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Creating a Resilient Watering System to Benefit Kids with Exceptional Needs at Farm and Nature-Based School

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Figure 1: Garden at Turn Back Time
Image Source: Cassandra Salafia

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Creating a Resilient Watering System to Benefit Kids with Exceptional Needs at Farm and Nature-Based School

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Sponsoring Agency:
Turn Back Time

Project Advisor:
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Abstract

Research shows exposure to nature is critical for child development. Turn Back Time, Inc., (TBT) provides farm and nature-based programs for children, including those with exceptional needs, to learn and develop through play in nature. The farm's gardens provide the context, materials, tools, and opportunities needed to run TBT's programs. A drought in 2016 dried up the farm's water source, killing the gardens. The purpose of this project was to engineer a resilient watering system to reduce the gardens' vulnerability to drought while ensuring TBT's programs, and their associated benefits, can continue.

Acknowledgements

We would like to thank our sponsors, Turn Back Time (TBT) and its founder Lisa Burris, for providing us with this opportunity and for informing us about the importance of nature-based education. Burris and TBT's team embraced our efforts throughout this project and offered much appreciated collaboration when executing the final deliverables.

Additionally, our team would like to thank Dr. Elisabeth Stoddard for advising this project and making this project available to us. We valued Stoddard's support throughout this project, and her guidance allowed us to present TBT with a rainwater catchment and irrigation system along with two educational modules.

We would also like to thank Dr. Robert Traver for assisting us during the initial planning stages of our project and for being one of our educational experts. Additionally, thank you to Mia Dubosarsky and Ali Johnson for being our two of our educational experts.

Our team would like to thank Peter Mimeault, Katie Piccionne, and Prof. David Sample for educating us through their rainwater catchment system expertise. We would also like to thank Prof. Sharon Johnson for reviewing our rainwater catchment system criteria.

Furthermore, we are extremely thankful to WPI's Engineers Without Borders team, WPI students, Peter Mimeault, and Jim Burris (Lisa Burris's husband) for their help in executing the final build of the rainwater catchment and irrigation system. Without them committing their time and energy, we would not have been able to provide TBT with a functioning system for the summer of 2018.

Executive Summary

Introduction

According to a study conducted by the Kaiser Family Foundation, 8-10 year old children in America average 7 hours and 51 minutes of total media exposure per day, while the recommended exposure is 1-2 hours (Rideout, Foehr, Roberts, 2010; Middlebrook, 2016). Increase in screen use and decrease in outdoor nature play has been shown to have detrimental impacts on childhood health and development. This includes double the number of children with diagnosed depression in the last five years, as well as rising rates of Attention-Deficit Hyperactivity Disorder (ADHD) and childhood obesity - with a sharp increase in rates of obesity for children aged 2-5 years old over the last three years (Cheung et al, 2016).

Exposure to and engagement with nature is critical for child development (Faber, Kuo, and Sullivan, 2001; Kahn and Keller, 2002; Strife and Downey, 2009). Citing research that spans over the last two decades, Strife and Downey explain that "access to nature and green space provides children with a myriad cognitive, emotional, and physical benefits, such as increased ability to concentrate, improved academic performance, reduced stress and aggression levels, and reduced risk of obesity" (p. 2). Nature play has heightened benefits for children with exceptional needs, including those with social, behavioral, and emotional issues such as Autism, ADHD, and emotional trauma. Nature-based education provides children with a setting that reduces sensory overload. When in nature, the frontal cortex slows down. This allows the brain to become relaxed, reducing symptoms of stress and anxiety that can be intense for children with exceptional needs (Williams, 2015).

Project Sponsor, Goal, and Objectives

In this project, we worked with our sponsor Lisa Burris and her farm, Turn Back Time (TBT). TBT operates on 58 acres of woods and farmland in Paxton, MA. They offer farm- and nature-based programs, serving over 500 children, and exposing them to almost 9,000 hours in nature. Thirty percent of the children TBT serves come from at risk populations with exceptional needs. During the summer of 2016, New England experienced a severe drought (Quintana, 2016). TBT relies on pumping water from its beaver pond to irrigate its crops. This beaver pond ran dry from pumping out what was left during the drought. Without water, the garden dried up, and the crops died. The gardens provide the context, materials, tools, and opportunities needed to run TBT's programs. Without the gardens, the farm cannot offer the opportunities that have been proven to provide so many benefits (Burris, personal communication, September 6, 2017).

The drought and its impacts on TBT's programs convinced Burris that she needed more climate resilient farming and watering practices. Resilient farming refers to a farming approach where extreme weather, such as droughts, is expected, and where mitigation strategies are built into the farm's structure and daily practices, instead of responding to disasters as they occur (Altieri et al, 2015). Burris wanted to increase the resiliency of her farm's watering capability by adding additional stored water sources and an efficient irrigation system that can connect to multiple water sources. This concern was the impetus for our project, with the goal of developing an efficient irrigation system that can attach to multiple water sources, including a new 1,500-gallon rainwater catchment, storage, and delivery system. Our goal also included providing science, technology, engineering, and mathematics (STEM) educational opportunities for the students to learn about rainwater catchment and water flow and movement.

We worked to achieve our goal through four objectives: 1) research STEM modules around rainwater catchment systems, focusing on those designed for preschool aged children, including children with exceptional social, emotional, and behavioral needs; 2) design and pilot two education modules and learning stations around rainwater catchment, storage, and delivery for 3-8 year old children; 3) evaluate TBT's site for characteristics that were most suitable and ideal for rainwater catchment, storage, and delivery, and to evaluate the water needs at TBT; 4) design and build the final system with the help of WPI's Engineers with Borders. In this executive summary, we will review the applicable literature, methodology, and results.

Review of the Literature

In this report, we review two areas of literature: 1) the benefits of learning through farm- and nature-based play for kids, including those with exceptional needs; and 2) methods of rainwater catchment, storage, and delivery as part of a resilient watering systems. Farm- and nature-based education is defined as learning through farm and nature-based play (Cadwallader-Staub, Redmond, Dixon, & Simon-Nobes, n.d.). Nature-based play facilitates the learning of math, science, counting, problem solving, teamwork, and other skills through child engagement with outdoor materials and activities, such as picking and counting vegetables, climbing and descending trees, making discoveries about their environment, working together to unearth a large rock, or managing conflict over water while making mud pies (Mills, 2009; Green Hearts Institute for Nature in Childhood, 2014; Burris, personal communication, October, 2017). Farm-based education has numerous benefits for children of all ages and abilities. These include reducing behavioral problems, improving social interactions, developing critical life skills, and building immunities to allergies (Strife and Downey, 2009). Our literature review explores each of these benefits in detail.

Rainwater catchment consists of either surface runoff or rooftop runoff. Surface runoff involves rainwater flowing over landscapes into bodies of water. Rooftop runoff involves a structure and storage unit to catch the rainwater that flows over the roof. We focused on rooftop runoff collection to create the most efficient resilient watering system. Rainwater collected from rooftop structures is stored in either a multi-barrel system or a single cistern. After storage, the collected rainwater can be delivered to the desired area with various types of irrigation systems (Padmanabhan, 2013). These systems include drip tape, soaker hosing, or a sprinkler system. Our literature review details each component for a resilient water system and offers the best option for the catchment, storage, and delivery of the water.

Methodological Approach

To meet our first objective of researching STEM modules around rainwater catchment, we conducted semi-structured interviews with educational professionals, experts in developing STEM modules for children, our sponsor, and rainwater catchment extension agents. We also engaged in secondary research by reviewing STEM modules on rainwater catchment systems and age appropriate water-related STEM concepts for children. We analyzed rainwater catchment construction videos and reports on rainwater catchment systems built in Ecuador by WPI's Engineers Without Borders (EWB).

To meet our second objective of designing and building STEM educational modules and learning stations related to rainwater catchment, storage, and delivery, we reviewed our research on rainwater catchment and STEM modules. We conducted semi-structured interviews with STEM education experts. These interviews evaluated the effectiveness of our module and station designs and offered possible assessment methods. With this feedback we further developed our modules designs, and then building the associated learning stations with materials donated to our project by local hardware stores.

To meet our third objective of evaluating TBT's characteristics for rainwater catchment and its water needs, we conducted semi-structured interviews with our sponsor, an agricultural extension agent with expertise in rainwater catchment for agricultural use, and a lean improvement methods expert. We created a design matrix using criteria developed through interviews with an industrial engineering expert and the rainwater catchment system extension agent. We used secondary sources to supplement of our design matrices, and then had the final matrix evaluated by the extension agent and our sponsor. Our team also conducted a site evaluation of TBT to determine the farm's ideal rainwater catchment characteristics.

To meet our fourth objective of designing and building a rainwater catchment system at TBT to meet its needs, we conducted semi-structured interviews with our sponsor and the rainwater catchment system extension agent. The information from the interviews and previous research was used to design the system. We presented the design with our sponsor and WPI's Engineers Without Borders (EWB) for feedback, as EWB members have made dozens of large scale rainwater catchment systems. This feedback allowed us to finalize and build the 1,500-gallon system with the help of EWB and others over May and June 2018.

Results

The results of our first objective of researching and building two STEM modules around rainwater catchment, resulted in the building of a water wall and a miniature rainwater catchment system, which we named Catchment Carl, along with associated learning modules with instructor notes. The water wall station consists of bottles and tubes that can be rotated along a wall, forming different paths for water to flow. The final product can be seen in Figure 2 below. Some of the STEM concepts and developmental skills the children gain through this activity include flow rate, problem-solving, group collaboration, and trial and error (Edwards, 2014). Group work helps facilitate friendships, compromise, and empathy, all while learning science related concepts (Williams, 2015). This station also allows the children to experiment with different starting points, and the actual act of scooping up the water and pouring it over the structure improves gross and fine motor skills (Alter-Rasche, 2014; Dubosarsky, personal communication, December 6, 2017).

Figure 2: **The Water Wall**
Image Source: Virginia Adams

Catchment Carl is an interactive, educational module that will help students understand rainwater catchment. The constructed roof for Catchment Carl can be seen in Figure 3 below. The system was designed to be similar to the large rainwater catchment system in order to help students understand how the system works. The building of the large system and the presence of a new feature on the farm will spark curiosity about the system among the students, and curiosity prepares the brain to learn and remember (Stenger, 2014; Burris, personal communication, Feb 10, 2018). We want to harness this curiosity for learning in a way that is safe and will not disrupt the function of the actual catchment system.

Figure 3: **Catchment Carl**
Image Source: Cassandra Salafia

To results of our second objective of researching different types of rainwater catchment, storage, and delivery systems, culminated in a design matrix using criteria developed through interviews with WPI Professor Sharon Johnson and Virginia Tech Professor David Sample. Professor Johnson recommended ranking the criteria to conduct an analytic heuristic process (AHP). AHP helps select the option that prioritizes the most important criteria. Professor Sample, an extension agent, offered comparisons between multi-barrel systems and single cistern systems. His input resulted in us selecting a single cistern system due to cost. The number of barrels and pumps required for the multi-barrel system was severely more expensive than the single cistern option. We reviewed irrigation options with Professor Sample, and he recommended using soaker hoses. However, our other secondary research through studies made us conclude that drip tape was a more water efficient method than the soaker hoses.

The outcome of our third objective of evaluating TBT's characteristics for rainwater catchment and its water needs, we interviewed Burris and conducted calculations. Burris expressed that TBT's garden, resulted in analyzing additional criteria for our design matrix, include climate resilience, efficiency, cost, efficiency, quality, durability, and safety. We also obtained dimensions for the garden and the barn. The barn dimensions helped us calculate how barn's potential rooftop runoff quantity, correlating to the recommended tank size. The garden dimensions assisted in calculating the amount of drip tape needed to water the garden. We observed the ground's slope and the soil material, deciding on a sand base for the system and a pump to get the water from the catchment barrel to the garden.

The outcome of our fourth objective of designing and building a rainwater catchment system at TBT that meets its needs, was the finalized system design, the purchase of materials, and the building of the system. We partnered with WPI's EWB team and Peter Mimeault, a local mechanical engineer, to construct the rainwater catchment and irrigation system over a series of three days. Funding for the materials (~$3,000) was obtained through fundraising events and grants awarded to Burris and our project advisor, Professor Stoddard. The completed system can be seen in Figure 4 below, with piping attached to the gutter system on two sides of the barn and to the 1,500-gallon collection and storage tank. Not visible in this image is the pump in the tank that connects to piping underground, which carries water across the dirt road to holding tanks that supply water via gravity to the irrigation drip tape in the gardens on the left.

Figure 4: **Completed Rainwater Catchment System**
Image Source: Virginia Adams

Conclusion and Next Steps

The purpose of the project was to design and build a more drought resilient watering system, including a new water source (1500-gallon rainwater collection and storage tank) and a more efficient irrigation system. The goal was also to create opportunities for STEM learning around the new watering system. Through the collaboration and mentorship of our sponsor and advisor, as well as expert input, help, and support from people with knowledge and experience in rainwater catchment, agriculture, and early STEM education, our team designed and built a currently functioning watering system and two educational modules. The members of the team learned a tremendous amount in the process, and the watering system has reduced the time our sponsor spends watering from two hours each day to five minutes each day. Further assessment of the system will be needed as winter approaches to see if the system is able to empty completely, including from the underground piping, to avoid damage. Further assessment of the educational modules is also needed. Through this project, we have worked to improve the farming infrastructure and to provide additional opportunities for children to engage with STEM to develop and learn in new ways. Through this process, we have been incredibly fortunate to develop and learn in new ways as well. Outside of TBT, our hope is that the project might be valuable to others who want to design and build a more resilient watering system for their farm or gardens.

Authorship

Each team member contributed to writing and revising each section of this paper. We all reviewed the paper and contributed equally to its varying sections.

Figure 5: **Our Project Team**
Image Source: Emilia Perez

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1.0 Introduction

Turn Back Time (TBT), a farm located in Paxton, MA, needs a climate resilient and low-labor watering and irrigation system. Lisa Burris, our sponsor, is both the founder and creator of TBT. TBT is located on 58 acres of woodlands and has a large garden area and farm animals, which are the two major components of their farm-based educational programs. These programs are catered toward integrated classrooms, allowing children with and without exceptional[1] needs to participate. Farm-based education is very important for children, as it uses their natural curiosity to help them learn STEM (science, technology, engineering, and math) concepts and life skills (Mills, 2009). In order to maintain these programs, the garden and animals need to be watered daily. Currently, Burris uses water from a local beaver pond. She pumps this water up to a storage tank and then uses hand watering cans. This is very laborious and time consuming, taking 1-2 hours each day. Recently, the farm's water supply diminished due to drought. This caused the plants to dry out and die. As a result, Burris was not able to offer the educational opportunities associated with growing, caring for, and harvesting the plants. The pond's water is now replenished, but TBT wants to avoid another water shortage and cut down on labor in the future.

The goal of this project twofold, 1) making the farm more resilient to drought, and 2) providing additional opportunities for STEM education at the farm. To make the farm more resilient to drought, we designed and built a rainwater catchment, storage, and irrigation system with the support of WPI's Engineers Without Borders (EWB). This system will have the ability to connect the irrigation portion to either the rainwater catchment system, the beaver pond, or any other water source TBT may have now or in the future. This is a key component as rainwater catchment is not replacing the water source but supplementing it.

To provide additional opportunities for STEM education at the farm, we created two educational modules and learning stations focused on water movement, catchment, and storage. We accomplished our two-part goal with the following objectives:

1. Research and build two STEM modules around rainwater catchment systems focused on preschool children with and without disabilities.
2. Research different types of rainwater catchment, storage, and delivery systems that operate at the scale and in similar climates to TBT.
3. Evaluate TBT site for characteristics that would be most suitable and ideal for rainwater catchment, storage, and delivery, and evaluate the water needs at TBT.
4. Design and build a rainwater catchment system at TBT that meets its needs.

In this report, we discuss current literature on the benefits and limitations of farm-based education for children, including those with disabilities, and the advantages and drawbacks of different rainwater catchment systems. We then move to our methodological approaches, which consist of scholarly research on both farm-based education and rainwater catchment. We also conducted semi-structured interviews with experts on rainwater catchment systems for agricultural use and experts on STEM, farm, and nature education for kids at the developmental

[1] Exceptional needs refer to children who struggle with social, emotional, and behavioral issues, such as Attention Deficit Hyperactivity Disorder (ADHD), Autism, trauma, and other cognitive disabilities.

ages of 3-8 years. These methods of gathering information allowed us to design the system and educational components.

After our sponsor and advisor raised $3,000 through fundraising and grants, we were able to purchase materials for the system and learning stations. The learning stations were built and delivered to the farm for implementation in April 2018. The system was built with the support of WPI's EWB on May 26, June 2, and June 16, 2018.

This system will provide TBT with 1500 gallons of water, two potential water sources for their needs, and a more efficient irrigation system. This system will also provide Lisa more time for building, developing, and running her educational programs, which is the heart of TBT. These designs have been made available on through WPI's Gordon Library website. This allows other farmers and farm-based educators to access, evaluate, and modify our model to improve it and/or to meet their needs.

2.0 Literature Review

This section reviews the literature that informs and supports the social and technical foundations of our project. First, we review the literature on farm-based education that informed the educational modules and learning stations that we developed and built. Next, we review literature on designing and building a rainwater catchment, storage, and irrigation system. We also describe our sponsor, Turn Back Time farm (TBT), and their needs. We will explain the harms associated with a lack of exposure to nature, the importance of farm-based education (the primary purpose of the farm and our project), the history of TBT, and how a rainwater catchment, storage, and irrigation system needs to be built to serve and sustain the farm's educational gardens.

2.1 Child Behavioral, Emotional, and Physical Problems Associated with a Lack of Engagement with Nature

Many children today spend less time outdoors and more time inside on screens. They spend half as much time outside as they did 20 years ago. According to a study conducted by the Kaiser Family Foundation, 8-10 year old children in America average 7 hours and 51 minutes of total media exposure per day (Rideout, Foehr, Roberts, 2010). The American Academy of Pediatrics, however, recommends only 1 hour of screen exposure for children ages 2-5 and about 2 hours of exposure for ages 6 and older. When children engage with screens (e.g. tablets, phones, televisions, computers, etc.), they disconnect socially from their parents, caretakers, and peers. Social disconnection can result in a lack of important social bonding and can also cause behavioral issues, such as aggression, frequent outbursts, and a tendency to argue. Screens visually and audibly overstimulate children. Therefore, children cannot fully process or understand their devices' noises and visuals. Overstimulation can cause stress, impact sleep, and cause short and long term behavioral problems (Middlebrook, 2016).

More evidence shows a correlation that links children's diminished contact with nature to important childhood mental, emotional, and physical health trends, including increased levels of depression, attention disorders, and cognitive disabilities, as well as increasing rates of childhood obesity, hypertension, and diabetes (Strife and Downey, 2009). Childhood obesity links to a number of other physical health problems, including hypertension, diabetes, stroke, respiratory problems, and some cancers (Strife and Downey, 2009).

Additionally, children are spending more time sitting and being inactive. The average elementary school student spends about 7 hours in class each day, sometimes without any recess (Strauss, 2015). Not only does increasing class time proportionally increase time spent sitting, but it often leads to burnout. Burnout occurs because students lack a break in between learning and, consequently, overuse their brains. For any adult or child, sitting causes the brain to "fall asleep." After about 20 minutes, the physiology of the brain and body changes, resulting in the brain losing energy and fuel. In contrast, physical activity stimulates the brain and increases neuron activity (Strauss, 2015). This is especially important for children, as they often learn as they play. Playing allows the brain to wake up and reset, thereby committing the learned concepts to memory (Strauss, 2015).

2.2 Benefits of Farm-Based Education

Farm-based education is defined as learning through farm and nature-based play (Cadwallader-Staub, Redmond, Dixon, & Simon-Nobes, n.d.). Farm-based education is driven by the following three principles. First, nature it integral to the school. It is incorporated in the school's philosophy, programs, and both the outdoor play and learning spaces. Second, farm-based education combined early childhood education and environmental education. The teaching of these educations should be high quality, so the staff of the school must have knowledge in both disciplines. Third, the school should create an environment that fosters both childhood development and conservation ideologies. Farm-based schools helps to develop the cognitive, social, physical, and other life skills while developing the child's environmental mindset (Larimore, 2016).

Nature-based play facilitates the learning of math, science, counting, problem solving, teamwork, and other skills through child engagement with outdoor materials and activities. Activities can include picking and counting vegetables, climbing and descending trees, making discoveries, working together to unearth a large rock, or managing conflict over water while making mud pies (Mills, 2009; Green Hearts Institute for Nature in Childhood, 2014; Burris, personal communication, October 2017). Farm-based education has numerous benefits for children of all ages and abilities. These include helping with the development of critical life skills, improving physical and immune health, and helping those with exceptional needs.

Being exposed to and engaged with nature outdoors is important for childhood development because it has been proven to increase concentration levels, increase academic performance, reduce their chance of obesity, help their social skills, reduces their chance of depression, and many other health reasons (Strife and Downey, 2009). Also, it has been shown that spending time in nature can reduce the symptoms of ADHD. Early childhood experience in nature significantly increases the development of lifelong environmental attitudes and values, including practicing conservation activities and working to reduce the environmental impacts of human activities (Strife and Downey, 2009).

2.2.1 Benefits of Unstructured Nature Play and Farm-Based Education for Developmental Critical Life Skills

Unstructured nature play is fun and voluntary, led by children with no specific end goal or reward (Gopnik, 2016). Unstructured nature play helps preschool age children (aged 3-6 years old) develop foundation, organization, socialization, and independence. When outdoors, they can behave creatively in ways that being indoors might not allow, such as climbing on objects or getting involved in messy activities (Adams et al., 2016). From this they gain an understanding of cause and effect, science concept knowledge, making connections, spatial awareness, different perceptions, and sound differentiation. These gains lead to higher literacy, memory, timing, and sequencing skills later in life (Adams et al., 2016). Nature play promotes the development of critical life skills and contributes to the effectiveness of farm-based education.

Farm-based education fosters the development of critical life skills. These are social skills, including: trust in others, self-care, self-esteem, adaptability, responsiveness to one's surroundings, responsibility, and empathy (TZVI, 2013). For example, farm education offers lessons about both animals and plants. Animal education teaches children how to responsibly take care of an animal. By feeding, cleaning, and tending to the basic needs of an animal, children indirectly learn how to take care of themselves (Green Chimneys, 2017). Additionally, children possessing strong connections to animals typically harbor a more positive attitude toward them. This attitude results in pro-social and more humane behavior in children (Roxanne D Hawkins, et. al 2017). Plant-life programs consist of children planting, watering, weeding, and learning how to maintain a garden. Gardening teaches children through hands-on work, and the lessons learned in the garden correlate to other classroom lessons.

2.2.2 Benefits of Farm and Nature Exposure for the Physical and Immune Health of Children

Spending time outdoors offers a series of physical benefits. A study conducted by Medical School of Wisconsin and the University of California, Berkeley tested the difference between children who spend time outdoors on farms versus those who do not. The results demonstrate that children who spend time on farms have a lower likelihood of developing childhood asthma (Adler, Tager, & Quintero, 2005). These rates are lower because these children have more exposure to animals, mold, dust, and other common allergens. Children can absorb, metabolize, detoxify, and excrete poisons differently because their organs are in constant development (Center for Health, Environment, and Justice, 2001). This exposure at a young age helps the children's bodies familiarize with these allergens and build immunities that lead to a lesser reaction during future exposure (Adler, Tager, & Quintero, 2005). Additionally, time spent outdoors on farms decreases exposure to harmful air pollutants found in urban areas, such as sulfur dioxide, carbon monoxide, particulate matter, and nitrogen oxides (Tarleton, 2001). Spending time outdoors exercising through play also reduces the risk of childhood obesity and diabetes (Strife and Downey, 2009).

2.2.3 Benefits for Kids with Exceptional Needs

While there are benefits of a farm-based education for all children, there are unique benefits for children with exceptional needs. For the scope of this project, exceptional needs refer to children who struggle with social, emotional, and behavioral issues, such as Attention Deficit Hyperactivity Disorder (ADHD), Autism, trauma, and other cognitive disabilities. Children with exceptional needs often struggle in traditional school settings, as noisy and crowded classes can be overwhelming and distracting for children with sensory and processing issues, such as those with Autism or ADHD. Additionally, lessons in traditional settings include mass instruction and time limits. These characteristics of traditional schools can be challenging for children with exceptional needs because they can have difficulty completing tasks on time, especially without individualized instructions or support (Garnett, 2010). These are broad problems with traditional schooling, but children with disabilities experience these problems disproportionately.

Children with behavioral disabilities can struggle with impulsivity and appropriate behavior in school. They often have difficulty having no control over their day or the transitions between activities. This can lead to acting out and spending more time being punished than the other children (Caughman, et. al, 2007). Punishments can further reduce their self-esteem and take them away from activities and learning (Caughman, et. al, 2007). Children who have experienced emotional trauma also experience trouble in the classroom. They often must overcome obstacles like poor self-regulation, trouble forming relationships, and challenges with executive and cognitive function such as poor memory and focus (Miller, 2018).

Children with disabilities related to socialization, such as social anxiety, nonverbal learning disabilities, social communication disorder, and autism, also have difficulty in traditional schooling. These disabilities lead to talking frequently and inappropriately, having trouble forming friendships and relationships with others, not taking turns as they should, giving up easily, and not listening well. In the context of a classroom, this results in not grasping the concepts taught, sitting out due to inappropriate behavior, being too shy to participate, not understanding what is being said, or giving up on the activity due to its difficulty (Patino, 2018).

When in nature, areas of the brain react differently from how they react during daily life. This means that the brain will function differently when learning outdoors rather than in a classroom. The frontal cortex slows down, relaxing after its overuse in busy life. The anterior cingulate and the insula, the areas that produce an individual's empathy and altruism, become active (Williams, 2015). Children should produce this empathy and altruism because these characteristics encourage social interactions and group activities while also facilitating teaching and learning. Empathy and altruism strengthen the child-parent bond, increase social attachment, promote prosocial behavior, and enable children's ability to foresee problems and the patterns around them. Therefore, this allows quick and successful responses to ever-changing demands in life (Burton M.D., 2014).

Nature based education also provides multiple ways to learn and experience accomplishment. For example, for students who are not commonly the top of the class and/or not getting internal or external praise for academic accomplishments, farm and nature-based offers opportunities for different types of success through activities like building, watering, gardening, and playing new games (Burris, personal communication, September 21, 2017). Nature is an educational environment that takes out the pressure of adult interaction, perfection, and strict classroom rule following (Burris, personal communication, September 21, 2017). At farms like TBT, it is also an environment that includes unstructured play.

Unstructured play, common in farm- and nature-based programs, also helps children with exceptional needs by allowing them more freedom and choice in their actions for the day. By allowing them more control, they are spending less time acting out and being punished and more time learning, doing, and socializing (Burris, personal communication, September 21, 2017). Additionally, playing outdoors improves mood, attitude, and classroom behavior. Play can lead to healthier emotional attitudes, improved adjustment to classroom life, and the formation of friendships (Strauss, 2015; Futterman, 2016). By making friends, children learn crucial social skills and may even increase their learning and attitude in traditional schooling (Futterman, 2016). Close friendships increase positive attitudes towards learning, and increases academic performance (Futterman, 2016).

In some situations, farm-based education can replace traditional schooling. For example, farm and nature-based preschools, as an alternative to more traditional preschools, is growing in popularity in the U.S. For example, in 2007 there were 20 nature preschools in the U.S.; today there are over 250 (Brown, 2017). However, at other ages, this is uncommon. Most children engage with nature and farm-based education through camps and afterschool programs (Cadwallader-Staub, Redmond, Dixon, & Simon-Nobes, n.d.). By adding farm-based education, these children still benefit from playing outdoors without having to fully replace their schooling. They are given the time needed to reset their brains, develop life skills, and feel successes they might not otherwise get in traditional schooling (Burris, personal communication, September 21, 2017).

2.3 History of Turn Back Time

Turn Back Time (TBT) is a non-profit farm- and nature-based education program that operates on 58 acres of land in Paxton, MA. Within these acres are plant and vegetable gardens, an extensive woodland trail system, a nature playground, and a beaver pond. The goal of the farm is to provide children, including those with exceptional needs, the opportunity to learn and develop through nature play and engagement (Burris, 2017). The farm was created by Lisa Burris and was inspired and informed by Burris's education, research, and personal experience with her two adopted children.

Burris's children demonstrated behavioral problems by the time they were five and six years old. For therapy, Burris noticed that her daughter enjoyed therapeutic horseback riding. However, her son, who has severe Autism, felt stressed and pressured when it came to riding the horse. This was not a total loss for him, as he did enjoy connecting with the horse by talking with her in a "silly" voice (Burris, personal communication, September 21, 2017). Burris looked for opportunities for her son to recreate this connection through 4H and boy scouts. This proved difficult because of his behavioral issues. She could not enroll him in these programs due to the lack of support and programming for kids with exceptional needs (Burris, personal communication, September 21, 2017).

The therapy for Burris's son came when she observed her son trying to catch frogs with other kids on a camping trip in the woods. Typically, Burris's son requires social and behavioral intervention every 5 to 15 minutes when in a social setting. However, in this case, he spent two hours playing and catching frogs in a stream with other children, not needing any intervention for that time (Burris, personal communication, September 21, 2017). Burris spent the next year researching why and how engagement with nature can serve as a therapeutic and educational space for all children, especially those with exceptional needs. Burris left her job at a medical device manufacturer to start a farm with integrated educational programs, Turn Back Time. Integrated and inclusive educational programs teach both children with and without disabilities (Burris, personal communication, September 21, 2017).

To assure the program's success, Burris researched how to serve at-risk children through nature and farm-based programs. At-risk children are those who possess disabilities, have experienced traumatic events, and those in foster care or who receive services through The Department of Children and Families (Burris, personal communication, September 21, 2017). Along with her research, Burris worked to develop her own expertise and credibility for her program. She earned an associate's degree in Human Service from Quinsigamond Community College, which focuses on improving the quality of life through services that meet unique population needs (National Organization for Human Services, 2017). She also completed a master's certificate in Nature-Based Early Childhood Education at Antioch New England University (Burris, personal communication, September 21, 2017).

2.4 Nature-Based Education at TBT

Burris currently runs over a half-dozen programs, serving over 500 children, exposing them to almost 9,000 hours in nature. Programs include a yearlong preschool camp, a six-week summer camp, school age programs, family farm times, and human service agency visits. Thirty percent of the children TBT serves come from at risk populations. These programs provide opportunities for children to develop critical skills (e.g. risk taking, cooperation, gross motor skills) at their own pace, while establishing deep, personal connections with the natural environment. Students play in the forest playground, care for the gardens, harvest the crops, explore the woods and beaver pond, and interact with and care for the farm animals. Burris has hired a certified preschool teacher to guide and develop student learning on the farm, and to work on developing an accredited nature and farm-based integrated preschool.

2.5 Problem at TBT: The Need for More Resilient Farming Practices

During the summer of 2016, New England experienced a severe drought (Quintana, 2016). TBT relies on pumping water from their beaver pond to irrigate their crops. Pumping water during the drought led to the pond going dry. Without water, the garden dried up, and the crops died. The gardens provide the context, materials, tools, and opportunities needed to run TBTs programs. Without the gardens, they can't offer the opportunities that have been proven to provide so many benefits (Burris, personal communication, September 6, 2017).

As our global climate continues to change, Massachusetts will see an increase in extreme weather, like droughts (EPA, 2016). With that in mind, Burris concluded that she needs to practice resilient farming and watering. Resilient farming refers to an approach to farming in which extreme weather, such as droughts, are expected, and where mitigation strategies are built into the farm structure and daily farm practices, instead of responding to disasters as they occur (Altieri et al, 2015). Mitigation strategies associated with watering practices include having multiple water sources, watering more efficiently, and enabling your soil to more effectively absorb and retain water moisture (Altieri et al, 2015). Using efficient watering systems, combined with controlling the amount of water emitted at each growth stage are also ways of practicing resilient farming (Kaplan et al., 2018).

To enable resilient watering practices at TBT, our team has been asked by Burris to design a rainwater catchment system that will provide a supplemental water source and an efficient irrigation system. This system will allow Burris to have multiple water sources, including natural rainfall, the beaver pond, and stored rainwater -- with the potential to add additional sources. The irrigation system will be able to connect to multiple water sources and will water the garden more efficiently, reducing both the water used and the time required by Burris to water the gardens. She currently spends two hours in the summer watering the gardens.

2.6 Rainwater Catchment Systems

Rainwater catchment systems consist of harvesting, filtering, storing, and delivering rainwater. Rainwater harvesting is the collection and storage of rainwater for domestic or commercial use. The collection can come from runoff, dams, trenches, slopes, water collection reservoirs, and/or underground tanks (Victor, 2016). The benefits of rainwater catchment include a cost-effective water source, reliable harvest water, a reduced impact of floods, and it can aid in preventing water pollution (Victor 2016). Some cities and states in the US actively encourage rainwater catchment. For example, in June 2010, Tucson, Arizona passed a law that requires the supply of commercial property irrigation water be at least 50% rainwater (Solloway, 2013). Rooftop rainwater catchment for personal and farm use have grown in popularity during the last two decades in other parts of the world as well, including in Africa and South Asia (Kisakye et al., 2018).

2.6.1 Collection

There are two types of rainwater harvesting or collection: surface runoff and rooftop runoff. Surface runoff is the water that runs off different surfaces. Rooftop runoff is where the roof itself becomes part of the catchment system, allowing the water to flow into storage tanks for later use (Padmanabhan, 2013). This system provides more water without damaging the groundwater table/water level.

For rooftop collection, water runs off the roof and into the gutters. The water flows from the gutters, to the pipes, and into storage containers. Filtration assures the water's usability, with different levels of filtration required for water used for drinking, bathing, agricultural use, etc. An agricultural rainwater catchment system must filter out large debris that can clog delivery pipes and water storage barrels (Padmanabhan, 2013). Using rainwater captured from a roof for a vegetable garden does not require more extensive filtration, as it would if it were used for drinking water. Water from rooftop fed catchment can be contaminated by coming into contact with chemicals from the roofing materials (Victor, 2016). As a result, roof fed catchment systems in which rainwater is used for drinking water requires extensive filtration and boiling (Victor, 2016). However, rainwater used for agricultural purposes does not require filtration beyond removing large debris like leaves and sticks, as research shows that the chemical contaminants from the roof are not present in the crops grown (Oilgae, 2017).

2.6.2 Storage

After filtration, the harvested water is stored in either a single cistern or a multi-barrel system. It can be stored above or below ground. Key components of an effective storage system include: inlet for rainwater inflow, outlet to access water, overflow pipe, and an air vent which can be the overflow pipe if it is open to air (Daily & Wilkins, 2012). The outside environment is also important for storage. The tanks need to be UV resistant, keeping out light and sun damage is important as algae growth can occur. The tanks also need to be on level ground, and if in a windy area they may need extra reinforcements to tie them down. For all openings in the storage tank there needs to be animal proofing, to avoid larger animals from getting in and insects, like mosquitoes, from laying eggs (Daily & Wilkins, 2012).

2.6.3 Delivery

TBT's current delivery system consists of Burris, her staff, and the children all hand-watering the gardens. Although hand-watering possesses as educational value, it is inefficient; the gardens are too large to hand-water each day. It currently takes two hours each day for Burris to hand water the gardens on her own. An automated irrigation system will resolve this issue by supplying the garden with water more efficiently and effectively. This will allow Burris to use hand-watering as an educational opportunity, and not a necessity. The first step of delivery is to decide how to get the water from the storage tank to the garden area. The next step is to decide which irrigation system is best in getting the water from the general garden area to the individual plants.

There are two options for distributing the catchment systems water: pump-fed systems and gravity-fed systems. A pump-fed system electrically forces water out of the catchment system. However, a gravity-fed system uses gravity's acceleration to help water flow (Wood, 2015). With either option, the rainwater catchment system design needs attachments that allow for water distribution. There are three main types of irrigation: hand watering, sprinkler systems, and drip irrigation. Hand watering, as previously mentioned, is a very labor-intensive task. This requires time and effort and uses excessive water, as splashback is common. However, this is a very inexpensive option (Greener Horizon, 2015). Sprinkler systems, after installation, require less effort. They can water plants by simply turning on when desired or by setting a timer. Sprinklers can cover large areas of garden at once, ensuring full coverage. However, it can be expensive to install and can be inefficient, as it delivers a large volume of water to the entire garden, instead of providing targeted amounts of water to areas of the garden that need more or less (Pros and cons of different irrigation methods, 2015).

Drip irrigation, a type of irrigation system, directly exposes plant roots to water. A timer determines when the system will be turned on and off. It can also control the flowrate of the water dripping, thus setting the amount of water emitted. Drip emitters, about the size of a coin, supply water to the crops. The emitters release less water than the other main irrigation techniques, including sprinklers and hand watering (Postel, Polak, Gonzales, & Keller, 2001). The African Market Garden evaluated the differences between hand-watering and low-pressure drip irrigation. Results showed the drip irrigation system saved time, water, and money (Woltering, Ibrahim, Pasternak, & Ndjeunga, 2011). Drip irrigation minimally waters the soil required for the plants. The system can be turned on and left alone. This means the farmer spends less time watering.

3.0 Methodology

The methodology section outlines the methods we used to achieve our goal of designing a rainwater catchment and irrigation system built by WPI's chapter of Engineers Without Borders (EWB) and developing associated educational materials for use by pre-kindergarten students at Turn Back Time (TBT) in Paxton, Massachusetts. We detail our objectives and methods associated with rainwater catchment, storage, and delivery. Additionally, we discuss our objectives and methods associated with designing and implementing STEM learning modules that enable learning around rainwater catchment, storage, and delivery. To collect data, we used the following methods: semi-structured interviews, site analyses, and secondary research.

Methodological Overview

Our first objective was to research STEM modules around rainwater catchment systems, focusing on those designed for preschool aged children, including children with social, emotional, and behavioral challenges and disabilities, such as Autism. The researched STEM modules were related to water play and rainwater catchment. To meet this objective, we conducted secondary research and semi-structured interviews with people who have experience developing pre-K modules around rainwater catchment systems. Our second objective is to design and pilot two education modules around rainwater catchment, storage, and delivery for 3-8 year old children. Our third objective is to evaluate TBT's site for characteristics that were most suitable and ideal for rainwater catchment, storage, and delivery, and to evaluate the water needs at TBT. To achieve this objective, we researched different types of rainwater catchment, storage, and delivery systems that operate at the same scale and in similar climates as TBT. We conducted secondary research to learn about the different types and styles of these systems. Our fourth and final objective was to design and build the final system with the help of EWB.

3.1 Research STEM Modules Around Rainwater Catchment

To meet this objective, we engaged in secondary data collection by reviewing modules on rainwater catchment systems for children, particularly preschool children and those with behavioral, emotional, and social disabilities. We also researched STEM concepts that were appropriate for those age and ability groups (developmental age of 3-8, with consideration of exceptional needs), and we modified rainwater catchment modules to create learning stations to meet their needs and development.

We also engaged in primary data collection through semi-structured interviews with people who developed and/or implemented modules on rainwater catchment systems for children, including children in our target group. These included interview with our sponsor Lisa Burris. We also interviewed a rainwater catchment extension agent Professor David Sample. We asked him questions on our design matrix, our design, and for overall tips on building catchment systems. Additionally, we discussed possible ways of implementing our design matrix with an industrial engineering and lean concepts professional, Professor Sharon Johnson. Finally, we interviewed two WPI Faculty, Dr. Robert Traver and Mia Dubosarsky. Robert Traver is an undergraduate studies professor who helped us in developing the educational modules. Mia

Dubosarsky works in WPI's STEM Education office, she also helped in developing the educational assessments as well as developing the module and learning stations.

3.2 Design and Build Education Modules and Learning Stations Around Rainwater Catchment, Storage, and Delivery

To meet this objective, we started by reviewing our research about rainwater catchment and STEM modules. In the review, we considered age appropriateness, viability in an outdoor farm setting, learning through play, and ability to meet the needs of exceptional children. We then developed two educational modules and associated learning stations: 1) Catchment Carl, a small-scale rainwater catchment system, and 2) a Water Wall. When designing these modules, we followed a template for educational module design process. This process considers the following concepts: defining learner needs, defining teach and institution needs, identifying desired learning outcomes, pinpointing the underlying learning theory, creating an assessment, and implementing that assessment to improve the module (Donnelly, & Fitzmaurice, 2005).

For the first educational module and learning station, we took a full-scale rainwater catchment system and scaled it down to a simpler model suitable for children, designed for learning through water play. We created informal opportunities to learn about rainwater harvesting, including visual and interactive educational activities. For the second educational module and learning station, we presented a water wall, a water relay race, and a waterfall race preliminary module and learning station and presented the options to Burris, our sponsor. With her feedback, we further developed the water wall educational module and the learning station. We created opportunities to learn about water flow, rate, and resistance through water play. Once we finished constructing these components, we implemented them at TBT. We also conducted semi-structured interviews with Mia Dubosarsky and Dr. Robert Traver, two WPI faculty that specialize in assessments and STEM education. Initially, we wanted to develop methods of assessment for the educational stations based on our interviews with Dubosarsky and Traver. However, the time limitations of our project prevented developing forms of assessment. Instead, we relayed the information to Burris and advised her on what learning outcomes she should look for if she conducts her own forms of assessment.

When we began our build process for the educational stations, we gathered materials and donations from Home Depot, Lowes, and Savers. Initially, we tried to receive donated materials from different stores for the project, but this venture was unsuccessful. However, we were able to acquire some recycled materials from WPI, such as the bucket for Catchment Carl. We also assessed the materials available at TBT, and we were able to acquire wood and shingles for the project. A detailed materials list is provided in Appendix D. Then, our team constructed the educational stations at apartments and delivered them to TBT.

3.3 Evaluate TBT's Characteristics for Rainwater Catchment and Its Water Needs

To meet this objective, began by interviewing our sponsor to learn about her water needs and key criteria to consider when evaluating different rainwater catchment designs. The data collected from this interview was used to create a design matrix, with which we then evaluated potential catchment, storage, and delivery designs. Criteria for the decision matrix also came from secondary sources, including templates on how to create effective decision matrices, as well as scholarly articles and informational videos on various rainwater catchment systems. We discussed the construction of our design matrices with Prof. Sharon Johnson, an industrial engineering and lean improvement methods expert at WPI. Johnson has experience with facility layouts and prioritizing options by using the analytic heuristic process (AHP). AHP ranks criteria by assigning a weight to each criterion, and each alternative option receives a rank for how well it exemplifies each criterion (Johnson, personal communication, November 8. 2017). This analytic method allows certain options to take priority based on how well they execute the most important criteria. Finally, our design matrix was informed by semi-structured interviews with Prof. David Sample, an agricultural extension agent from Virginia Tech with expertise on rainwater catchment systems for used for agricultural production. The final criteria for the decision matrix included the system's maximum storage capacity, total cost, safety, maintenance/sustainability, irrigation compatibility, overall cleanliness, and ease of use. The criteria were organized in a design matrix, which can be found in Appendix C, and the ratings for the criteria were filled in while we were on-site during the site evaluation.

During the site evaluation, we analyzed TBT to determine the farm's ideal rainwater catchment characteristics. These characteristics included collection, storage, delivery, and water needs on the farm. When conducting this assessment, we unanimously decided the barn would be the best building for the system. It provided the largest roof surface area, was close to the garden, and allowed for electricity if required. We then determined what tools and equipment were necessary and took measurements of the barn. We also measured the distance from the barn to the garden, the overall acreage of the garden, and the size and number of raised beds in the garden. These measurements were used in the final design and construction of the system.

3.4 Design and Build a Rainwater Catchment System at TBT that Meets its Needs

We used information gathered from the previous objectives to design and then build our rainwater catchment, storage, and irrigation system. While designing, we kept the Engineering Design Process in mind. This is a process engineers follow to ensure the needs are being met and the design created is the best fit for these needs. It consists of six steps: defining the problem, brainstorming, planning, creating, testing, and improving (May, 2017). We defined the problem as water resilience, brainstormed the solution as a rainwater catchment system with a multi-source irrigation system, and began to create a design of this system.

The design was created using our decision matrix. We used this to determine what aspects of different systems from our research best met TBT's needs. However, we decided to not utilize AHP during our decision making because we believed there was only one feasible option once we conducted all our research. We created a materials list, found in Appendix E, that included all necessary parts to build the system. Our team presented this system design and materials list to both Burris, our sponsor, and Professor Sample, the extension agent, for feedback. We used their feedback to finalize the design. When the design was finalized, we met with Burris and Engineers Without Borders, a student-led organization who help with international development work, to go over the materials list and construction plan. To start construction, the storage unit is placed on level ground next to the barn. Next, downspouts are attached to the ends of the gutters on opposite sides of the barn, these downspouts lead to the filtration devices. One of the downspouts is located above the storage unit. A Tee-PVC adapter is attached to the bottom of each filtration device. Then a horizontal and vertical PVC pipe are attached to the Tee-PVC adapter. The vertical pipe is the first flush. The horizontal pipe leads to the storage unit. The horizontal pipes that are on the opposite side of the barn and the storage unit need to be attached to one another until they reach the storage unit. This requires utilizing multiple 90-degree PVC adapters to guide the horizontal pipes along the sides of the barn. The horizontal pipe that connects to the Tee-PVC adapter near the storage unit connects directly to an inlet on the top of the storage unit. After, the pipes are attached and connected to the storage unit, a submersible pump is place inside the storage unit. Attached to the pump was poly plumbing pipe, the pipe was lead out of the top of the storage unit, along with the pumps electrical cord. It was then fed across the farm's roadway and into the garden, where it was met with two smaller tanks for overflow or a hookup for irrigation. The pump and piping were sketched out in design and then reviewed and altered, as seen in Appendix F. The poly plumbing pipe was used for the course of this, with elbows used to connect different length pieces. A drainage system was implemented in the middle using a T piece, this is to help drain the system fully in the winter. Most of the pipe was buried in a pipe underground.

4.0 Results

In this section, we detail the results of our data collection, analysis, and the final deliverables of our project under each of our project objectives.

4.1 Research STEM Modules Around Rainwater Catchment

One of TBT's goals is offer more STEM-based educational games in its programs. Therefore, we researched what makes effective learning modules for students to learn STEM concepts around water and, more specifically, rainwater catchment. To achieve this objective, we collected data to answer the following research questions:1) What STEM concepts are appropriate for children ages 3-6? 2) What considerations need to be made for kids with exceptional needs? 3) What water and rainwater catchment lessons exist that are adaptable to the context and needs of TBT? The information was gathered from scholarship on teaching STEM to preschool children, educational websites focused on preschool education, and educational websites focused on incorporating STEM into preschool education. We also conducted semi-structured interviews with Mia Dubosarsky, a STEM education professional, and Ali Johnson, a farm- and nature-based educator at TBT and certified preschool teacher. This information was used to create two education modules and learning stations, one focused on rainwater catchment and the other focused on water flow, rate, and resistance (Bardige & Russell, 2014).

4.1.1. Existing Rainwater Catchment Lessons

We spoke with Katie Piccionne, a WPI alumna, who created a rainwater catchment curriculum. However, Piccionne's program is geared toward children who are around high school age (Picchione, 2016). We looked online and found the youngest age group a rainwater catchment curriculum existed for was 5th grade. We considered modifying these curriculums for preschoolers, but we decided against this option. Creating a curriculum is an extremely detailed process, and we determined it is outside the scope of our project. We decided a less time-consuming option would be to create one rainwater catchment educational module and associated learning station. In education, the term "module" refers to an instructional unit that focuses on a particular topic (Sweet, 2018). A module is a portion of a curriculum, which is a unit of lessons in a specific course or program (Partnership, 2015). For our module to fit within the educational philosophy of TBT, we aimed to develop a module that taught STEM concepts through play in nature. Learning through play is commonly used by psychologists and educators because play is how children make sense of the world around them as well as learn new concepts. Play shares a large link with many developmental areas in a child, including: language, math and spatial awareness, executive functions, and even social and emotional development (Hassinger-Das, Hirsh-Pasek, & Michnick Golinkoff, 2017). This idea of learning and developing through play is a core part of the philosophy at TBT (Burris, 2017).

To meet the goals of our project, we focused specifically on teaching STEM concepts through children playing with a miniature rainwater catchment system in the farm's gardens. Game-based play fosters learning by encouraging the children to play with certain objects, learning, for example, water flow and resistance, as they play with and manipulate objects (The difference between gamification and game-based learning, 2014). We also aimed to develop modules that would draw on the children's curiosity of the full-scale rainwater catchment, storage, and delivery system once it is built on the farm. Researchers at the University of

California have found that not only does curiosity prep the brain for learning, but it makes the subsequent learning rewarding by allowing the brain to remember more information unrelated to the initial curiosity (Stenger, 2014).

4.1.2. Foundational Water Modules in the Literature

We found several water-related activities that could be developed into learning stations and could be easily implemented into the daily schedule at TBT. These include a water wall, a water relay race, and a water zig zag race. A water wall is composed of bottles connecting through different paths, so water can flow from the top to the bottom of the wall. Children pour water at the top of the wall and observe how the water flows through the bottles to the bottom of the system. The water wall combines water play with investigative learning. Children learn problem solving skills, how water can move through different paths, and the importance of water security. They learn this by using their problem-solving skills to get the water from one bottle to the end bucket. They must assure the tubing and bottles line up in a way that the water flows to the final bucket (Alter-Rasche, 2014).

A water relay race is a problem-solving module that allows children to move, run, work together, and test out different strategies. The children work in teams and race to fill up the largest bucket through using smaller buckets to transfer water. The water relay race teaches creative thinking, teamwork, how to test different strategies, and how to practice trial and error (Fitzgerald & Fitzgerald, 2017). A water zig zag race is a learning game guided by the engineering design process. Children are given modeling dough and a cookie sheet. The objective is to sculpt a system where water moves the slowest over a sloped landscape. Children learn basic engineering design concepts (Ask, Imagine, Plan, Create, and Improve) by building a structure that yields the slowest flow of the water (Engineering is Elementary, 2018). Also, children learn how water moves through different paths and improve teamwork skills. We presented the options to Burris, along with our design for a miniature rainwater catchment module. We presented simple lesson plans, as well as the associated learning outcomes, materials lists, setup section, and a possible assessment. We asked her to choose two options based on engagement, age appropriateness, and educational value. She chose the miniature rainwater catchment system and the water wall.

4.2 Design and Pilot Two Education Modules Around Rainwater Catchment, Storage, and Delivery

In this section, we discuss the two education modules and learning stations we designed and built: the water wall and the miniature rainwater catchment system we named Catchment Carl.

4.2.1. Water Wall

A water wall is a wall with bottles that connect to one another and eventually lead to a collection bucket. These bottles can move or turn and can be connected by tubing or simply have open space between them as shown in Figure 6. The water is poured at the wall’s top, and the

Figure 6: Water Wall
Image Source: Virginia Adams

children watch as the water flows through the bottles and tubes to the collection basin (Edwards, 2014). The game teaches children the basic concept of how a catchment system functions (Edwards, 2014). They can see how water falls onto a structure and gets collected after passing through tubing and pipes. This module shows the three components of rainwater catchment: water collection, storage, and delivery. What the children do with the water is comparable to delivery.

Some of the STEM concepts and developmental skills children gain through this activity are as follows. By pouring water over the wall and moving the parts, children can see how some bottle positions stop the water flow while others increase the rate of flow. It also teaches children problem-solving, group collaboration, and trial and error (Edwards, 2014). It requires the children to work together to get the water into the end container. This station also allows the children to experiment with different starting points (Dubosarsky, personal communication, December 6, 2017). The actual act of scooping up the water and pouring it over the structure improves motor skills (Alter-Rasche, 2014). This STEM-related learning helps to jump start a child's interest and ability in science. The children can work with other children while doing this, so it becomes a collaborative effort. Group work helps facilitate friendships, compromise, and empathy all while learning science related concepts (Williams, 2015).

4.2.2. Mini-Rainwater Catchment System: Learning with Catchment Carl

Catchment Carl is an interactive, educational module that will help students understand rainwater catchment. We wanted to design a module similar to the final rainwater catchment system design in order to help students understand how this system works. The building of the system and the presence of a new feature on the farm will spark curiosity about the system among the students (Burris, personal communication, Feb 10, 2018). This curiosity will prepare the brain to learn and remember new information (Stenger, 2014). We want to harness this curiosity for learning in a way that is safe and will not disrupt the function of the actual catchment system.

Catchment Carl represents a single cistern system. The “cistern” is made of a plastic bucket. In the initial lesson plan, featured in Appendix B, our design for Catchment Carl varied from the design we implemented. Initially, Catchment Carl was going to sit on a grass pad in a small wagon. The grass pad represented the actual ground. The wagon made the activity portable based on where it may be more useful. A small, roof-like structure was going to be built onto the wagon above Catchment Carl. This structure included a “gutter system” made of PVC pipes. Inside the cistern, a strainer acted as a filter for the “first flush system.” There were going to be anywhere from one to four spigots on the cistern exterior. Additionally, a vacuum hose was going to connect the cistern to the gutter system. Finally, there were going to be pouches on the sides of the roof-like structure to contain cloud-shaped sponges.

We found a lesson plan format on an educational website with eight distinct sections: learning objectives, introduction, explicit instruction or teacher modeling, guided practice or interactive modeling, independent working, differentiation, assessment, review and closing (“Number Recognition 1-10,” 2015). We modified the format of this lesson plan to fit the needs and context of TBT by dropping three of the categories and adding four of our own. The categories we added include: designed for ages, materials, set up, and follow up activity. These were added because of the nature of TBT. Designed for ages to indicate which program the module would be appropriate for. TBT has a large variety of ages, so we deemed noting age appropriateness important. Materials and set up sections make the lesson plans easier to assemble. Since traditional assessments do not work with TBT free-slow nature, a follow-up activity section was added (Burris, personal communication, September 21, 2017). This was to give Burris a way to assess the educational value of the modules.

For a thorough understanding of the Catchment Carl educational module, refer to Appendix B. However, a brief overview of the module, as well as an image of Catchment Carl, are provided in the rest of this section.

The main learning objectives of this educational module are to introduce students to rainwater catchment systems and the water cycle. The activity starts with an instructor introducing the students to Catchment Carl and asking them questions about rainwater catchment/the water cycle. This portion is to gauge how much the students already know about these concepts, so the instructors can tell if the module met its intended outcome. We need to decide what we want the children to know and then ask questions to see if they know it. This can include questions like: Where does rain go after it hits the ground? How can we capture rain? How can we capture rain if we are not there when it rains (it rains at night)? Where would we put the rainwater? After asking these questions, the instructor will know what was already known and can begin showing the children the system (Traver, personal communication, February 21, 2018).

Next, the instructor shows the students how the system worked while explaining the water cycle and how the catchment system works. The instructor fills cloud sponges with water and squeezes them over the roof. The water runs through the gutter system and into Catchment Carl. The instructor opens the spigots and guides a hose over the grass pad. Then, the spigot is turned off, and the instructor absorbs water back into the sponges from the grass pad. The instructor will continue the process for another cycle, and students will join. Afterwards, the students will use the system without the instructor.

When the activity is over, the instructor will ask similar questions to those that were asked initially. By having students answer these questions, the instructor will assess the modules’ effectiveness. At TBT, the educational module’s physical placement on the farm is quite important, we want the children to use it and be hands on with it frequently. Concrete and hands on interactions with science help the children learn new concepts, and children can remember these concepts by having connections to their everyday life (Dubosarsky, personal communication, December 6, 2017). The module's primary location will be next to the mud kitchen, where children make mud pies, mud coffee, and more!

Figure 7: **TBT Students Playing in the Mud Kitchen**
Image source: TBT Facebook

Figure 8: **Mud Kitchen**
Image Source: E.A. Stoddard

There are buckets and tools with fake stoves and ovens and even a restaurant. In this kitchen the children can learn how to create and cook, while letting their creativity flow (Burris, 2018). By having the water modules located near the mud kitchen, students can regularly use Catchment Carl while engaging in these activities. Additionally, using the replica rainwater catchment system's water for cooking in the mud kitchen teaches students about the potential real-world uses for catchment water. Teachers can facilitate conversations about how catchment water is used in different contexts across the globe, providing opportunities for learning around global diversity and water sustainability.

According to Burris, students using the mud kitchen deal with issues of water shortages and associated conflict, as the mud kitchen lacks access to a water source other than rain. This has led to developmental learning opportunities around conflict and resource management (Burris, personal communication, January 15, 2018). They can learn about new ways of water collection, how to solve their low water problems, and how water conservation plays a role in a lot of aspects of like gardening, cooking, cleaning the pots and pans, etc. We built Catchment Carl with multiple spigots to increase water access, but also as another opportunity for students to manage available resources (e.g. spigots, water, containers to transfer water, etc.).

The mud kitchen is the primary location, but sometimes Catchment Carl may be needed somewhere else. Therefore, he needs to be portable. For example, Burris sometimes has a group of second graders come to the farm on a field trip. On this field trip, they spend their time in the garden, not the mud kitchen (Burris, informal conversation, February 1, 2018). Catchment Carl would be great to have in the garden on days like that because those children can see how rainwater catchment works (Burris, informal conversation, February 1, 2018). The potential use for the Catchment Carl Learning module on multiple locations on the farm is the reason why we designed a portable system.

When we created Catchment Carl, we modified the system from our initial design. We made the roof-like structure out of recycled wood and shingles from TBT. However, we purchased a portion of plastic downspout to act as the gutter and downspout for the system. Then, we removed some of the plastic to create an opening that allowed the downspout to also function as gutter. This design is featured in Figure 9. We did not attach the system to a wagon because Burris felt it was small and lightweight enough to be carried to different locations.

Figure 9: **Catchment Carl Roof Structure**
Image Source: Cassandra Salafia

For the actual Catchment Carl cistern, we kept the design close to the initial design by using a plastic bucket, a "first flush system," and a single spigot. However, we decided to not use a strainer for the "first flush" because we believed it would be difficult to find the right size strainer and to clean the cistern once the strainer was installed. An employee at Home Depot recommended we use a plastic mesh material to filter debris, so we attached that to the interior of the cistern. To make the system more engaging for the children, Catchment Carl was decorated to look like a minion, which is an animated character that became popular from the *Despicable Me* and its sequels. Figure 10 displays Catchment Carl and the roof structure. Some of the modifications made to the design resulted from the intentions Burris has for using Catchment Carl in the mud kitchen, but the system can be built upon and utilized for the initial lesson plan as well.

Figure 10: **Catchment Carl**
Image Source: Cassandra Salafia

4.2.3. Assessment

In order to ensure the modules and learning stations meet the learning objectives, we researched how to assess the educational value of an activity. We found that the best assessments are either written ones or observable ones (Bardige & Russell, 2014). Given the nature of our sponsor's teaching style (e.g. learning through play) and the age and ability of the children, the written assessments, such as tests, quizzes, writing assignments, etc., are not the best tools. Therefore, we focused on observable assessments, such as taking photos and notes of how the children interact with the activity, and answering questions such as: Are the children engaged? Are they curious? Are they testing out different ideas? (Chalufour & Worth, 2005). The instructors' interactions with the children will reveal more than the previously mentioned assessment methods. Asking the children what they are doing, and why they might be doing it will help see if there is any reasoning behind their actions related to the learning outcomes or if stations were simply entertaining (Chalufour & Worth, 2005). It is fine if stations are simply entertaining to the child, as they learn other valuable developmental skills - such as exploration, observation, cooperation, and fine motor skills. However, if there is reasoning behind their actions linked to the learning objectives, it is clearer to see that module has a strong educational impact in the areas of the learning objectives (Chalufour & Worth, 2005). A combination of taking down notes and asking the children questions will help our sponsor assess if they are benefiting/learning from the activities as they should. With this feedback she can also change how the children interact with the stations and modules and/or /how often they do so.

4.3 Evaluate TBT's Characteristics for Rainwater Catchment and Its Water Needs

In this section we will review the current watering system in place, discuss the results of our site analysis used to evaluate water needs and constraints, as well as our designs and the matrices used to evaluate them.

4.3.1. Current System in Place

The first site analysis of TBT provided information on the current water storage system, measurements of the garden, and an idea of what type of system Burris desired. The water storage system in place before our project existed comprised of two 1,000-liter units shown below in Figures 11 and 12.

Figures 11 and 12: **Current Watering System**
Image Source: Cassandra Salafia

The water is pumped up to the gardens from the beaver pond, stored in these containers, and then gravity fed to the garden via buckets and hand watering. This system utilized surface runoff water as the Beaver Pond is a natural collection area of surface water. The surface runoff water is accumulated from precipitation that flows over sloped landscape into the pond. A portion of the precipitation seeps into the ground to replenish the Earth's water table (Perlman, 2016). The rest of the precipitation becomes the runoff into the larger bodies of water. This is a more environmentally friendly option as Lisa's only other source is tap water. Not only is tap water expensive, it is heavily treated as it is intended for human use. This level of treatment is not necessary for farming (Sample, Personal Communication, Feb. 16, 2018). However, the potential for drought with no back up water option makes the beaver pond as the sole source of water not resilient in the face of extreme weather events, such as drought (Altieri, et. al, 2015). In addition, this system does not account for water distribution, such as irrigation.

4.3.2. Site Analysis

The goal of this analysis was to help determine the optimal location on the farm for rainwater catchment. The site analysis provided us with information to calculate how much water structures on the farm would collect, how much water the garden needs, and what kind of power is needed to make the system run efficiently. We then took measurements of the different farm structures, the garden beds, the distance from the barn to the garden, and the slope of the land.

We used these measurements, combined with overhead maps and blueprints, to collect the numbers needed for the calculations.

We used a Texas A&M Agrilife Extension site to determine how to calculate the average amount of collected rainwater and how much water the garden needed. While performing the site analysis at TBT, we mapped out the plausible locations to catch the rainwater. Based on distance to the garden and the area of the rooftop, we found two plausible locations, the barn and the structure located within the garden. The equation to calculate the average amount of water collected is shown below:

Harvested water (gal) = Catchment area (ft^2) * rainfall depth (in.) * 0.623.

The catchment area only depends on the length and width of the rooftop, the pitch of the roof affects how quickly the water flows into the gutters (Catchment Area, 2018). The barn structure, shown in Figure 13, has a 2,400 ft^2 catchment area. Rainfall depth is the total amount of precipitation and the number 0.623 is a conversion factor to get the total harvested water in gallons.

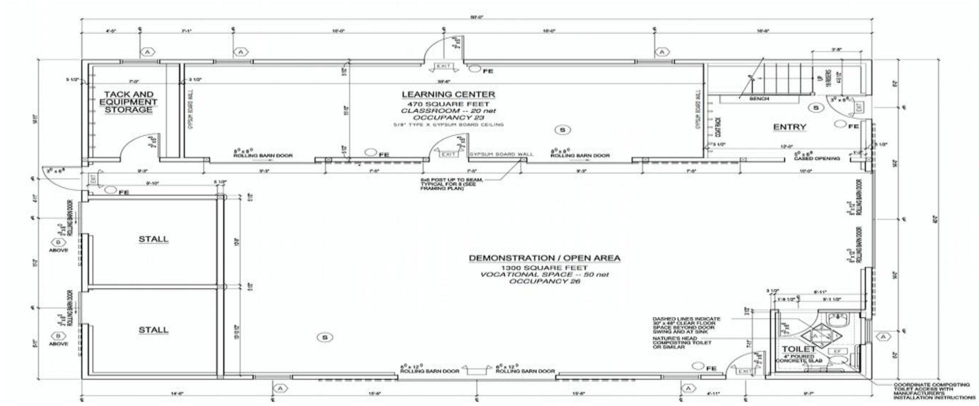

Figure 13: **Barn Blueprint**
Image Source: Lisa Burris

Figure 14: **Aerial View of the Farm**
Image Source: Google Maps

Taken from Google Maps, an overhead shot of the garden can be seen in Figure 14 above. On the image's right side, one can see the garden and its corresponding area. We visited the farm to take measurements of the garden and found the area to be roughly 9,000 ft^2. However, half of the square footage is walking space due to the garden raised beds.

Calculations provided by the University of California's Agriculture and Natural Resources department enabled us to determine the amount of water the garden should receive. During the summer months, at least 1 inch or 0.623 gallons per square foot of water should be applied over the surface area of the garden bed per a week (De Peyster, 2014). At TBT there are 2 different sized garden beds, a 104 square foot bed and a 36 square foot bed. To determine how many gallons each bed needs per a week, we multiplied the area of the garden bed by 0.623 gallons per square foot. The 104 square foot bed requires about 65 gallons per a week. Depending on how often the garden is watered, gallons per a week can be changed to gallons per a day or gallons per hour. These calculations were then then validated by Professor Sample, who is an assistant professor and extension specialist for Virginia Tech (Sample, Personal Communication, Feb. 16, 2018).

4.4 Designing and Building a Rainwater Catchment System at TBT that Meets Its Needs

In this section, we discuss how we developed the design for a rainwater catchment and irrigation system for TBT. We also discuss how we finalized the materials, how we purchased them, and how we built the catchment system with WPI's Engineers Without Borders team. The design presented here was created using the information from secondary sources, semi-structured interviews with extension agents, as well as by our site analysis.

4.4.1. Multi-Barrel System

We began our research by investigating the types of designs that are predominantly used, with a focus on low-cost systems and systems used for irrigating large garden plots. We found YouTube, a video sharing website, to be a great resource for this initial research, as designs are both explained verbally and visually. We supported these initial findings with information via interviews with extension agents. One design we explored was based on a multi-barrel system. This system used a series of pickle barrels (barrels of about 60 gallons initially used to hold vinegar to pickle cucumbers) to collect water off a rooftop, with the first barrel containing the first flush. The first flush system is used to divert any large contaminants, such as leaves, from the storage of the water (Notap, 2014). This system also consisted of PVC piping to the gutter, an overflow system, and vacuum tubing between the barrels. An example of a multi-barrel system is featured in Figure 15.

***Figure 15*: Multi-Barrel Harvesting System**
Image Source: Pintrest.com

Initially, our team believed we would utilize a multi-barrel system because the barrels are often relatively inexpensive or can be recycled from other purposes, such as the pickle barrels. However, we conducted further research on a secondary source website to help us avoid any hazards. We learned that if we used recycled containers, they needed to be opaque and designed to store water because this reduces potential algae growth, prevents toxins leaching into the water, and can withstand freezing temperatures (Tips for installing a rainwater collection system, 2009). Additionally, the secondary source warned against putting the system near objects children can climb on and areas they play in. Since the system will be installed on the barn's side, it is not located near any of the primary play areas for TBT's students. However, we determined that using gravity-fed system similar to the one in the previously mentioned video would create too large of a risk. The video's system placed all the barrels on a wooden structure several feet above the ground. With adventurism being encouraged at TBT, we worried that children may climb the structure, which could cause the barrels to possibly fall on them. Such an accident could cause fatal injuries, so we decided the system needs to be placed directly on the ground. However, this would require electrically powered pumps to disperse the water, and this will be discussed further in the next section.

4.4.2. Single Cistern System

A single cistern system is when one barrel or tank functions as the primary method for collecting rainwater (Young & Sharpe, n.d.). The single cistern system differs from a multi-barrel system in several ways, but the primary differences are the number of barrels and barrel size (Ciulla et. al., 2014). Often, the multi-barrel system is considered the more affordable option for residential gardens because it is easier to obtain recycled buckets or containers for a multi-barrel system than for a large single cistern system. This is typically the result of people either needing many small barrels or one large barrel to collect enough water. These were the trends we found from conducting secondary research on building rainwater catchment systems. However, it is possible to have expensive and large multi-barrel systems or to have small and inexpensive single barrel systems. The type of system depends on garden size, budget, and available space.

There are various materials available for the single barrel cisterns. Throughout our secondary research, we came across images of steel and clay cisterns. However, the WPI EWB team used a plastic cistern when they built rainwater catchment systems in Guatemala (Manning, 2012). Even though Guatemala experiences different weather patterns than Massachusetts since Massachusetts has extremely cold winters, we learned from our secondary research that plastic containers are ideal for freezing temperatures (Tips for installing a rainwater collection system, 2009). Therefore, we determined a plastic cistern would be best if we decided to select the single cistern system since it functions well under extreme heat and extreme cold. We did not further investigate the other material options since they were more expensive, and our other research supported using plastic.

Another difference between the single cistern and multi-barrel systems is how the system executes water distribution. The water needs a means to leave the catchment barrel(s), but this becomes increasingly difficult if the system is not gravity-fed. In this case, the system requires electrically powered pumps. Through speaking with Professor Sample, an assistant professor and extension specialist in rainwater catchment, we learned that a single cistern system would only require one automatic pump to disperse water from a non-gravity-fed system, whereas, a multi-barrel system would require a pump for each barrel (Sample, Personal Communication, Dec. 13, 2017). We learned that despite a recycled, multi-barrel system being more affordable through barrel-cost, it would become significantly more expensive than the single-cistern barrel, as the price increases by $100 per pump. Professor Sample estimated, based on our numbers, that we would need approximately ten barrels and ten pumps to distribute the water (Sample, Personal Communication, Dec. 13, 2017).

To determine which tank option would be the best suitable given our conditions, we developed a design matrix to highlight the main components of the two systems we proposed to our sponsor. A design matrix is a plot of all the variables to consider in making our design with respective advantages and disadvantages. These variables included irrigation compatibility, storage, collection method, filtration, and pumps, and highlight their advantages and respective prices. The design matrix can be found in Appendix C.

4.4.3. Irrigation System

During our project, we focused on the rainwater catchment system's compatibility with an irrigation system. Burris utilizes hand-watering for her current distribution method, but its inconvenient, inefficient, and takes approximately 2 hours each day during the spring, summer, and early fall. Burris finds that this watering often does not get done because other responsibilities, like teaching and managing the programs, take precedent. This results in a loss of crops, which are the materials Burris needs to run her programs. Adding an irrigation system will reduce the loss of crops due to lack of water, and it will allow Burris to use those two hours for teaching and program development. When we began our research, our initial criteria for irrigation systems was that were affordable and easy to maintain (Burris, Personal Communication, Oct 30, 2017). Burris also requested to be able to choose to connect the irrigation system to her current storage containers or her house's water supply through additional piping.

The first type of irrigation system our team investigated was the Quick Snap Sprinkler Kit, which was described visually and verbally through a YouTube video published by CNET. CNET is an American media website that globally publishes various, reviews, articles, podcasts, videos, etc. (CNET, 2016). This system includes an in-ground sprinkler with a hose connector. With this method, a large sprinkler is buried into the ground, the hose is attached, and an Orbit Single Dial Hose Timer controls the system. An Orbit is a water powered, rotating sprinkler with adjustable aim and swivel, to cover different areas with various dimensions. Essentially, it is timed water valve (Bennett, 2016). There are also hose adapters, which can connect the Orbit to any standard garden hose (Bennett, 2016). Despite this system being affordable and automatic, it is not the ideal solution. The water fans out of the sprinkler vertically and rotates horizontally. This distribution causes a general area to receive water versus targeting the specific plants/areas that need water. If the water does not penetrate the soil evenly, then water is wasted, and plants are improperly irrigated. Any water that goes deeper than the plant roots is wasted water and any water that does not penetrate to the bottom of plant roots results in brown spots or stressed plants (Mullarkey, 2017).

The second type of irrigation system we researched was Rain Bird's automatic sprinkler system. This system has 6 sprinkler heads that get buried in the ground along with a timer and hose connector attachments ("Rain Bird 32ETI Easy to Install Automatic Sprinkler System," n.d.). The kit sells for approximately $142, which is another affordable option. However, this system has a similar water-waste problem as the previous system, though it is better than the first system as the water is distributed over six smaller areas versus one large area. Another flaw with systems lies within the timer. While the timer allows the gardens to be watered without the time and oversight of a person, it cannot adjust to changes in weather, which can result in the garden being over or underwatered.

The third system we looked researched was a soaker hose, which was recommended to us during our interview with Professor Sample (Sample, personal communication, December 13, 2017). The soaker hose kit comes with 25' of 0.5" PVC garden hose, 50' of 0.5" recycled rubber soaker hose, and plastic connectors ("Snip-n-Drip Soaker Hose Watering System | Gardeners.com," n.d.). This costs about $40, and additional sets of six couplers can be purchased for about $10.The advantage to soaker hose is that water seeps out of holes in the hose material. This allows for targeted watering of plants, as the hose is placed around grouping of plants and waters the soil in those specific areas. However, these hosing kits can only be divided into four watering zones, and Burris's garden will require more than four zones, as the gardens consist of approximately 30 beds and distinct plant areas. This means Burris would need to buy additional hose kits and couplers, increasing the price eightfold.

The fourth system we researched was a drip irrigation system, another method recommended to us by Professor Sample. The drip tape provides the targeted watering of crops, reducing the volume of water used. The drip tape waters the soil, not the leaves, reducing the incidence of plant disease, soil erosion, and nutrient leaching (Harper et al, n.d.). We analyzed a variety of drip tape styles based on Burris's needs and set up, as well as by considering the limitations of the other irrigation methods. Analyzing a well-known and highly rated commercial supplier of drip tape (Drip Depot: https://www.dripdepot.com/), we found that a buyer can customize his/her drip tape purchase based on its wall thickness, emitter spacing, emitter flow, and roll length ("Irritec P1 Ultra 5/8" Drip Tape," n.d.). Wall thickness is specified in mils, a mil is a thousandth of an inch, and it is the thickness of the drip tape. The emitter spacing is the distance between the openings in the drip tape, they are typically spaced every 8 to 16 inches. Emitter flow is specified in gallons per a minute per 100 feet of tape (gpm/100 ft), the flow ranges from 0.2 to 1.0 gpm per 100 feet. Roll length is the actual length of the drip tape, in a typical kit the roll length is 100 feet of drip tape (Harper et al, n.d.). Based on these selections, the cost for the tubing is between $100 and $300. Though the drip tape is more expensive than the other options, and additional hoses would need to be purchased to make sure the entire garden is accounted for. Since the roll length of drip tape is 100 ft, three rolls of drip tape should be sufficient for the entire garden. Three hose attachments and connectors would also need to be purchased, but they are low cost at less than $1 each. In the end, the cost between the different systems are going to be roughly the same.

Irrigation System	Cost
Quick Snap Sprinkler Kit with 5 sprinkler heads	$119.66
Rain Bird automatic sprinkler system	$141.90
Soaker Hose Kit	$54.95
Drip Tape Irrigation Kit	$32.31

***Table 1*: Cost of Each Irrigation System**

With all system's costs being close to equal, we found the drip tape to be the best option for efficient, targeted watering. Like the soaker hose, drip tape offers more targeted watering by releasing water through outlet holes. The outlet holes are closed by small flaps when water pressure is not applied. This method of releasing water causes less wasted water than the sprinkler systems. However, unlike the soaker hose, the drip tape is buried in the soil. Therefore, the water directly wets the soil around the vegetation, and this causes the plants to receive water faster, and less water is wasted through surface evaporation. Also, most fuzzy-leafed plants and vegetables do not like to get their leaves watered (Wisdom, 2012). The plants can rot away if their leaves are watered more than their roots. Burris's garden contains plants that need to be watered at the root. As a result of our analysis, our team chose a drip irrigation as Burris's best irrigation option.

4.4.4. Final Design

We presented Burris the various systems but recommended she choose the single cistern system with the drip irrigation. For the system, we recommend Burris purchase a 2100-gallon plastic tank. We chose this size because it would hold almost enough water to maximize the rooftop runoff and to function as the garden's primary water source. However, we did not select a larger tank that could possibly further maximize the rooftop runoff because a larger tank would assume that Paxton, Massachusetts receives the same amount of rain every week. For the difference in cost and high probability the tank would not be completely utilized on a regular basis, we opted for a smaller size. We chose a Norwesco tank for approximately $976, but Burris opted for a different tank due to the Norwesco one requiring an additional $400 for shipping. Burris selected a 1550-gallon tank from the Tractor Supply Store having a cost of about $800 and in-store pickup. This tank is made of polyethylene (plastic) and is an opaque white color, therefore, it meets our other recommendations for the single cistern system.

Additionally, we recommended Burris purchase an overflow bag, which we discovered in the video mentioned in the multi-barrel system section (Notap, 2014). The overflow bag curls up and connects to the catchment system. When the system is filled, the bag unwinds and fills with water. However, Burris decided she could connect her existing water-storage containers to the system for overflow. She decided that she and her husband will determine how they want to attach the additional containers after the initial build occurs. Therefore, the overflow is no longer within the scope of our project.

During our research, we learned that WPI's EWB team constructed a concrete base for their systems in Guatemala (Manning, 2012). This provides a level surface for the system, but we felt the ground outside TBT's barn was fairly level. Throughout our research, we also came across images of single cistern systems resting on sand. When we discussed the system with current EWB members, they felt the concrete base would be unnecessary and excessive for TBT's property (Harting & Ismail, personal communication, February 19, 2018). The believed either no base or the sand would both be suitable options. We discussed these options with Burris, and we decided on using sand, as it is easier to level and cheaper to purchase.

When suggesting the system to Burris, we provided a system that was easy to use with either a timer or a manual valve. This is import for solving Burris's problem about how watering is a time commitment. Burris would be able to set a timer if she chooses, and it would cause the water to release from the tank into the drip irrigation. However, we did not include the timer in the initial design because it is not necessary for the functionality of the system. The timer is an aspect Burris can add to the system if she feels it is necessary for her busy schedule. The pump can be manually turned on and off when she chooses the utilize the water.

For the water distribution to the garden, we recommended drip tape irrigation. This is one of the most cost-effective options and is relatively easy to install. Additionally, drip tape is the most water efficient irrigation option and this was discussed in the irrigation section. By utilizing the most water efficient option, the water stored in Burris's tank will last her longer during the growing season. Burris agreed to use this option.

4.4.5. Fundraising and Building Assistance

Our team initially planned on both designing *and* building the rainwater catchment and irrigation system during our project. However, this was not a feasible option with our sponsor's budget. Burris had a barn built at TBT during our project, and this was a large expense at approximately $100,000. However, our team and project advisor saw value in implementing the system this year, so we worked with other organizations to make this happen.

Our project advisor, Lisa Stoddard, worked with Burris to secure grants for to fund the building of the catchment and irrigation system. They have received three grants: one from Staples for $1500, a second from Country Bank for 100 dollars, and a third from Flexcon for $250. Additionally, Burris held a fundraiser and silent raffle and raised $2300. The money raised will be used to pay for the catchment and irrigation system materials. However, we still needed to bring in builders who have experience and expertise in building large scale rainwater catchment systems. We contacted Worcester Polytechnic Institute's Engineers Without Borders (EWB) team to see if they would be interested in leading the building of the system. WPI's EWB team has over five years of experience building large-scale rainwater catchment systems in Guatemala (Bringing water to Guatemala, 2016). In addition, EWB plans will be going to Ecuador in August of 2018 to install large scale rainwater catchment systems in local communities. As a condition of their trip, new members, who did not participate in the Guatemala project, must have experience installing a local rainwater catchment system before traveling elsewhere to install more (Harting & Ismail, personal communication, February 19, 2018). This requirement was established to prevent EWB teams from being ill-prepared when traveling elsewhere to do work. Therefore, we collaborated with EWB in the building of the system, using their expertise in rainwater catchment construction and our expertise in the system for TBT specifically.

The actual build took three days. The first day was May 26, 2018. T, May 26, 2018, June 2, 2018, and Jun 16, 2018. Build day number one, May 26, 2018. The crew for this day consisted of our team, EWB, our sponsor, our advisor, and a fellow WPI student. We were able to put up a large portion of the collecting pipe on the barn's exterior. The images of this build can be seen in Figures 16 and 17.

Figures 16 & 17: **Construction Day 1:**
Beginning to Construct Collection Piping
Image Source: Emilia Perez

This lead to build day number two, June 2, 2018. The crew for this day included half of the team, our advisor, our sponsor, and a volunteer local retired mechanical Engineer Peter Mimeault. Mimeault was asked to join the build portion of the project by our advisor because he has previous experience with similar systems and so he could help us to evaluate each part of our work plan. We finished up the rainwater catchment and storage portion of our system on this day. The images of this build can be seen in Figures 18, 19, and 20.

***Figures 18 & 19:* Construction Day 2:**
Finishing Collection System
Image Source: Lisa Stoddard

***Figure 20:* Construction Day 2:**
Moving Barrel into Place
Image Source: Lisa Stoddard

Mimeault continued to assist leading up to and throughout build day number three, June 16, 2018. The crew consisted of one team member, our sponsor, our advisor, and Mimeault. Leading to this day consisted of the preparation for an efficient and working piping and pumping system. With Mimeault's input, we improved the piping and pumping design. This day consisted of finishing up the system and ensuring the water is pumped across the farm's roadway successfully. The pump functioned, and the construction was over. The images of this build and final product can be seen in Figures 21, 22, 23, and 24.

Figures 21 & 22: **Construction Day 3:**
Piping Leading to Overflow and Irrigation Connection (left)
and Profile of Barrel Where White Is Collection Pipe and Black Is Delivery Pipe (right)
Image Source: Virginia Adams

Figures 23 & 24: **Construction Day 3:**
The Final Piping and Irrigation (left) and Collection and Storage (right)
Image Source: Peter Mimeault

5.0 Conclusion

In this section we discuss the limitations of our project. We also include next steps that we believe will help to address these limitations. Finally, we discuss the significance of the project.

5.1 Limitations

When engineering, it is important to follow the Engineering Design Process. This process includes the following steps: defining the problem, brainstorming, planning, creating, testing, and improving (May, 2017). We have completed the first four steps for the rainwater catchment and irrigation system: 1) defining the problem of water resilience, 2) brainstorming possible water systems, 3) planning and designing a rainwater catchment and irrigation system, and 4) building said system. However, proper engineering practice means completing all the steps. In attempt to help complete the steps of testing and revising, we gave Burris some criteria to watch for. These criteria include signs of inefficiency or improper function, freezing in the winter, water quality, ease of use, fill frequency, and how the water is used. With these criteria, Burris can see where the problems in the system are and create measures to improve said system. Unfortunately, we were unable to test and revise our system, as our project had time limitations. With these limitations we had to prioritize, focusing on the building the system and two STEM educational modules while writing the report.

The process for creating the educational modules was different from the engineering design process for the rainwater catchment system. For module design, the following concepts should be defined in the context of the problem, learner needs, teacher needs, institution needs, desired learning outcomes, underlying learning theory. After this is defined, the assessment can be created, with the learning outcomes and theory, and should be implemented (Donnelly, & Fitzmaurice, 2005). We have defined the learner needs, teacher needs, and institution needs by looking at the age and ability of the children and the structure of the farm. We also defined the necessary learning outcomes, theory, and created the criteria for the assessment. However, due to the time limitations stated before, we did not have enough time to fully construct and implement the assessment. We gave Burris criteria with areas to be assessed and she has measures in her school that she will use in this context, such as the desired learning outcomes for each module.

5.2 Next Steps

For this project, the next steps would be to assess the educational components for effectiveness and the rainwater catchment design for function. We recommend that Burris and Johnson (a certified preschool teacher at TBT) use our module assessment tools to evaluate if and how the modules and stations are meeting the intended learning outcomes. We also recommend that they make observations to identify any additional, unexpected learning outcomes. After the modules and learning stations have been evaluated by Burris and Johnson, we recommend they (alone or with another student team) revise the modules and learning stations and assess learning again. They can continue this process of assessment and modification to modify the modules and stations to meet students' and the programs' changing needs and interests.

As for the rainwater catchment system, the criteria give to Burris should allow the system to be tested and thus revised. This would complete the last two steps of the engineering design process, improving the overall quality of the system. Lastly, the close relationship with WPI will be maintained through the Center for Sustainable Food System. This relationship will allow creation of subsequent projects to further assess and modify they system if necessary.

5.3 Project Significance

We designed a rainwater catchment system that provides an additional water source and efficient irrigation system for TBT's gardens, making the farm more resilient in a changing climate and ensuring TBT can offer the educational programs and opportunities that have proven to provide cognitive, physical, mental, and emotional benefits to children, including those with exceptional needs. Prior to this system, Burris spent 1 to 2 hours a day watering, a laborious task. This time commitment took her away from her running and expanding her educational programs. The catchment system will give Burris back that time, reduce her manual labor, and ensure the gardens, and therefore the farm and nature program, are kept alive and robust.

The irrigation systems, in addition to the second water source, has increased the farm's resilience in the face of drought. The system is flexible, allowing the irrigation drip tape to attach to multiple sources including: the rainwater catchment system, the beaver pond, municipal water, and any other future sources developed. The drip tape also provides the targeted watering of crops, reducing the volume of water used. The drip tape waters the soil, not the leaves, reducing the incidence of plant disease, soil erosion, and nutrient leaching (Harper et al, n.d.). We also aimed to increase the impact of our design beyond TBT by sharing our design with extension agent Professor Sample, who has given us key insights and support. He asked to see our final designs and results so that he may pass them on to the farmers he works with, as well as other extension agents (Sample, personal conversation, December 2017). Our hope is that this will allow others in the agricultural community to have a watering and irrigation system that can make their farms more resilient in a changing climate.

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Appendix A: Interview with Sponsor Lisa Burris 9/21/2017

Unstructured Phone Interview

To learn more about Lisa and her background on the farm, we composed the following questions to ask her:

1. Could you elaborate more on your educational credentials and background with farming education? Particularly your degree?
2. Could you tell us, in depth, how your decision to adopt arose and how it inspired you to create the farm?
3. Could you share with us a couple of programs on the farm, and explain how they help with their basic life skills? (Risk-taking, confidence, social skills, etc.)
4. Do you know of any additional sources that might be able to help us with our research?
5. You mentioned how the children chose the activities for the day, but is there a base plan for the day? Do you have a rough structure for what the children will be doing?

Appendix B: Catchment Carl Module

Lesson Plan: Rainwater Catchment System

Lesson Name: Learning with Catchment Carl

Designed for Ages:
3-8 years

Learning Objectives:
Students will learn how a rainwater catchment system functions and why the system is important. Additionally, students will learn about the water cycle's different stages.

Materials:

- Artificial grass strip that does not absorb water for at least 5 minutes
- Functioning rainwater catchment system prototype
  - A smiley face is added to the front of the prototype to create "Catchment Carl"
- Hose extension for rainwater catchment system between 7 inches and 12 inches long
- Cloud shaped sponges
- Bucket
- Water
- Small roof-like structure
  - Includes a "gutter system" made of PVC piping or rubber tubing cut across its diameter
  - Must be at least 3 inches taller than the rainwater catchment system prototype
- Additional PVC piping or rubber tubing (un-cut)
- Rainwater catchment poster featuring:
  - An internal view of the rainwater catchment system
  - Raining clouds
  - Ground with grass and flowers
  - Rooftop structure
  - The stages of the water cycle
  - Labels indicating the different parts of the rainwater catchment system
  - Brief descriptions of the parts' functions
  - Arrows demonstrating the flow of water into, through, and out of the system

Setup:

- Artificial grass strip is placed on a flat, stable surface.
  - Make sure this is low enough to the ground that the students can reach above the roof structure's "gutter system" once it is place on the grass.
- Rainwater catchment system is placed on top of the grass.
- The hose is attached to the front of the rainwater catchment system.
- The roof structure is placed above the rainwater catchment system while touching the grass.
- The cloud sponges are stored in mesh pockets on the sides of the rooftop structure.

- The roof structure's "gutter system" is attached to the rainwater catchment system's opening with the additional PVC piping or rubber tubing.
- The water bucket is placed near the rainwater catchment system where the students can easily dip the sponges into it.
- Put the poster on a wall near the rainwater catchment system.
    - Make sure the system does not obstruct students' view of the poster.

Lesson Introduction (10 minutes):

- Students are gathered and brought to the rainwater catchment system prototype.
- Instructor will say something similar to, "Today, we're going to learn about rainwater catchment from Catchment Carl!"
- Ask the students if they know anything about rainwater catchment.
    - This will be more applicable to schools that already utilize a full-sized rainwater catchment system.
    - If students do not know anything about rainwater catchment, tell them not to worry because Catchment Carl will help them learn about it!
- Other questions to ask the students in order to gauge previous knowledge include:
    - Who knows about the water cycle? Does anyone know the different stages of the water cycle?
        - Sought after response: evaporation and transpiration → condensation → precipitation → subsurface flow and infiltration
        - It is unlikely the students will provide all these responses. Acknowledge that students correctly identified stages and tell them there are even more stages they are going to learn about today!
    - Where does rain come from?
        - Sought after response: the clouds
    - What usually happens to the rain that falls during a storm?
        - Sought after responses: the ground, other bodies of water, and sewer systems
        - Inform the students about any of the missing responses

Explicit Instruction/Instructor Modeling (10 minutes):

- Draw attention to Catchment Carl.
- Explain that Catchment Carl loves saving water because stored water can help gardens, animals, and people long after a rainstorm! By having rainwater catchment systems like Catchment Carl, rainwater gets saved instead of going into sewers or instead of overwatering certain parts of the ground.
- Grab a "cloud" and dip it into the bucket. Let the students touch the cloud to feel it is wet.
    - Let the students grab and wet any additional clouds. They can hold them or play with them during the explanation. Tell them to avoid squeezing the clouds for now because Catchment Carl needs the water later.
- Explain how water evaporation causes the water from the ground and other bodies of water to enter the air and then the clouds.
- Also, explain how transpiration causes water to leave plants and enter the air and clouds.
- Squeeze the cloud over the roof structure to simulate rain.

    - Introduce this step by saying something similar to, "Now, it's about to rain!" This gives you the opportunity to explain how rain is a form of precipitation.
- Continue filling the clouds with water and squeezing them over the roof. Let the students squeeze their clouds onto the roof now, too!
    - As this happens, explain how Catchment Carl is a rooftop runoff system because rainwater travels off the rooftop (as runoff), into the gutters, and then into the rainwater catchment system.
- Once there are a few "clouds" worth of water in the system, explain that the water is now stored in the system until it is ready for use.
- Guide the hose over the grass.
- Twist the valve to release the water.
    - For older groups, consider explaining the concept of "first flush." This is how the system gets rid of debris from the roof before the water can be used for animals and people. The system releases the dirty water first for living creatures to only use clean water.
        - People and animals cannot drink directly from the rainwater catchment system because the water should still be sanitized. Make sure the children understand this to keep them and nearby animals safe.
    - The water on the grass can be used to explain how water traveling below the ground's surface is subsurface flow. Then, infiltration can be described as how the water will work its way down into the soil and rocks below the grass's surface.
- Once the water is on the grass, press a "cloud" onto the grass.
- When enough water is in the cloud, squeeze the cloud over the system again. Draw attention to how this is continuing the water cycle through evaporation and transpiration again.

Guided Practice/Interactive Modeling (5-10 minutes):

- At this point, the students have been walked through the system once. Give them about 5-10 minutes to play with the system on their own. They can try adding water to the system. They can also try draining the system with the hose.
    - Consider bringing over some potted plants and letting the students water the plants with water from the rainwater catchment system.

Assessment (10 minutes):

- Ask the students to show each step of the water cycle once you announce the step.
    - Ex: You announce evaporation, and the students will fill the clouds with water.
- Ask the students the questions from the beginning if they did not know some of the answers in the beginning. If someone did know the answers in the beginning, ask other students to try answering them. (Questions can be asked in a different order.)
    - What is rainwater catchment/what does it do?
    - How does rainwater catchment help living creatures?
    - Who knows about the water cycle? The different stages of the water cycle?
    - Where does rain come from?
    - What usually happens to the rain that falls during a storm?

Follow-up Activity (10 minutes):

- On a different day, try reviewing the water cycle through utilizing the poster.
- Point to the different stages of the water cycle on the poster and then simulating them with the prototype.
- Go into additional detail discussing how the rainwater catchment system works. Point to the parts of the system mentioned on the poster. Explain their function. Then, simulate with the prototype.
- On different days, further assessment can occur by reviewing the poster and asking students to share what the different water cycle stages are and what the different rainwater catchment parts are.

Aspects to Include in the Final Lesson Plan:

- Pictures of the setup
- Pictures of the activity being demonstrated
- Picture of the poster

Appendix C: Design Matrix for System

Options	Design 1	Design 2
Irrigation options	Drip tape --Diameter: 1/4 in. -Can be buried into the ground near garden beds -Uniform water distribution -Low pressure requirement - Length: 100 ft. - Kit contains: 100 ft. drip tape, barb tubing coupling, barb tubing tee, goof plug, Inline hose filter, 6 in. micro-tube stabilizer, and a hose thread. -Maximum flow capacity: 30 gallons per hour -$32.99	Soaker Hose -Diameter: 3/8 in. -Length:100 ft. -Kit contains: 100 ft. soaker hose, 6 male couplings, 2 female couplings, 2 feeders and 2 T connectors -Conserves up to 70% of water -Waters at the roots -Hose between garden beds can be buried so kids do not trip on them -$31.99
Storage options	2100 Gallon Cistern -87 in. diameter x 89 in. height -1 inlet, 1 outlet, 1 manway/lid -Weighs 290 lbs -$969.99	550 Gallon Cistern -67 in. diameter x 44 in. height -1 inlet, 1 outlet, 1 manway -Weighs 99 lbs -$369.99
Collection Options	Industrial Gutters -Industrial gutters will be added to the barn -unsure of dimensions, must be larger than traditional house gutters with the size of the roof (two 62x28ft faces)	Industrial Gutters -Same as design A
Filtration options	Leaf eater and downspout -7.6 in. length x 6.6 in. width x 12.6 in. height -Weighs 4 lbs -Single screen deflects debris away from the flow of water -Minimizes maintenance and enhances catchment efficiency -Suits both vertical or Horizontal downspout. -$29.99	First Flush Diverter Kit -Utilize a ball and seat system -The diverter chamber empties through a slow release valve and can be connected to an irrigation system -For a 2400 sq. ft. roof area, about 120 gallons needs to be diverted. (need a large downspout to hold the 120 gallons) -Kit comes with complete instruction manual -$19.99
Pump options	A soaker hose would require a pump of no more than 25 psi. A submersible 25 psi pump should cost $300 at most, depending on the flow rate of the pump.	A sprinkler would require a pump providing between 30 and 50 psi. A submersible pump for this pressure requirement would cost slightly more than that for a soaker hose, but not by a significant margin.

Appendix D: Educational Stations Materials List

Water Wall Materials:

- Wooden pallet (donated)
- Sandpaper
- Screws
- Various plastic containers and tubes
- Green spray paint
- Wood sealer spray

Catchment Carl Materials:

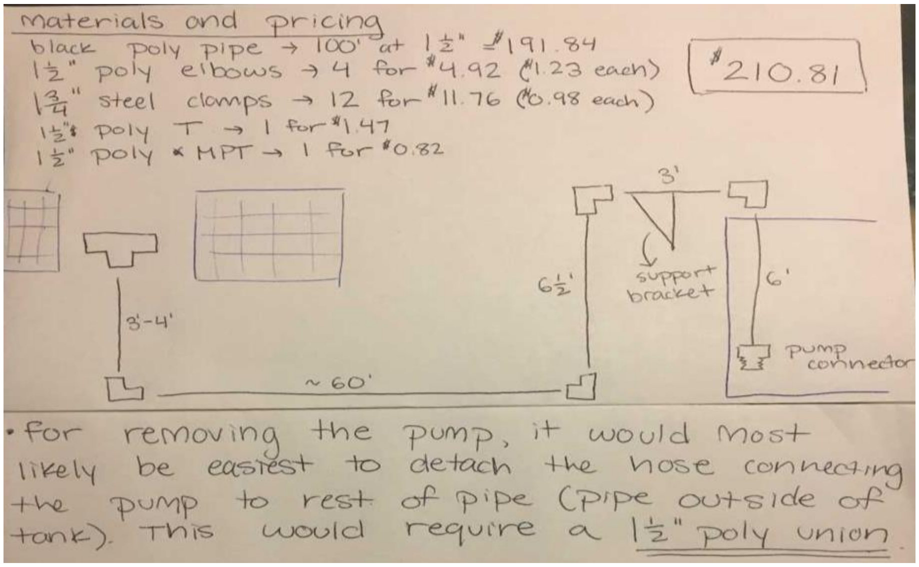
- Bucket (donated)
- Wood (from TBT)
- Shingles (from TBT)
- Paint (from a teammate)
- Screws
- Plastic downspout
- Plastic filtration mesh
- Spigot

Appendix E: Materials List for Rainwater Catchment System

- 1500 Gallon Cistern
- Two 4 in. Round Leaf Eater Advanced Rain Head
- 2 in. x 50 ft. Strongway PVC Discharge Hose
- Eight 4 in. x 10 ft. PVC Schedule 40 Plain End Pipe
- Seven 4 in. x 10 ft. PVC Schedule 40 Sewer and Drain Pipe
- Wayne 3/4 HP Submersible Sump Pump
- Black poly plumbing pipe
- 1 ½ inch poly T joints
- 1 ¾ inch steel clamps
- 1 ½ inch poly elbow joints
- 1 ½ inch poly and MPT connector
- 1 ½ twist off plug
- Eight Fernco 4 in. x 4 in. PVC Mechanical Flexible Coupling
- Three NIBCO 4 in. PVC All-Hub 2-Way Cleanout Tee
- Fernco 1-1/2 in. x 1-1/2 in. Flexible PVC Coupling
- NIBCO 2 in. x 1-1/2 in. PVC Reducing Coupling
- NIBCO 4 in. x 2 in. PVC Reducing Coupling
- Two DIG 1/4 in. x 100 ft. Poly Tubing
- Two NDS 4 in. PVC 90- Degree Hub x Hub Long-Turn Elbow
- Two 4 in. Drain Fitting Cleanout PVC
- DIG 1/2 in. Compression End Cap
- DIG Drip and Micro Sprinkler Kit

Appendix F: Pump Design Sketches

First design sketch:



Second and final design sketch based on feedback from sponsor, advisor, and Mimeault: