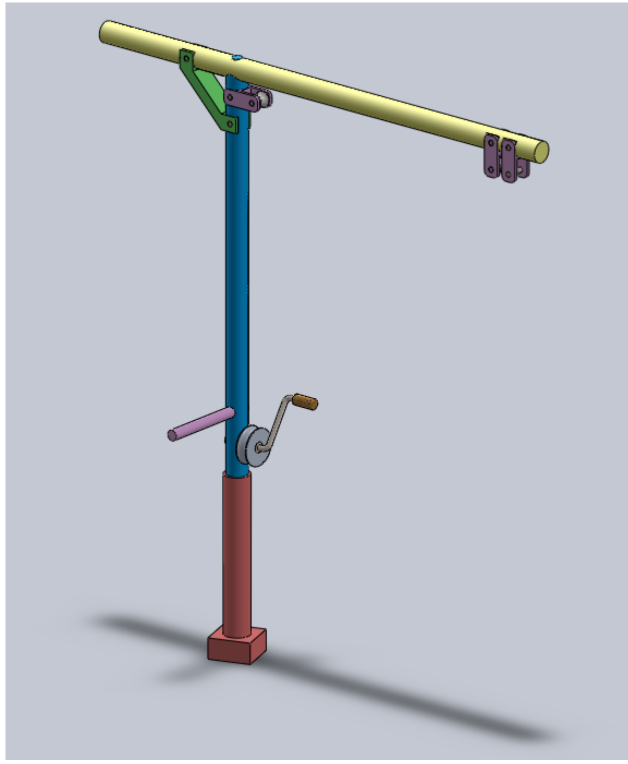

Figure 3: High Rise Tower Crane Model

The Bucket Pulley on A-Frame (seen in Figure 4) was ranked with a score of 132. It also only required two students to operate (one to move the bucket along the horizontal axis and one to operate the digging tool). The design included a pulley system to raise and lower the bucket, a screw system to move across the horizontal axis, and a wheel and axle to operate the screw. Due to the length of the overhead rod and the estimated stress it could receive, it was rated at a 3 out of 5 for resistance to student damage as pulling on the rod could possibly bend the system.

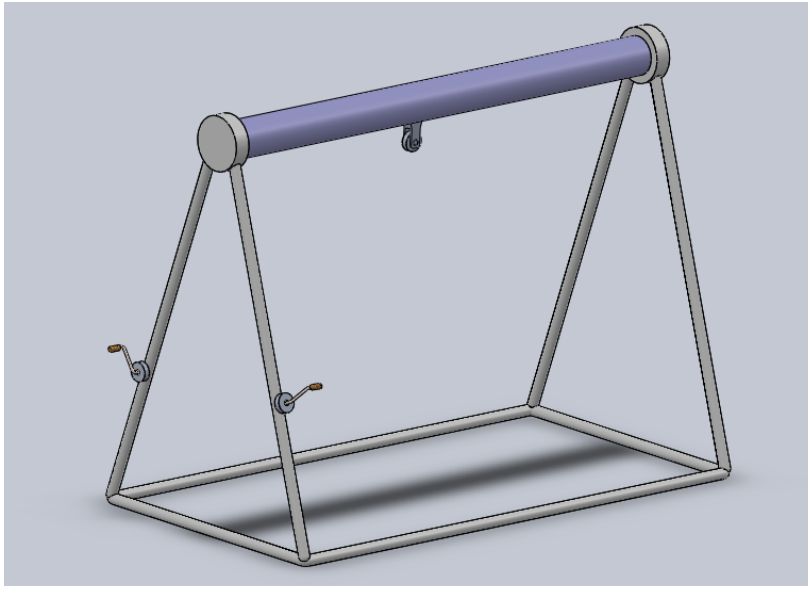

Figure 4: Bucket Pulley on A-Frame Model

Overall, the majority of the other designs fell short due to the number of children that could operate it at any given time. A few designs such as the Auger and the Giant Excavator had safety concerns that eliminated the potential to continue with the designs.

4.4 Selection of Final Design:

The IQP team presented the YWCA CM preschool teachers with the three designs (High Rise Tower Crane, Bucket Pulley on A-Frame, and 3-D Printer) and their estimated costs in a presentation format (presentation in Appendix F). The teachers showed a significant preference for both the tower crane and 3-D printer design, but disregarded the bucket pulley due to its limited reach and applications. Because of the near tie in the selection of the design between the teachers and the unanticipated sickness of the YWCA CM director prior to the presentation, the design selection was delayed a few days until the director was able to render the tie breaking vote. The High Rise Tower Crane design was eventually chosen for its cost and for the minimal time required for installation.

The teachers were also asked the following questions in relation to the designs presented:

Are there any significant safety concerns?

The first suggestion that teachers proposed is that the toy must eliminate all pinch points and prevent small crevices. The main reason behind this is that teachers do not want students' fingers to be stuck. For the team, the suggestions are extremely useful because these tips help eliminate the chance of accidentally using unsafe parts.

Will the children have difficulties using any of the designs?

The teachers think the kids will be able to use any of the designs that we proposed without any problem. On our side, this means that we do not have to simplify our designs and we can even add more simple machines onto our current designs during the final design phase.

Do you have a preference for materials?

The teachers gave us a no on this question but still gave us some suggestions on choosing the material. They indicated that the materials should be safe and weather proof, besides that, they do not have any specific preference. Because the materials are not limited, we can always use the materials that work best for our designs.

Does the design need to be collapsible or weather resistant?

The teachers really want the toy to be collapsible as most of the toys and equipment are taken off of the playground during the winter months or when the playground will not be used for an extended period of time.

Any color preference for the final equipment?

The color should be bright and attractive, besides that, teachers do not have much preference.

4.5 Final Material and Parts Selection

The final list of parts and materials (Appendix G) primarily consisted of pre-shaped parts that would require as minimal modification as possible to minimize time during the construction and assembly process. To this end, the IQP team searched primarily at large hardware stores such as Lowes, Home Depot, Amazon, and McMaster Carr as they have a large inventory of pre-manufactured parts.

The overall structure of the toy was made of galvanized steel pipe as it provided a cheap, relatively lightweight, and corrosion resistant metal that was able to withstand the wear and tear of a playground environment. The use of a standard size galvanized pipe (2 ⅜" OD) also allowed for compatibility with other pipe fasteners and joints that were also used in assembly for mounting and the 90 degree angle joint at the top.

The hand crank used to raise and lower the bucket will be a high contact surface that all of the students will be manipulating. Sharp edges, pinch points, or anything that could be uncomfortable for a child to use would highly discourage them from using the toy in the future. The plastic hand crank chosen was used to ensure a smooth surface with minimal pinch points for the children to use. Additionally, as it was designed to withstand long exposure to marine environments, it is robust enough to endure the frequent rains and other environmental conditions of central Massachusetts.

The pulleys themselves were stainless steel pulleys made to accommodate upto ½" rope. The stainless steel construction provides the environmental resistance for the outside area it will be used in. The accommodation of wide diameter rope allowed for the use of a thick rope that the children can easily manipulate and use without struggling to hold.

The team elected not to use the maximum width rope for construction. While it did provide a better surface to hold and grab, ½" rope limited the total length too greatly to be useful. ⅜" rope was used instead as it provided sufficient length for the block and tackle pulley system to be used and was easier to grab and hold than ¼" rope.

A 3.7" handle that was made of a 3.7" long M10 bolt and a 3.1" plastic cover was used as a handle that was to be inserted into the left side of the tower crane for the students to grab and rotate the upper central post and the overhead arm.

Three colors were chosen for the final paint color of the system. Yellow, red, and blue were chosen as they are the primary colors in the natural color system as they cannot be mixed or created from any combination of colors. These colors seemed an appropriate match for the young children that would be using the end result. The colors were found in a spray paint with a glossy finish and highly saturated pigment to accommodate the request for bright colors. Additionally, a spray-on primer was acquired to assist with the color uniformity across the surface.

Internally, two types of bearings provided a smooth turning system for the tower crane to rotate around its Z axis. Two ball bearings were inserted into the blue colored upper section of the pipe (see image 3 above or image 5 below) with steel screws above and below the bearing to hold them in place. The bearings were sealed to prevent water damage. A third ball bearing was inserted in the red colored lower section (see image 5 above) to stabilize the pipe in the lower section. The team also used a thrust bearing (aka sandwich bearing) in between the two pipe sections to help reduce metal on metal grinding as the upper section rotated.

Image 5: Ball Bearing Inside of Blue Upper Section of Tower Crane

The bearing would need something to rotate around, so the team used a 1 ¼” solid steel rod as the shaft of the bearings to facilitate the smooth rotation and assist holding the structure together.

Concrete sleeve anchors were selected as part of the mounting hardware as they are designed to securely connect the structure to the YWCA CM concrete retaining wall near the dig pit.

Two steel fence brackets were used in conjunction with the metal sleeves to provide a flat surface that the metal pipes could be mounted to the wall. The brackets have a D shaped design that wraps around the pipe and provides four points to secure to the wall.

4.6 Construction

The team began construction with measuring and then cutting the galvanized pipe that made up the outer shell of the tower crane. The ends were filed to remove any metal burrs or shavings that could cut or scratch the children. The upper section of the main stem and the overhanging arm were then drilled with two ⅜” holes for the pulleys’ mounting hardware.

The solid steel rod that would sit inside of the assembly was cut from its initial length of four feet to 22 inches to reduce stress on the system. The ends of the rod were then filed down for safety. The sides of the rods were filed to remove the outer coating as the coating made the rod slightly larger than the inner diameter of the bearings that would need to slide onto it. The cut posts and filed rod can be seen in Figure 6.

Image 6: Cut Galvanized Posts and Filed Steel Rod

The steel posts were then drilled with two 5/32” holes per ball bearing installed. One hole was above and one was below the position the bearings were to be installed at for the set screws that would hold the bearings in place. The holes were tapped with a 10-24 tap that matched the screws.

The posts were then heated using a heat gun to expand them slightly. Once heated, the ball bearings were inserted into place and secured with the set screws.

The thrust bearing did not have as much surface area in contact with the post as anticipated so a 2.5 inch outer diameter washer was epoxied above and below the thrust bearing to provide better surface contact. The bearing and washers were left for 24 hours to cure.

The metal plate used to hold the hand crank in place was drilled for the mounting holes. Three holes were drilled to secure the hand crank and then four were drilled (two on the left side of the plate and two on the right) to attach the plate to the post brackets that wrap around the upper section. The metal plate after drilling is seen in Figure 7.

Figure 7: Metal Plate for Mounting Hand Crank

The hand crank had corresponding holes drilled through its handle for the three mounting holes. The rope that initially came with the hand crank was removed and replaced with the larger ⅜” diameter rope. It was determined that 18’ of rope was needed as the system needed three feet to reach the overhead arm from the hand crank, three feet to reach the end of the arm, five feet to reach the ground, five more feet to reach the pulley on the arm for the block and tackle system, and about two feet of additional rope to remain wrapped around the hand crank.

The team then assembled the central posts and inner rod to test the inner assembly's ability to rotate and its smoothness. The lower section was found to have too much play in the inner rod as the far end of the shaft could go from one wall of the pipe to the opposite side of the wall. Two 3-D printed cylinders with an inner diameter of 1.3”, an outer of 2.18”, and a height of 2” were printed using ABS filament. They were inserted into the lower section to secure the rod in place. These cylinders prevented the excess movement and the system moved smoothly.

The system was disassembled and a hole was drilled and tapped to allow a handle to be attached on the left side of the tower crane.

The assembly was sanded with 120 grit sandpaper to scuff the galvanized coating to allow for easy paint adhesion. An initial and secondary coat of primer was used to prep the surface. This was followed by a top coat of spray paint. Red was used for the lower section of the main stem, blue was used for the upper section, and yellow was used for the overhead arm. The painted posts are seen in Figure 8.

Figure 8: Painted Posts Waiting to Dry

After 24 hours, the paint was dry enough to handle, so the system was reassembled to test for any defects (Figure 9). No defects were found besides a couple minor paint scratches, so it was approved for assembly.

Image 9: IQP Team Testing Assembly Under Load

The lower half of the system including the inner rod was removed and everything was made ready for transportation to the YWCA CM.

4.7 Installation

Installation inadvertently became a two phase process. Initially, the plan was to arrive at the YWCA CM, confirm the location on the retaining wall for installation, drill four mounting holes using a hammer drill to accommodate the anchor sleeves, attach the anchors, attach the lower post, and then the rest of the assembly. This was attempted in the first of the two phase process.

The team drilled the first hole with success, but the second hole was significantly more shallow than the first hole. The drill could not advance further due to an unknown obstacle that was narrowed to either rebar or significantly dense aggregate in the concrete mixture. A similar pattern occurred in the other two holes that were drilled. The team attempted to adjust the position of the mounting holes three times to no avail. During this process, the masonry drill bit became overheated and slightly melted due to the friction and constant drilling. Figure 10 shows the holes that were drilled on the first day. Two of the six holes were a proper depth for the sleeve anchors to be installed.

The team stopped the installation and reconvened to identify mitigations for the obstacles.

Figure 10: A Series of Failed Holes in YWCA CM Retaining Wall

The second phase commenced after the purchase of a rebar locator, a new masonry drill bit, and shorter concrete sleeves. A rebar locator is an electromagnetic device that can detect the presence of rebar (or other magnetic materials) in concrete. The IQP team confirmed at that time the obstacle encountered in the first attempt was in fact rebar. The rebar was spaced at 24” intervals starting at the end of the wall. An area was located in between two sections of rebar that allowed for installation to continue. The team drilled ¼” pilot holes into the desired mounting positions followed by ½” holes for the shorter anchor sleeves. The holes were drilled to a depth of 2 ¾”. The bolts were inserted and then the sleeves were pounded into place using a mallet.

The post bracket was inserted over the bolts and then lock nuts were tightened to secure the brackets. The red lower section was attached to the bracket and secured approximately one inch off of the ground (see Figure 11) to prevent water from accumulating on the interior.

Figure 11: Red Post Elevated Off of the Ground During Installation

The inner rod was lowered in place through the 3-D printed cylinders and bearings that were already inside the post. This was followed by the sandwich bearing and then the upper assembly (see Figure 12).

Figure 12: Inner Rod Placed in Lower Post (Assisted by Enthusiastic YWCA CM Child)

The rope was fed back through the upper pulley and secured to a fixed point for the block and tackle system (see Figure 13). The entire system was given a test for functionality and then secured to prevent unnecessary movement while it was unused. Some paint that was scratched during installation was repaired at the end of installation.

Figure 13: YWCA CM Child Tests Toy Immediately After Installation

4.8 Final Observations

During the observation session after installation, a group of 15 students played in the playground where the toy was installed. The number of students actively interested in the toy varied from a low of seven to a maximum of 11 over the 40 minute observation session. The maximum of 11 consisted of six boys and five girls indicating that in this group of students, the toy does not appear to discourage any particular gender from engaging with or using the toy.

During the observation period, no student appeared to struggle with operating the system beyond a reasonable amount. The most difficult portions to control were the hand crank when the system was under load (i.e. the bucket was completely full of dirt) and the most complicated part, the hand crank release. The students organically discovered the release after about 10 minutes of play and did not have significant struggles with it afterwards.

While the kids did not struggle to rotate the crane, it appeared that the crane was in fact too easy to rotate as holding the arm in one position was hindered by the lack of friction or another resistant force on the rotation. This was particularly noticeable when one child attempted to crank the pulley up, putting torque on the system, and caused the arm to inadvertently move.

When the children were playing with the tower crane the wind made the system difficult to control due to the lack of resistance. Two children were heard saying “Stop! We don’t want this swinging,” and “It’s not me! It’s the wind” as they tried to stabalize the system. The major concern with the lack of resistance beyond the inability of the children to precisely control the system is the safety of an overhead object swinging quickly across a wide arc like a wrecking ball.

Although the system was designed to be tall enough to avoid hitting any children, the toy appears to be the perfect height to hit teachers in the head when it rotates from one side to the other. The concern for potential harm was significant enough that our advisor, Professor Rosewitz, stepped in after the observation and implemented a temporary restriction on the range that the crane arm can reach.

The arm was wrapped with two bungee cords that were attached on the adjacent fence to prevent the students from moving the tower crane too far or too quickly from one side or the other. Additionally, the originally metal pulley connected to the bucket was replaced with a plastic one as the significant risk of a metal object falling on a child’s head.

From a social perspective, the students were able to communicate to create a coordinated effort in moving the toy. Three students worked cooperatively to load, raise, and position to the crane in different areas of the dig pit through verbal communication. While being monitored by both the teachers and the IQP team members, the students took turns with the different mechanisms of the toy and helped each other with the toy.

5 Conclusion and Recommendations

5.1 Things That Were Done Well

After the observations, it was very clear that the children thoroughly enjoyed the new addition to their playground. It is something that should bring them and the future children of the YWCA joy for many years.

The simple machines integrated into the designs will provide the children the opportunity to ask questions and investigate the mechanisms of their environment in a manner that leads to inspiration and a yearning to learn more.

The interplay between children from a diverse set of demographics was a great encouragement to the success of the design to be engaging to all children regardless of background which suggests successful alignment with the YWCA missions.

5.2 Things That Were Done Poorly

Given an infinite amount of time to work on this project, the IQP Team would definitely have spent more time gathering more observations both prior to and after the installation of the toy in the YWCA playground. It has been several years since any member of the team played on a playground so more understanding of their habits would be a great asset to the team. Additionally, the data gathered for the findings may be sufficient for the case study approach, but is lacking to provide a more generalized conclusion to the success or failure of this venture.

From a time management perspective, the team should have started construction at least one full week earlier. A lot of time was used in B and C Term for minimal progress that could have been used for more effective research and development. With the aforementioned timeline, a more complex machine would allow the children a greater opportunity to learn and develop the intuitions that could aid them in future educational opportunities.

The team's oversight on the height of the teachers and the possible risk they take by being within the tower crane's reach is a failure in our roles as engineers. It was our duty to ensure the safety of all participants and not just the primary users. This was an error on our part that will need a mitigation for safe usage.

5.3 Recommendations for Future Improvements

Should any group or individual pursue a similar project or take it upon themselves to improve the system this team installed, we have a few recommendations for the future development.

- The height of the system should be increased to allow for clearance over the heads of the adults
- Rotation of the crane arm needs more friction or some resistance to allow the children more precision in placing the arm
- Both the handle on the left of the crane and on the hand crank should be longer and thicker to make it easier for the students to use.
- A clear coat of sealant or a protective layer of paint should be applied to prevent scratches during standard wear and tear.
- A cap should be created to place over the lower section when the system is disassembled during the winter months, so the entire post does not need to be disconnected from the wall.
- A series of lightweight digging toys could be made to swap out with the bucket such as a sieve, funnel, or controllable scoop.

5.4 Conclusion

It is evident that play provides a quintessential area for young people to investigate, discover, create, and reinforce thoughts on how the world around them operate. To provide the best environment and circumstances possible for a wide audience of students to explore complex topics while at play, it is imperative that children are provided with positively affirming (or at the bare minimum, not negatively affecting) examples that they can connect with so as to not deter the children from pursuing similar careers, ideas, or goals. The ability for children to develop positive experiences related to these fields has been shown to encourage children (especially those in traditionally underrepresented populations in STEAM) to pursue and take interest in these fields.

Organizations (such as YWCA CM) that promote early childhood STEAM education work to create and expose children to these positive experiences. They aim to encourage all interested children to pursue STEAM regardless of background or externally perceived identities. However, few items exist for children to utilize in an outdoor setting that are both engaging and educate on foundational STEAM principles (i.e. simple machines).

This project sought to produce an educational toy capable of demonstrating rudimentary physics and engineering principles in an engaging and accessible manner.

Based upon the information gathered from teacher interviews and student observation, it was established that creating an experience centered solely around technical skills would be ineffective in bettering the student as a whole. Instead, the designs need to work to help the student improve both their traditional “book smarts” and their interpersonal skills such as peer-to-peer communication and coordination of tasks amongst a small group. Additionally, the team needed to ensure the safety of the children as people of their age group have a propensity for breaking things and not using devices for their intended purposes.

After the development of eight designs that were narrowed down to three designs that the team felt confident met the defined criteria set by the observations, interviews, and overcame the shortcomings of currently available devices, the teachers selected two designs of similar merit. However, external constraints such as time and financial feasibility caused the team to select the less complex of the two designs for production and installation.

As the team finalized designs and communicated with the YWCA CM instructors, the importance of the CAD models became blatantly obvious. The 3-D models enabled easy communication of ideas both within the IQP team and between the team and the teachers. The model of the proposed designs and a scaled replica of the playground was critical in conveying our ideas in a meaningful way. It also assisted in the construction process as all of the measurements and proportions were based upon the work done in the CAD software.

Installation at the YWCA CM highlighted the importance of proper planning prior to execution of the plan as improvisation can only get you so far. We failed to anticipate the rebar as a possible obstacle and experienced setbacks due to the lack of foresight. The quick acquisition of proper tools allowed us to continue with only a minor delay, but still cost us valuable time that could have been used for data collection and reflection.

In the end, the project produced a fun and educational device that all of the children thoroughly enjoyed using during our observation. The children were able to analyze the different mechanisms at work in the device and quickly learned how to manipulate them to whatever end they could imagine.

While the teachers shared similar comments in regards to the effectiveness of the toy for the students, they also identified safety concerns we had failed to anticipate during design, construction, or implementation. The oversight led to our faculty advisor stepping in and applying temporary fixes for the concerns until a more permanent solution can be implemented.

This project blended together the development of interpersonal communication, foundational physics, play theory, and drilling into concrete into a singular toy made to be used by ages two years old and up. We were able to assist the YWCA organization in the betterment of their students and hopefully the betterment of the YWCA CM facilities through the creation of this system. The students have gained a new outlet of exploration. The IQP team has obtained a much more thorough understanding of the engineering design and development process.

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Appendix A: Sponsor Description

The YWCA is dedicated to eliminating racism, empowering women, and promoting peace, justice, freedom, and dignity for all. (YWCA USA, 2021). The history of YWCA can be traced back to 1855 when the philanthropist Mary Jane Kinnaird established the North London House for nurses who traveled to and from the battlefield. In 1877, 22 years later, it merged with the organization Prayer Union, a bible study group created by Emma Robarts. Finally, in 1894, the World YWCA was established (YMCA USA, 2021).

In the late 19th century, as part of the continued industrialization of the United States, young women started to come to Worcester searching for jobs and education. The YWCA was founded for the needs of these women and provided services from educational and job-training resources to safe, affordable housing and health-promoting programs. These services and programs empower young women to become self-reliant and financially independent when many of them are not (YWCA CM, 2018).

Today, over 20,000 local YWCA centers are located in more than 120 countries, such as the United States, Canada, and the United Kingdom (YWCA USA, 2021). Our local YWCA, YWCA Central Massachusetts, was founded in 1885 and is the longest-serving agency in Central Massachusetts. YWCA Central Massachusetts serves more than 13,000 individuals annually from 64 cities and towns (YWCA CM, 2018). The primary operating site of YWCA Central Massachusetts at One Salem Square currently consists of a five-story building that houses: early education and care center, domestic violence services and youth development programs, young parents program classrooms, and administrative offices with meeting spaces, all of which are dedicated to their mission of helping early education and caring, promoting racial and social justice, and improving women's health and wellness (YWCA CM, 2018).

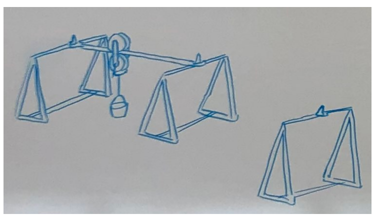
YWCA provides four different programs for children from one month to five years old. These programs include the Infant Program for children from one month to 15 months, the Toddler Program for children from 15 months to 36 months, the Preschool Program for children from 2.9 to 5 years old, and the Pre-Kindergarten Program for children from 4 to 5 years old. The goal of these projects is to cultivate children's language skills such as reading and writing, athletic skills such as swimming, social skills such as cooking, learning skills such as STEM activities, and creative skills. YWCA hopes to stimulate each child's curiosity and encourage them to learn through these programs (YWCA CM, 2018).

Appendix B: Initial Designs

1. Shovel on Wheels:

This idea is inspired by the handle truck. With a shovel installed and foot pedal at back. It's like a shovel with a wheel, or a handle truck with a shovel bucket. So, kids can hold the handle and use a fool padal as a force supply to shovel dirt. And lift to transform. This design uses three simple machines: wheels and axles

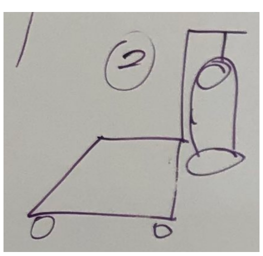
2. Bucket Pulley on A-Frame:



Two or more stands across the dig pit. This stand could hold either rod or rope which hold the pulleys. Pulley can help students move heavy objects like sand and dirt. The reason why using several stands is because we could make a smart rail for pulleys to transform in farther distances without taking off it.

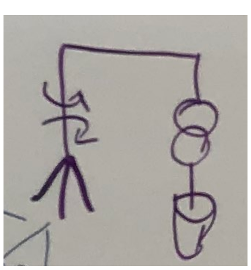
- Add pulley across length to allow for moving from either side

3. Moving platform with pulley bucket:



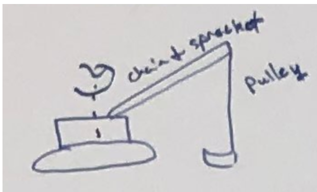
A movable platform is used to help children easily move heavy objects such as dirt and sand. This simple machine includes Wheel and axle, pulley, inclined plane and wedge.

4. Rotating pole with digging tools:



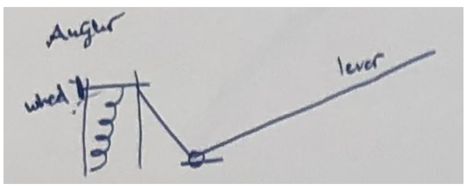
A fixed pillar buried in the ground. The column has arms that can move horizontally 360 degrees. Pulleys are attached to the arms to help children move heavy objects such as sand or dirt within a limited range. This one includes gears and pulleys?

5. Model Crane:



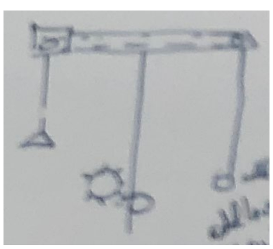
A small stationary excavator. Pulley can help students move heavy objects like sand and dirt. Wheel and axle helps students move the excavator around its Z axis. In addition to moving heavy objects it can also dig dirt.

6. Auger:



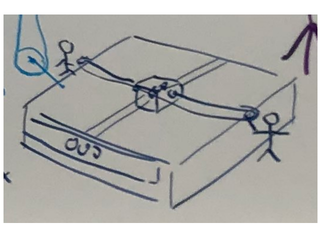
A tool capable of digging holes in dirt. Move the soil through the screws. When the kids turn the tool, the dirt moves along the screw. Additionally, a lever could be used to raise or lower the auger into the ground

7. Rotating Post with extended pulley system (High rise crane):



This one inspired by the high rise crane, which has a center rod and an extended lever on top to extend the pulley system. The bottom part could be either a bucket or hook. The extension lever could be rotated using the bottom part, and the back grip is connected with the front hook by a rod and wheel system.

8. 3-D printer with hanging digging mechanism:



This design is trying to help students move dirt around in the dig pit. Like a container crane, all its frameworks are above students. The crane is designed with belts and screws to move the actual hook (digger). The digger will be a pulley set.

- **Block and tackles to move along axes**

- **Mount controls at the post**
- **Ratchet and pinion to lock**
- **Switchable center tool**

Appendix C: Physical Design Characteristics

- Safety
  - Number of pinch points
  - Overhead objects
  - Areas that children could climb on or crawl over
- Number of Students Required to Operate
  - A heavy emphasis on teamwork for the design to work due to results of teacher interview
- Number of Unique Simple Machines
  - Allowing students the ability to manipulate and play with varying types of simple machines would enable them to develop a better understanding of their usages and their ability to identify similar systems in their everyday life
- Number of Simple Machines
- Fun
  - This design is created for a playground, it must be fun for students to play with
- Resistant to Student Damage
  - Number of supports
  - Placement of supports
  - Distribution of load
- Obstructs dig pit use
  - Dig pit still needs to be able to perform its current function so avoiding complete obstruction is essential
- Repairability
  - Possible maintenance should be kept to a minimal
  - Unique or hard to acquire parts should be avoided
- Installation ease
  - The system will have to be setup quickly and by novice workers (aka the IQP design team)

Appendix D: Student Observation Considerations

- Interacted with the toys
    - Which toys did they interact with the most?
        - Take Photos of those
    - How long do students interact with one toy or an area of the playground
    - How many students use a piece of equipment at a time
    - Do some students not use any toys? Why?
        - Take photos of unused toys.

  note: they may not playing those at that day, but take photos
    - Anywhere be empty or crowded?
- Interacted with their classmates (*solo vs group)
    - Talking or non-verbal communication?
    - Do they share toys with each other?
        - Fight for toys？
        - How do they fight?
    - How many students work together (per group)
        - The ratio of boys to girls in a group?
    - Are there conflicts?
        - How are they handled?
        - Results (solved by themselves or teacher involved)
    - Any student being alone
        - What are they doing alone (solo play)
- Interacted with the teachers
    - Did they go to the teachers only for help?
    - Do teachers interact with students during play
        - How?
- Characteristics of the toys (take photos)
    - Type
    - Size
    - Colors
    - Materials

- The Dig Pit Specifically
    - How many kids on average are playing around the dig pit?
    - How are kids playing in the dig pit?
    - Does the dig pit dirty their clothes while playing?
- Accessibility Concerns
    - Student ableness
    - Is there a space students avoid?
        - Why?
        - Different than the well-used spaces
    - Introverted vs Extroverted
    - Fine motor skills?

- Questions for the students
    - What is you favorite toy in the playground
    - How do you play with it
    - Who do you like to play with
    - What is your favorite color
    - Show me how you play in the dig pit

Appendix E: Teacher Interview Questions

A. Teacher Information
    a. Name
    b. Pronouns
    c. Permission to quote the teacher in the report: Y / N
    d. What age range do you teach?

B. Lesson Plans
    a. What is the best method for introducing new material to very young students?
    b. What are the primary components of your lesson plans?
    c. Does Massachusetts have specific requirements regarding lesson plans?
    d. How do you begin creating lesson plans for science topics?
    e. Do you have any resources you use to generate ideas for lessons or applications?
    f. Would you describe the typical class that you teach as diverse?
    g. When creating lessons, how do you ensure the ease of accessibility of the material to a diverse group?
    h. How do you design activities for students that you do not interact with directly such as when a substitute teacher engages with them?
    i. How do you develop activities for students to do on their own?
        i. During freeplay, activities are setup for students but they are not discouraged from playing and exploring on their own

C. Teaching STEM
    a. What curriculum do you follow?
        i. What age ranges do you think this curriculum is most applicable to?
        ii. Do you feel like there is a better curriculum to follow?
    b. What states are doing the best in STEM education?
        i. What are they doing that makes them the best?
    c. Do you use any educational toys or physical aids as demonstrations?

i. What are they?
ii. How do you use them?
iii. What benefit do your students receive by using these demonstrations?

D. Evaluating Understanding:
   a. How do you check for understanding in your students?
   b. What do you recommend we integrate into our plans to ensure understanding?

E. Accessibility
   a. What accessibility considerations should we be aware of when designing playground equipment?
   b. What are the qualifications for the least restrictive environment?
      i. What are common modifications to a physical area to enable the least restrictive environment?
   c. Can you describe the level of fine motor control for the students you teach?

F. Students at play
   a. How often do you use play as a method of teaching?
   b. When students play, what do you look for to see if they are gaining anything from the experience?

G. The Toy
   a. What kinds of toys do the kids like to play with?
   b. Are there any prohibited toys that we should know about?
   c. How do children usually play in the playground and the dig pit?
   d. What type of STEAM (science, technology, engineering, art, math) lesson would you like the toy to help teach the kids?

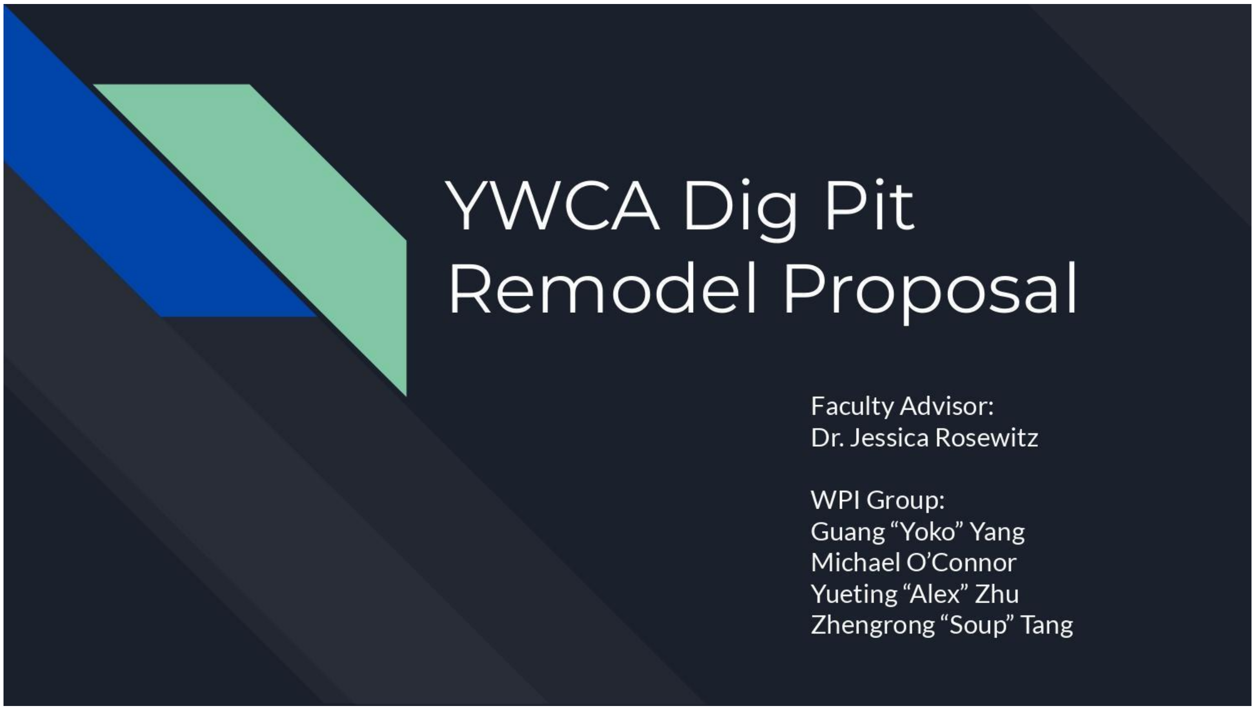
H. Concerns and Comments

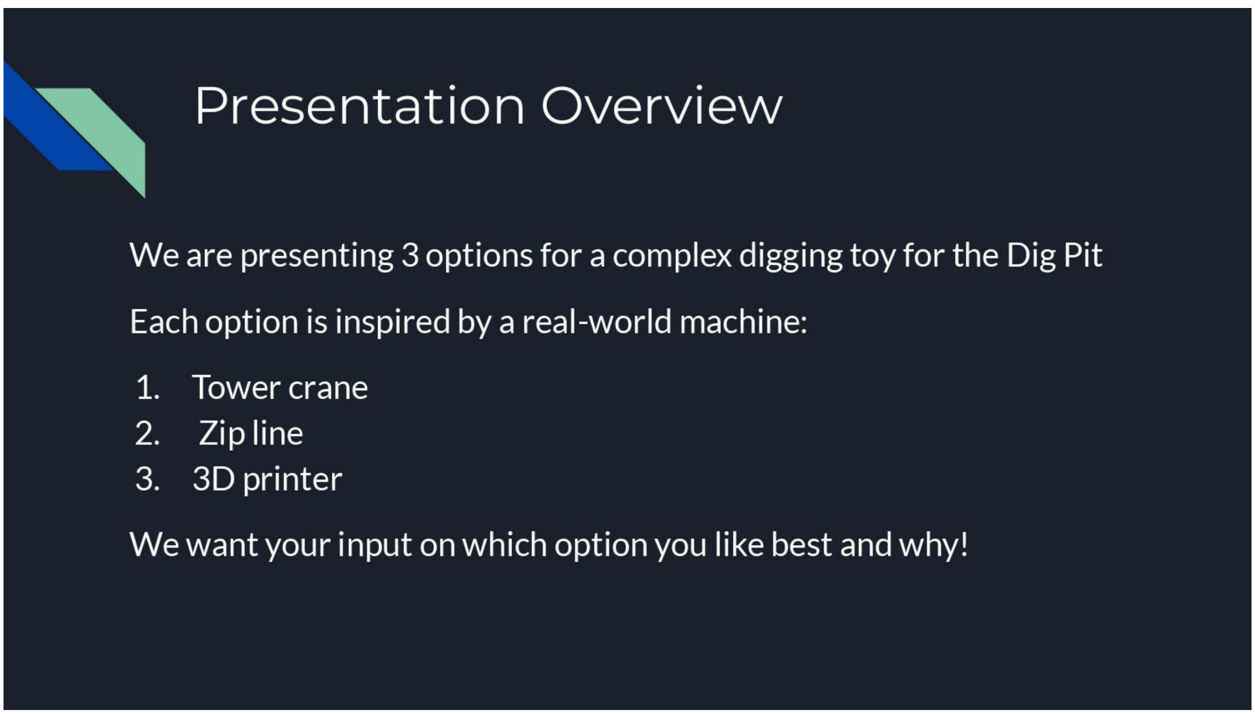
a. Given that students will be using and playing with the final creation of this project, what are the major concerns we need to be aware of?
b. What are some characteristics that you would be interested in seeing in the final design?

I. Closing

a. Is there anything else we should have asked you?
b. Do you have any further comments, questions, or concerns?

Appendix F: Presentation of Proposed Designs





Option #1: Tower Crane Digging Toy

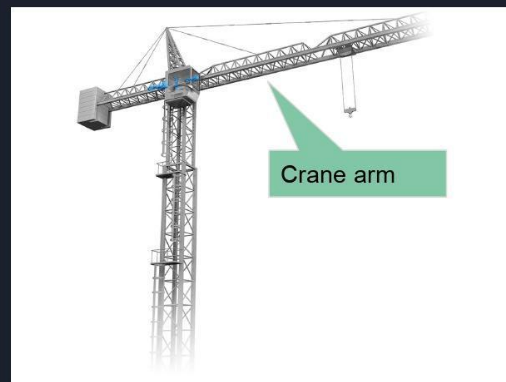
Design inspiration:

Tower crane

Purpose:

Use pulleys and levers to move heavy objects

Rotate the crane arm to reach a wide area



A tower crane

Simple Machines used in Option #1: Tower Crane Digging Toy

1. Pulley:

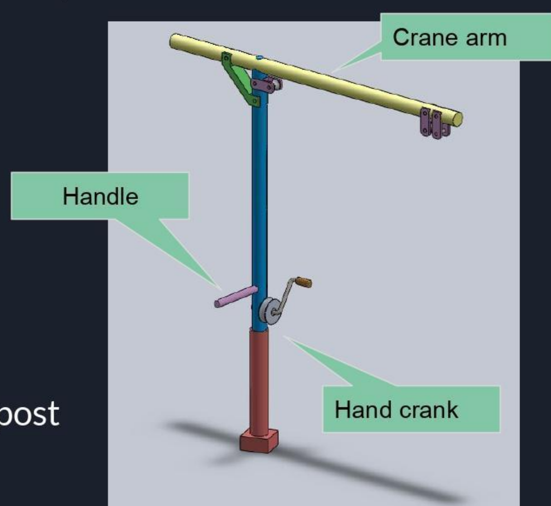
   Lift and lower bucket of dirt

2. Wheel and Axle:

   Hand Crank to raise and lower bucket

   Handle to rotate crane around post

Digging tool (bucket) not shown



Our tower crane digging toy

Simple Machines used in Option #1: Tower Crane Digging Toy

1. Pulley:

   Lift and lower bucket of dirt

2. Wheel and Axle:

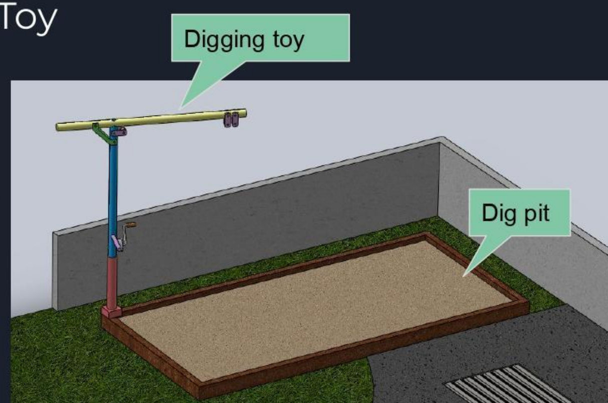
   Hand Crank to raise and lower bucket and turn the crane arm

Digging tool (bucket) not shown

Our tower crane digging toy

How Children Interact with Option #1: Tower Crane Digging Toy

- One child rotates the crane arm
- One child raises and lowers the bucket using a hand crank, rope, and pulley
- One child loads bucket (not shown)



Our tower crane digging toy at the dig pit

Advantages & Disadvantages of Option #1: Tower Crane Digging Toy

Advantages:

- Small footprint
- Simple structure
- Guesstimate lowest cost
- Easy to operate
- Can be installed anywhere

Disadvantages:

- Limited digging area based on arm length of crane

Option #2: Overhead Zip Line or Track Rail Digging Toy

Design inspiration:

Zip Line or Track Rail on an A-Frame

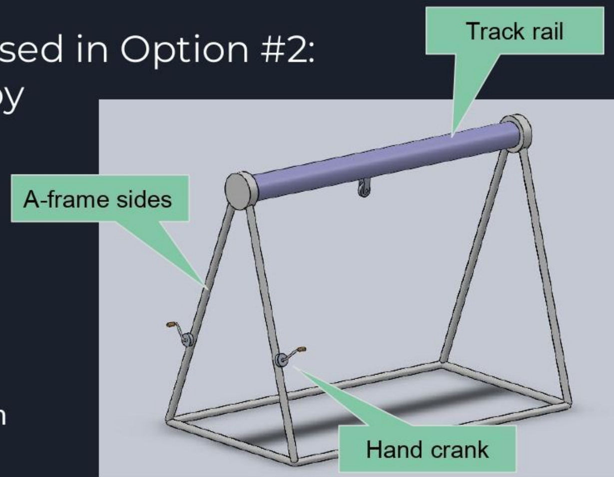
Purpose:

Use slot pulleys on top to move move heavy objects along the rail

A track rail hoist

Simple machines used in Option #2: Zip Line Digging Toy

1. Track Rail:
   Support weight
   Provide rail for transporting
2. Pulleys:
   Move digging tool up and down
3. Wheel and Axle
   Hand crank to move pulley along track rail



Our zip line digging toy

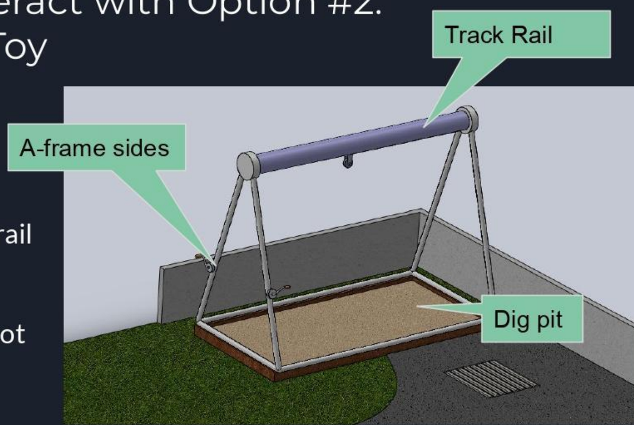
Simple machines used in Option #2: Zip Line Digging Toy

1. Track Rail:
   Support weight
   Provide rail for transporting
2. Pulleys:
   Move digging tool up and down
3. Wheel and Axle
   Hand crank to move pulley along track rail

Our zip line digging toy

How Students Interact with Option #2: Zip Line Digging Toy

- One child to move tool along track rail
- One child to raise and lower tool
- One child to operate digging tool (not shown)



Our zip line digging toy on top of the dig pit

Advantages and Disadvantages of Option #2: Zip Line Digging Toy

Advantages:

- Simple structure
- Guesstimated middle cost
- Easy to operate

Disadvantages:

- A-frame posts may block access
- Tool has limited access to dig pit only over center

Option #3: 3D-Printer Inspired Digging Toy

Design inspiration:

Easy to use at-home 3-D printers

Purpose:

Move objects in 3D (X, Y, Z axes) using motors and rails

At home 3D printer

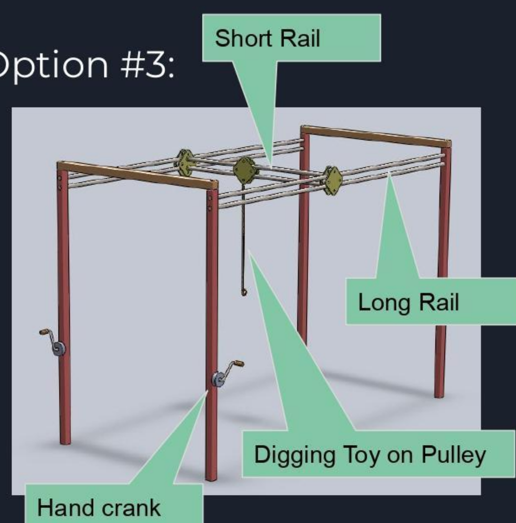
Simple Machines used in Option #3: 3D Printer Digging Toy

1. Pulley:

   Lift and lower digging tool

2. Wheel and Axle:

   A hand crank will be used to move the pulleys for the long rail and short rail



Our 3D printer digging toy

Simple Machines used in Option #3: 3D Printer Digging Toy

1. Pulley:

   Lift and lower digging tool

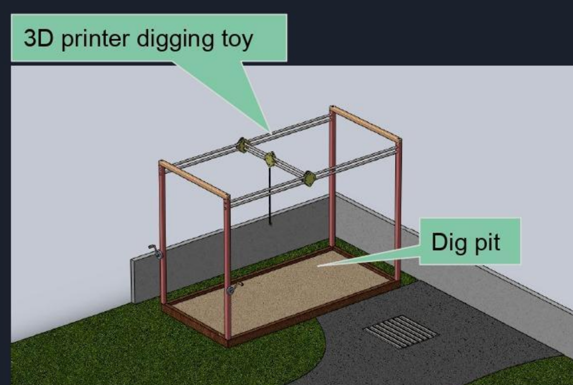
2. Wheel and Axle:

   A hand crank will be used to move the pulleys for the long rail and short rail

Our 3D printer digging toy

How children will interact with Option #3: 3D Printer Digging Toy

- **Children's roles**
  - Moving the digging tool along the long direction using a hand crank
  - Moving the digging tool along the short direction using a hand crank
  - Raising and lowering the digging tool
  - Operating the digging tool

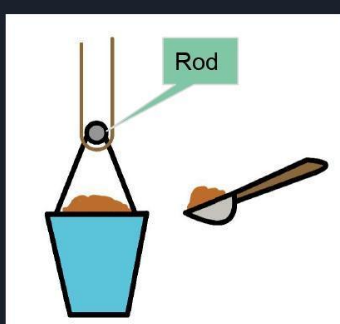


Our 3D printer digging toy at the dig pit

Advantages & Disadvantages of Option #3: 3D Printer Digging Toy

- Advantages
  - Learn teamwork
  - Most children to operate at once
  - Covers a wide area
- Disadvantages
  - Complicated installation
  - Guesstimated highest cost
  - Complex usage

Simple Machines Used for the Digging Tools

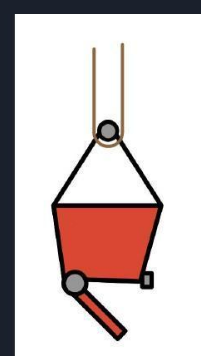


Bucket and Shovel

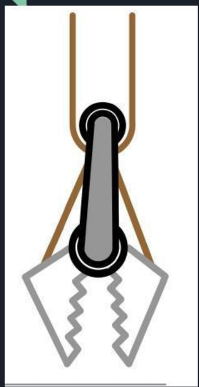
- Optional sieve
- Rotates around rod

Flap Bucket

- Bottom opens on lever



Simple Machines Used for the Digging Tools

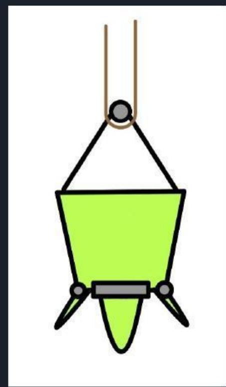


Claw Excavator

- Grabs soil
- Holds until release

Harverster

- 3-4 Angled Shovels
- Step on to Push into Soil



Applicable Standards and Themes for All Designs

- Pre-K students focus on enjoy playing in the dig pit, using the simple machines, making observations of the world around them, and learning STEAM knowledges.
- Every design requires :
  - Student Collaboration
  - Sequential Planning
  - Manipulating Simple Machines to Create a Specific Action
- Applicable Standards
  - PreK-PS2-1(MA)
    - Identify how something moves
  - PreK-PS2-2(MA)
    - Aware of factors that influence structural stability

How to address costs:

- WPI students will:
  - Create a full list of materials based on your preferred option
  - Approach local hardware (Ace Hardware) and big box stores (Lowe's and Home Depot) for donations
  - Obtain donated materials from WPI laboratories

We want your input!

- Which option do you like best?
- Why?
- Safety Concerns?
- Will the children NOT be able to use one of the designs?
- Do you have a preference for materials?
  - Metal
  - Painted wood
  - Plastic Pipe
- Does the design need to be collapsible or weather resistant?
- Paint color preference?

Thank You!

Appendix G: Final Parts List and Price

Purchase Receipt	Description	Link to webpage for item to purchase	Number of units	Unit (Linear feet or Each)	Price per Unit ($)	Shiping	Total price
Home Depot Online	3/8 in. x 3 in. External Hex Hex-Head Cap Screw (6-Pack)	home depot	3	6-pack	14.03	0	42.09
Home Depot Online	2.375 in. x 2.375 in. Aluminum Silver Post Cap	home depot	1	each	2.38	0	2.38
Home Depot Online	3/8 in.-16 Zinc Plated Nylon Lock Nut (10-Pack)	home depot	2	10-pack	2.73	0	5.46
Home Depot Online	1/2 in. x 3 in. Zinc-Plated Steel Hex-Head Sleeve Anchors (10-Pack)	home depot	1	10-pack	14.45	0	14.45
Home Depot Online	3/8 in. Zinc-Plated Flat Washer (25-Pack)	home depot	1	25-pack	4.31	0	4.31
Home Depot Online	Steel 2 Wood Fence Bracket WAP-OZ	home depot	2	each	4.24	0	8.48
Lowe's	2-in Fixed Single Pulley in Nickel	lowes	1	each	5.78	0	5.78
Lowe's	1-in Swivel Single Pulley in Nickel	lowes	3	each	3.88	0	11.64
Lowe's	2-in Wall/Cleaning Mount Pulley in Zinc Plated	lowes	2	each	6.58	0	13.16

Lowe's	1/2-in x 3-15/16-in Interlocking Spring Snaps in Zinc Plated	lowes	1	each	4.38	0	4.38
Lowe's	2-3/8-in x 2-3/8-in W x 6-ft H 16-Gauge Silver Galvanized Steel Chain Link Fence Terminal Post	lowes	2	each	28.48	0	56.96
Lowe's	Blue Hawk 0.3125-in Braided Nylon Rope (By-the-Foot)	lowes	4	per feet	0.75	0	3
Amazon Online	Pail and Shovel	amazon	1	each	10.22	0	10.22
Grainger Online	Structural Pipe Fitting: Elbow, 2 in For Pipe Size, For 2 3/8 in Actual Pipe Outer Dia, Aluminum	grainger	1	each	34.09	10.98	34.09
Home Depot	2 in. Galvanized 2-Hole Pipe Hanger Strap	home depot	2	each	0.74	0	1.48
Home Depot	5 in. x 8 in. 16-Gauge Stud Guard Safety Plate	home depot	1	each	1.98	0	1.98
Home Depot	15 oz. Flat Gray Primer Spray	home depot	2	each	7.98	0	15.96
Home Depot	12 oz. Protective Enamel Gloss Cherry Spray Paint	home depot	1	each	5.48	0	5.48
Home Depot	12 oz. Protective Enamel Gloss Sunburst Yellow Spray Paint	home depot	1	each	5.48	0	5.48
Home Depot	12 oz. Protective Enamel Gloss Sail Blue Spray Paint	home depot	1	each	5.48	0	5.48

Amazon Online	Scuba Diving Reel with Thumb Stopper	amazon	1	each	16.99	0	16.99
Fastmetals Online	1 1/4" x 4' Internal Rod	fast metal	1	each	33.71	0	33.71
McMaster-Carr Online	Ball Bearing, Shielded, Trade No. R20-2Z, for 1-1/4" Shaft Diameter	McMaster Carr	3	each	14.43	25.02	43.29
McMaster-Carr Online	One-Piece Steel Thrust Ball Bearing for 1-1/4" Shaft Diameter, 2-11/32" OD, Shielded	McMaster Carr	1	each	28.06	0	28.06
					TOTAL shipping		36
					TOTAL without Shipping		374.31
					TOTAL overall		410.31