Creating a Pest Resilient Garden at Turn Back Time to Support Nature-Based Education Programs

An Interactive Qualifying Project

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by

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2. Abstract

Nature-based education creates novel opportunities for problem-solving, environmental education, and is critical to social and behavioral development. Turn Back Time is a farm and nature education center, with gardens that provide much of the context for learning. Due to pests, the garden is not yielding the produce needed to create opportunities for learning. We designed and built a novel predator proof-garden system that is designed for efficiency and enhanced learning opportunities.

3. Executive Summary

3a. Introduction

Turn back time (TBT) is a 58-acre farm and nature school that provides critical education experiences for children ages three to thirteen. The farm's gardens, animals, forests, beaver pond, and hiking provide the context or "textbook" for the children's learning. Due to lack of a sound garden structure and predator protection, each year, the farm loses the majority of their crops to wildlife. The director of TBT, Lisa Burris, asked our team to help research, design, and build a predator-proof garden enclosure and educational feature gardens.

TBT's programs offer children a chance to appreciate nature, an entrance to environmental advocacy, and a place for children with special needs to learn and grow outside of a traditional education system. By being exposed to nature at a young age, children grow comfortable being outdoors, in the woods, and around animals, which leads to an appreciation of nature later it in life (Strife & Downey, 2009). The early exposure and appreciation of nature as a child often results in adults who are passionate about the environment and who serve as environmental stewards (Wells & Lekies, 2006). The open space the farm uses for nature education, and the increasingly rare opportunities for children to engage in unstructured play (e.g. climbing trees, making mud pies, rolling down hills) helps provide an outlet for a child's excess energy. This farm's environment leads to better focus, concentration, and the overall mental health of the children who attend (Strife & Downey, 2009).

3b. Project Goals and Objectives

TBT's garden is currently unable to provide all possible learning opportunities due to its state of disarray. Figure 3b shows the deteriorating garden beds and predator fencing, as well as weeds that are taking over the garden. The sponsor believes that the time, money, and resources used each spring, summer, and fall to prepare, grow, and maintain the garden is not worth the minimal payoff (Burris, 2018). The little produce the garden does yield is ravaged by pests almost immediately.

Figure 3b: Picture of the Garden at TBT in disarray (Zimak, 2018).

The goal of this project is to assist Turn Back Time Farm with the implementation of an innovative garden design aimed to improve productivity, labor efficiency, educational opportunities, and pest management. We worked to achieve this goal by first determining the best garden layout based on shade and light areas, bed dimensions, accessibility for children and equipment, and pest management. We used these criteria to create a garden layout and a comprehensive garden plan. We then designed two unique feature gardens that showcased alternative methods of growing produce to engage children in agriculture. Finally, we gathered materials and constructed the planned garden, which included the raised beds, an improved fence, and an aerial enclosure. The garden's improved productivity will help develop a community-supported agriculture plan (CSA) that will help fund more of their educational programs.

3c. Literature Review

The literature review contains a brief discussion about our sponsor, Turn Back Time (TBT), their programs as well as current garden practices and problems at TBT. It also holds a discussion on how those problems in the garden create a loss of educational value on the farm. This section closes with a review of garden design principles regarding water and pest management, which guide research into resolving the problems of the garden.

Turn Back Time serves over 500 children and exposing them to almost 9,000 hours in nature through eight different programs. Participants in 2018 consisted of over 30% coming from underserved populations, including children with a documented diagnosis and children living below the poverty line. " (Burris, 2019, p. 1). There are three major problems with the current garden at TBT that affected the functionality of the garden. To start, the structure and design of the garden beds provided optimal growth conditions for weeds. The garden currently uses a lasagna style gardening technique, consisting of multiple layers of soil and natural compounds (Burris, personal communication, December 13, 2018). The layers are built from cardboard, twigs, leaves, compost, yard waste, and topsoil. The cardboard is intended to prevent weeds from entering the garden from below (Vanderlinden, 2018). Usually, this is an effective gardening method. However, the current beds are so low that weeds easily invade the beds and choke out any plants trying to grow there.

Secondly, the current garden pest protection measures are inadequate. Pests enter and exit the garden leisurely. As a result, pests such as deer, birds, rabbits, and rodents are eating the plants and fruits days before they are ripe (Burris, personal communication, December 13, 2018). There is only a single deer fence that marks the boundaries of the garden area. This fence provides little if any pest protection from underground, above ground, or from the air. Finally, the garden lacks a solid plan for water and nutrient management. While there are significant rainwater collection and recycling infrastructure on the farm, the implementation of these resources in the garden is inefficient (Burris, personal communication, December 13, 2018).

Garden design literature shows two superior approaches for constructing the raised beds using natural materials found on the farm, or milled lumber. Natural materials include stones, branches, and logs. These materials are perfect for low-cost garden boxes as they are often readily available. However, natural garden boxes often require a lot of time to set up and maintain in addition to being geographical stuck where they are set up, do to weight. Milled lumber such as 2x4s and other standard building cuts are easy to purchase and will create a garden with a clean look. Additionally, these beds will be light enough to be moved if necessary. The biggest drawback of milled lumber is often the cost. The use of raised beds, regardless of design, would keep the garden more organized and make maintenance easier (Smith, 2009).

The literature also discusses the benefits and limitations of different pest management techniques (Parker et al., 2013). First, with indirect pest management, predators are attracted to the garden and encouraged to resolve the pest issue through natural processes. The downside of this natural pest solution is that predators will be abundant in the area. something that should be avoided to maintain the safety of any children present. Direct pest management involves discouraging pests from staying in the garden area and can be accomplished through companion planting, pest resilient infrastructure, and scaring mechanisms. Companion planting involves utilizing plant combinations that share natural pest protection features to benefit each other. Pest resilient infrastructure may be a fence, netting, or anything that prevents pests from entering the garden area. Scaring mechanisms involve light, noise, or motion devices that startle smaller pests and discourage them from staying in the garden area.

In terms of water management, the literature notes two approaches for water sustainability in the garden. The first method would be the reduction of hard surfaces in the garden such as clay and rock will assist in the absorption and retention of water in the soil. Hard surfaces prevent water from absorbing into the ground, which can lead to poor soil moisture in some places and runoff, leading to pooling and oversaturation in other places. The second method would be the use of in situ water harvesting, the practice of increasing rainwater uptake in soils by increasing the surface area through the creation of small reservoirs in between crop rows (Climate Technology Centre & Network, 2017). These reservoirs refill during rainstorms while transferring water to crops at a steady rate naturally.

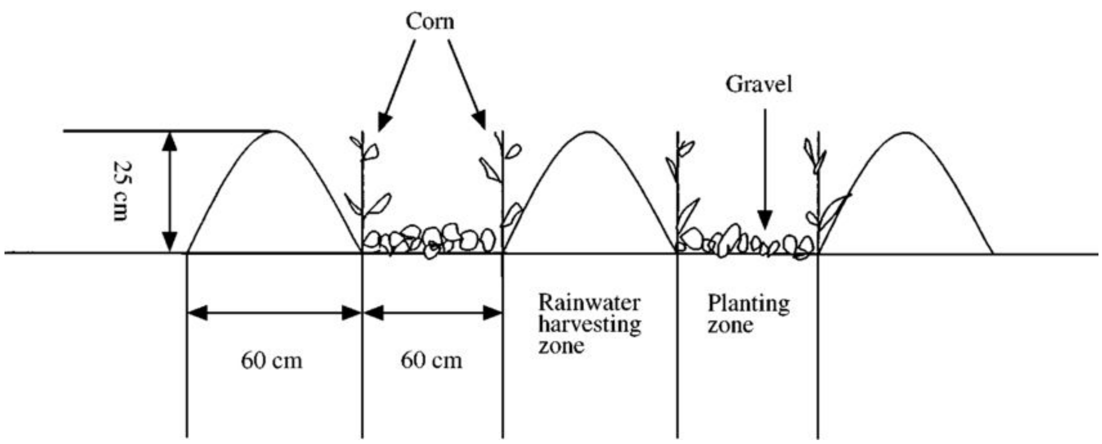

Figure 3c. “Schematic diagram of in-situ rainwater harvesting combined with gravel mulch system” (Li, Wei, and Gong, 2000).

The reservoir comes with the drawback of additional maintenance, and will only work on a relatively flat grade.

3d. Methods

In order for our team to effectively collaborate with Mrs. Burris, we had to understand the best practices associated with constructing pest resilient raised bed gardens. We had to factor shade and light areas, bed dimensions, accessibility for children and equipment, and pest management. To determine shade and light areas, we used satellite images and help from Mrs. Burris to create a map that displayed the amount of sun each part of the garden receives. To determine the ideal bed dimensions for productivity and accessibility we interviewed gardeners with growing experience in New England. To design for pest management, we interviewed Turn Back Time staff in regards to current pests, and we interviewed gardeners and farmers on other properties to learn how they dealt with similar pests. To learn how to make feature gardens engaging to children, we interviewed experts in the field of farm-based education. We also utilized gardening books, academic agricultural journals, and university agricultural extension websites as secondary sources.

After our research and interviews were completed, we presented our designs Mrs. Burris who shared them with her team of board members, farm educators, and project managers. We also had our designs reviewed by experienced engineers and builders. Based on multiple rounds of feedback, we revised our designs, including the fencing design and garden bed design, five times. Once the designs were confirmed, we created a materials list and visited multiple garden stores, including Home Depot and Lowes, to request a discount on our approximately $5,000 purchase. We were able to secure a 25% discount from Lowes. After the materials were delivered to Turn Back Time, we worked from April 13 to May 22 with volunteers and staff at Turn Back Time to dig trenches for the fence posts, pour concrete and set the fence posts, build twelve garden beds, install the fencing and bird netting, and build the feature gardens.

3e. Results and Recommendations

Our team has three main recommendations for our sponsor. The first is the pest-proof garden design plan. This design incorporated all of our findings regarding shade and light areas, pest management, and shade and light areas for the garden were determined through semi-structured interviews with Mrs. Burris in the garden. Our final proposed design is below.

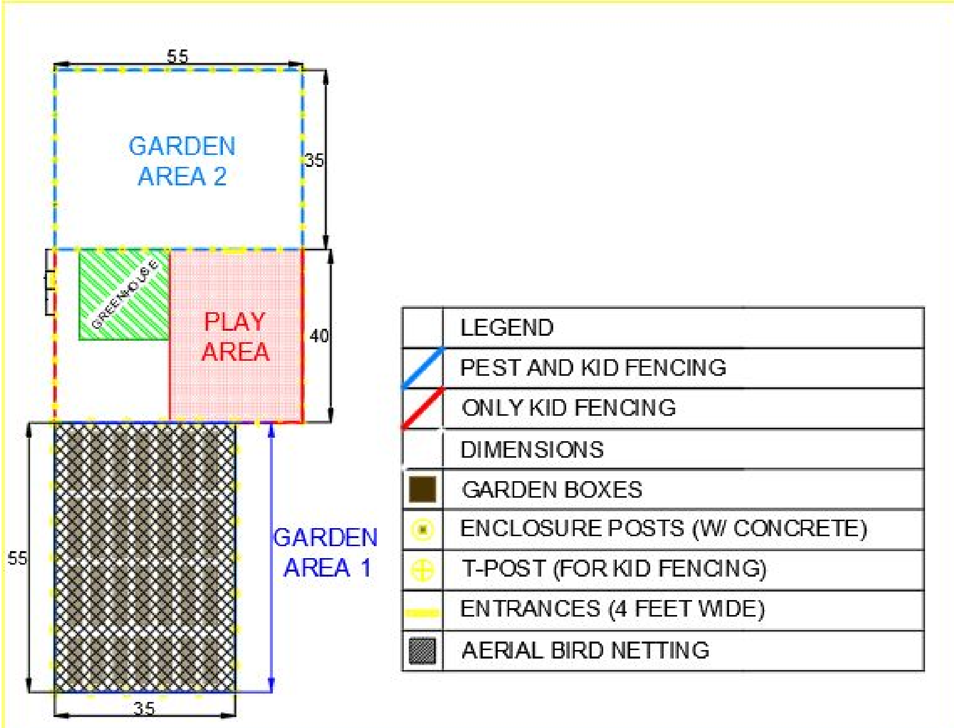

Figure 3e.i: Proposed to scale garden plan for Turn Back Time (Zimak, 2019)

Mrs. Burris was able to point out that the area closest to the barn received the most sun while the forest side got the least sun (Burris, personal communication, December 13, 2018). From the information collected in our interview, we were able to create a sun chart for selecting plants below, Figure 3e.ii.

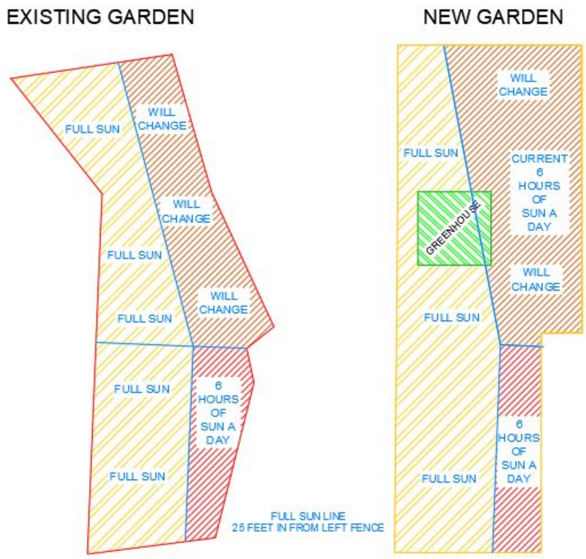

Figure 3e.ii: Sun model for the original garden (left) and the newly built garden (right). These charts will be used when selecting plant locations and feature garden locations. (Zimak, 2019)

The primary purpose of pest management is to control animals that would damage a harvest so the farm can retain more produce to increase educational opportunities. We focused solely on keeping animals out of the garden, as opposed to focusing intensely on insects and weeds, as this was the main concern for our sponsor. An eight-foot fence consisting of a small diameter mesh that extends underground is sufficient to keep out most animals, while still allowing pollinators to pass through (Schoff, 2018). Wire fencing buried a food down and out underground will prevent animals such as woodchucks, raccoons, and opossums from digging under the fence. A netted roof for the fence will prevent birds from entering the garden to eat tomatoes and other crops.

Figure 3e.iii: Final garden with 8-foot high fencing, handcrafted door, and overhead bird netting at the completion of the build process (Stoddard, 2019)

The bird netting should be supported by marine 1/4 inch steel wire to prevent sagging. See Figure 3e.iv below.

Figure 3e.iv: Fencing with ¼ inch steel wires run across the width to support the bird netting (Zimak, 2019)

Raised beds allow separation between growing soil and the surrounding dirt. This reduces the ability for wild grasses and weeds to find their way into the garden beds and take over

(Lamp'l, 2018). Ideally, beds should be 12 to 18 inches high for easy access. The beds should be no wider than four feet, or it becomes difficult to access the center of the beds. The length of the beds is dependent upon the needs of the farm and space (Lamp'l, 2018). The beds shouldbe made from raw woods, because treated wood can leach chemicals into the soil that could be harmful to humans. Raw woods, such as cedar, redwood, and oak are good options, as they can stand up to rain, snow, and sun (Lamp'l, 2018). We recommend making the beds at Turn Back Time three feet by thirteen feet and18 inches high. These dimensions allow us to maximize growing potential while giving room to comfortably maneuver inside the garden. See eight completed beds built by WPI and other volunteer teams below, Figure 3e.v.

Figure 3e.v: The first set of plants in the newly constructed beds at Turn Back Time. Beds were constructed by a variety of volunteer groups at the farm (Scherrer, 2019)

The second recommendation is the design of at least two unique feature gardens. Feature gardens were designed and created through semi-structured interviews, gardening books, and gardening blogs. It was determined these gardens must be low cost and also show non-traditional gardening methods. We proposed using tower Gardens or hanging gardens to engage the children since the farm already has most of the materials for these projects (Burris, personal communication, December 10, 2018).

To conserve space and money, two distinct feature gardens were chosen for the garden. These gardens are both vertical in nature to conserve space and are visually appealing to kids while still allowing the farm to sell the produce from these feature gardens. One of these feature gardens is the tower garden made by stacking pots, with large pots on the bottom and small pots near the top. The second feature garden is a hanging garden that involves hanging bottles or other containers from posts. An example hanging garden is below, Figure 3e.vi.

Figure 3e.vi: An example of a hanging garden (Designing Idea, 2018)

The creation of the feature gardens will happen over the course of the farms 2019 summer programs. The low complexity of the feature gardens makes them excellent projects for volunteers and older children to construct (Burris, personal communication, May 18, 2019). The feature gardens can be created by volunteer groups with minimal labor experience and those with exceptional needs over the course of 2019.

Third, was the gathering of materials and construct garden features that include raised beds, improved fencing, and predator-proofing. Materials were originally sized and selected through Home Depot online. After searching the local area for the best price, we were offered a 25% discount from the Lowes on Lincoln Street in Worcester. At the store, each item was hand selected based on our materials list and placed in a contractor invoice.

The construction of the garden was handled by the project team, Turn Back Time (TBT) staff, and volunteer organizations. TBT staff cleared and leveled the proposed garden area. The project team then marked the outline for the fence and aided the TBT staff in the digging of holes for the fence posts, which were then set by TBT staff. The project team then attached the wire mesh to the fence posts as well as the support wire for the bird netting. Volunteers built the garden boxes, as well as assisting the project team and TBT staff in the setting of the bird netting.

Figure 3e.vii: Fence posts set 2.5 feet in the ground with the top layer of wire mesh netting attached. (Zimak, 2019)

In order to complete the project by the end of the WPI academic year, a timeline was created to facilitate the construction process. Due to inclement weather, the original timeline was unable to be followed as strictly as anticipated. Below lies the modified timeline the project followed.

Date	Task
March 11	Finalize Garden Design
March 17	Garden area cleared
April 1	All materials purchased
April 6	Mark final garden Areas
April 14	Holes for posts dug
April 28	Posts set
May 6	Set door
May 7	Finish fencing
May 8	Attach guide wires and hooks for bird netting
May 11	Hang bird netting
May 31	all garden boxes built

Figure 3e.vii: Timeline for project completion

Turn back time used various volunteer groups in June 2019 to finish the construction, including the building of the remaining raised beds, and the construction of the feature gardens. In July, the garden had produced enough produce for Turn Back Time to start a Community Supported Agriculture (CSA) program, where people can buy farm shares to receive farm produce each week. They also opened a farm stand, which supports new programing for children 10-13.

Figure 3e.viii: Volunteers at the farm posing with the garden boxes they created. WPI students from Sigma Alpha Epsilon fraternity (left) standing next to the beds they helped construct. Umass Memorial Health Care Han Resources (Right) sitting in the box they created (Turn Back Time Facebook, May 8)

3f. Conclusion and Next Steps

At the end of our project, two gardens one fully enclosed with new 8 foot fences were erected. These enclosures have allowed the garden to efficiently grow produce to support their mission of Community supported Agriculture and have also created additional and long-lasting agricultural education opportunities for the children. Additionally, we were able to construct twelve, 13 by 3 foot raised beds for the garden enclosure, which are also used as a model for staff at Turn Back Time on how to make more beds.

Figure 3f.i: Finished garden boxes. Four boxes placed in the garden area (Left) during the final garden construction. (Zimak, 2019) A TBT employee (Right) showing off the beds first harvest. (Turn Back Time Facebook, Aug 12)

We expect no major repairs will be required on the garden enclosures until the eight-year mark, as that is how long the wooden structures last in outdoor conditions (Pilch, Personal

Communication, February 2019). Since the garden fence and beds will be exposed to rain, snow, wind, possible ground shifts may occur. . This, as well as gardening activities and play will cause wear and tear on the garden. In about eight years,the garden fencing materials will need to be assessed for to fix any large holes created by playing children; posts may need to be releveled or altogether replaced from children attempting to climb them, and the overhead netting system may require renovations from excessive weight from snow or tree debris tearing holes. To increase the life of the overhead netting, we suggest that it be removed each fall and reattached each spring. We expect that the garden beds will last on average 10 years, the lifespan of milled lumber (Pilch, Personal Communication, February 2019). By refusing pressure treatment to prevent toxic chemicals from entering the soil, the lumber of the garden bed becomes susceptible to its natural decomposition process. The project involved the management of a $5000 budget to accomplish our project goals. It involved balancing the needs of our sponsor with what we could accomplish in our given time frame. As a group, we needed to be adaptable as the project's goals and designs for our garden's changed on multiple occasions. Along with our designs and goals changing we had to deal with changes in our timeline due to inclement weather and on a few occasions worked in the rain to meet our construction deadlines. Our hard work culminated with the construction of the new garden fence, and full enclosure, garden beds, and design of feature gardens that will be a lasting mark on the farm. Which will allow the farm to increase its productivity, efficiency, and the number and type of educational opportunities with its new gardens and pest protection measures.

All three group members were able to utilize this opportunity for personal growth. Not only were we able to develop our general writing skills, but all were afforded the opportunity to practice small group leadership skills and tasks such as scribe, meeting leader, and key personnel liaison. Matthew advanced his skills in expectation management and communication. These skills later helped Matthew when speaking to our sponsors, the staff at Turn Back Time, and when interviewing with subject matter experts. Michael took many leadership and supervisory rolls around writing aspects of the project. Additionally, Michael was able to gain practical knowledge of basic construction through his partnership with his father as a subject matter expert. Jon was able to practice many literary skills through correspondence with subject matter experts and this report. Additionally, he was able to gain a better understanding of taking engineering drawings and plans from online to real life including the sizing and selection of materials and equipment.

4. Introduction

Turn Back Time Farm is a 58 acre farm and nature education site with school year and summer programs for children ages 3-13, located in Paxton Massachusetts. Turn Back Time's farm animals, gardens, nature trails, beaver pond, mud kitchen, apple trees, and more are the context or curriculum for their school aged programs. The gardens currently struggle to produce sufficient vegetables for programming, as crops are eaten by pests, and there is little distinction between plant beds and the garden's floor. According to our sponsor, Lisa Burris, Director of Turn Back Time, the garden is not as fruitful as it could be. Therefore the garden does not provide the educational benefits it is intended to. Burris is also interested in having the gardens support a community supported agriculture (CSA), which can create learning opportunities for older children and support the farm financially, including the newly created garden educator position. The garden educator will be the lead farmer and will help to create additional educational opportunities through the garden. Therefore, the goal of our project is to assist Turn Back Time with the design and implementation of a raised bed garden and pest management systems to improve garden productivity and profitability, labor efficiency, learning opportunities, and pest management. To meet our project goal, we completed the following objectives:

First, determine the best garden layout based on 1) shade and light areas, 2) bed dimensions, 3) accessibility for children and equipment, and 4) pest management to create a comprehensive garden plan. Second, design at least two unique feature gardens that showcase alternative methods of agriculture that would be attractive to and educational for children. Third, gather materials and construct garden features that include raised beds, improved fencing, and predator-proofing. We collected data for each objective via interviews with experts and through a review of relevant literature. Our designs were analyzed and critiqued by our sponsor, the farm's foreman, Neil McCarthy-a consultant with 20 years of carpentry and roofing experience, and our advisor. We then finalized our designs, created a materials list, and began the building process with the help of volunteers from WPI and the Worcester community.

In this paper, you will first find a review of the literature on garden design and predator protection, as well as background on Turn Back Time, their goals, and their needs. Next, our methods section details our research approach to gather data to meet each objective. Third, you will find our results section, which discusses what we found during our information gathering process. Then, you will find our recommendations section, which details the designs we found to be the most beneficial to the farm's garden to improve efficiency and reduce the amount of plants lost to pests. Finally, we conclude by discussing the limitations of the projects, as well as recommended next steps.

5. Literature Review

In this section, we discuss our sponsor, Turn Back Time, in detail, including the organization's history, mission, and programs, as well as current garden practices and problems at Turn Back Time. We then review the literature on the principles of garden design.

5a. Turn Back Time: Mission, Programs, and Garden Practices and Problems

Turn Back Time has a clear mission of supporting children's physical, emotional, and mental health through unstructured outdoor play, as well as through farm- and nature-based education. TBT's gardens are intended to support child health, growth, and development through planting, harvesting, watering, observing, experimenting, and tasting fruits and vegetables. However, the garden beds and fence structures are falling down, and animal pests from the surrounding woods are eating the crops. This has resulted in a loss of educational opportunities, as well as a loss in financial resources invested in the garden.

5a.i. Turn Back Time's Mission and Programs

Turn Back Time has been working to improve the lives of children through nature exploration, farm education, and play since 2012 (Burris, 2019). Research shows that in farm and nature-based education programs and outdoor play can improve children's ability to concentrate, academic performance, reduce stress and aggravation levels, and reduce the risk of childhood obesity and depression (Chawla, 2015).

Our sponsor describes the farm as " serving over 500 children and exposing them to almost 9,000 hours in nature through a preschool program, summer camp, school age programs, family farm time, and human service agency visits" (Burris, 2019, p. 1). TBT serves school age children, 30% of which have a documented diagnosis or live below the poverty line. Through these programs at Turn Back Time, children build empathetic connections with other children, camp counselors, and the animals they interact with. These empathic connections help build social skills (Zaki & Weisz, 2017). Building social skills are critical for academic and social success and can be particularly challenging for children with ADHD, Autism, those who are neurodiverse, and for those who have experienced trauma (The Australian Parenting Website, 2017). Building empathy with animals and translating that skill to interpersonal connections allow the children to help understand each other, creating a deep interpersonal bond (Turn Back Time, 2012b). Developing interpersonal bonds early is important because the lack of these bonds leads to greater overall potential and happiness (Winston & Chicot, 2016). By offering this chance to create interpersonal bonds in the non-classroom setting provides an opportunity for at risk children to reach their full potential. It is also through these connections that Turn Back Time improves children's ability to concentrate, academic performance, and reduces stress and aggravation levels (Chawla, 2015).

The farm also offers research and project opportunities for high school and college-age students, including those at Worcester Polytechnic Institute, Clark University, Quinsigamond Community College, Antioch University New England, and the Bancroft School (Burris, 2019,

p. 1). These students engage in research and projects on outdoor STEM education, innovative water management, wildlife biology, structural and environmental engineering, business, nature and health, and more.

5a.ii. Turn Back Time's Current Garden

While the programs on the farm attempt to assist the children, it is the garden that is the farm's largest selling point (Burris, personal communication. Dec 2018). Without a strong garden, the farm will never be able to live up to its mission.

Figure 5a: Weeds taking over garden beds at Turn Back Time on September 21, 2018 (Zimak, 2018).

A lack of time, labor, and haphazard garden design have resulted in the use of low gardens that are overrun by weeds and grass, as shown in Figure 5a. As a result, the garden currently fails to produce food that can be enjoyed by children, used for teaching, or sold by the farm. With the current garden, 3-4 hours of daily garden maintenance is required. Our sponsor believes that this time investment is not worth the minimal educational and financial payoff (Burris, informal conversation, March 2018).

5a.iii. Turn Back Time's Current Garden Practices

Every spring, the sponsor spends a significant amount of time preparing the garden for the upcoming growing season. All plants are pulled out of the garden "boxes", which consists of branches laid on the ground in a rectangle. A layer of cardboard is then placed over the box area and the boxes are filled with topsoil. Throughout the growing season, the sponsor fights weeds, insects, rodents, and other animals. The little produce the garden does yield becomes ravaged by pests days before ripeness. This culminates in an experience that is not enjoyable, over burdensome, and not beneficial to the children or our sponsor.

The garden currently uses a lasagna style gardening technique. Like lasagna, these gardens consists of multiple layers. The layers are built from cardboard, twigs, leaves, compost, yard waste, and topped with topsoil. Cardboard prevents weeds from entering the garden from below (Vanderlinden, 2018). Twigs provide structure and drainage for the bed (Blackwell, 2016). Compost provides fertile soil for the plants. When leaves break down they return carbon to the soil yard waste returns nitrogen to the soil (Densmore, n.d.). Carbon and nitrogen are essential for plants to grow strong and healthy as key components in proteins and cells (Khan Academy, 2019). Topsoil layered just before planting provides a place for seeds to germinate (Blackwell, 2016). These layers reach approximately 18 inches tall and creates a similar setup to a raised bed.

While lasagna gardening is normally productive in raised beds, the farm's beds have been created level with the ground. The fallen branches that mark the bed borders do not provide an effective barrier against weeds and wild grasses. As a result, weeds often take over the bed and choke out the produce. Every season, a fresh layer of compost is laid down on top of the cardboard, letting weeds from previous seasons grow back from roots in deeper layers. Compost includes manure, surrounding plant matter, and topsoil which creates ideal growing conditions. However, weeds take advantage of this environment before the intended seeds get a chance to sprout (Burris, personal communication, December 2018). Weeds grow rapidly and block sunlight from reaching other plants. When conditions are right, weeds can undergo explosive growth that will completely choke out the desired plants (Boeckmann, n.d.).

To prevent the growth of weeds, proactive and ongoing measures must be taken. When weeds appear they must be removed quickly, before they produce seeds. When removing weeds, all parts must be removed as they can grow back from any roots left in the ground (Boeckmann, n.d.). When removing weeds, all of the tools must also be kept clean. This is because weeds can spread from residual parts left on tools. Even after fully weeding the top layer of soil, the weeds may grow back almost immediately (Boeckmann, n.d.).

A combination of flowers and produce are seeded into each bed which makes the differentiation between the weeds and produce even harder for the children who assist in the weeding (Burris, personal communication, December 2018). This culminates in a haphazard garden experience and results in extra labor required to maintain the garden. With the minimum educational value and a loss of economic value, the current garden design and practices need to change to serve TBT's mission. 5a.v. Current Garden Pests

Several pests run rampant through the garden destroying the crops the garden tries to produce. These pests include cucumber beetles, birds, deer, chipmunks and other rodents, and rabbits. Currently, the farm employs a short deer fence to keep out pests (Burris, personal communication, December 10, 2018). Other than the deer fence, little infrastructure currently exists to prevent pests. Additionally, the fence has not been effective and requires significant upgrades and renovations to keep out common pests.

Cucumber beetles come in two varieties that are easy to identify, spotted and striped. Both beetles have a yellow-green carapace with black designs and are defoliators that eat leaves, flowers, and fruits (Bessin, 2011). Cucumber beetles eat much more than cucumber plants as they affect beans, cucumbers, melons, asparagus, corn, eggplant, and squash (Rhoades, 2018). The excess defoliation can kill plants, but the bacteria residue left on the leaves causes terminal wilting (Bessin, 2011). Row covers, or lightweight mesh netting, can deter modest amounts of beetles. An infestation requires natural predators or insecticides to keep the beetles in check (Rhoades, 2018).

Birds on the farm have been known to eat planted seeds from the ground as well as produce days away from peak ripeness (Burris, personal communication, December 10, 2018). Birds are receptive to audio and visual cues of danger, making these possible choices for deterrence. Loud noises from a radio or cannon can instill fear to any birds, temporarily scaring them away. Hanging shiny objects or silhouettes of predators will be strange enough to keep them at bay. However, birds eventually will grow accustomed and will enter the garden without fear (Gardener's Supply Company, 2019).

Deer have also been observed eating young plants (Burris, personal communication, December 10, 2018). Deer are capable of jumping low fences, requiring fences to be at least eight feet high. The current fence at turn back time is only about 4 feet high (Burris, personal communication, December 10, 2018. Alternatively, two fences, one three feet behind the other, can prevent deer from entering the garden. This type of fence will prevent the deer from entering the garden as they fear being trapped (Schoff, 2013).

Evidence of rodents feasting on the Turn Back Time garden is rampant. Rodents will take single bites out of produce days away from being ripe, ruining the crop (Burris, personal communication, December 10, 2018). Rabbits, due to their small size, can fit through gaps in the fence that they can fit their heads through. Additionally, they are proficient at burrowing under fences and other obstacles (Schoff, 2019). A solution to this is using a fence with gaps smaller than an inch so that rabbits and other small rodents cannot squeeze through the fence. To prevent burrowing one can bury the wire fencing a foot down and out a foot from the fence line (Schoff, 2019).

5b. Raised Garden Beds and Garden Layout

Turn Back Time already uses a variation of garden beds to grow. However, their beds are deteriorating and do not provide all of the benefits of properly constructed raised beds. Once these beds are created, they must be located in the garden areas that optimize growing conditions.

5b.i. Raised Bed Materials

Raised beds will allow easier garden maintenance as they are more organized and keep weeds from growing into the beds and choking out the plants. They will also raise the plant's height to waist level to allow for easier weeding and plant maintenance (Smith, 2009). Proper raised beds should be a minimum of 8 to 12 inches high (Smith, 2009). Almost any natural material can be used to create raised beds. Smaller thickness wooden plank beds are easy to move as they are often lighter, however, they require bracing every 4 feet and will eventually rot (Smith, 2009). Four-inch by four-inch timbers can be used as they are sturdier and will rot slower, but they are more expensive. Logs can be used as they can often be harvested nearby relatively cheaply and will last many seasons. However, logs are significantly harder to handle, shape and move (Smith, 2009). Cement blocks can be used in heating or cooling the beds are a problem. These beds allow the soil to stay warmer in the spring and cooler in the summer and require little maintenance after their initial setup. However, these blocks are typically unattractive, expensive, and can contain harmful chemicals that can leach into the soil (Smith, 2009).

5b.ii. Garden layout to optimize function and access

A garden plan requires optimizing plant location, plant selection, water, and fertilization. The physical location of the garden is important because it sets the growing conditions for the plants. These conditions include sunlight intensity, soil moisture content, wind effects, and garden size (Smith, 18-20). The location of structures in the garden is also important because the microbiome of the garden may change dramatically. For example, a garden area that generally has full sun may have some partial sun areas near the edges of the garden area. Similarly, a typically dry garden may have some wetter spots that can drastically affect plant growth (Smith, 2009).

Plant beds, walkways, and water supplies should all be taken into account before breaking ground. Some plants will need more space to grow than others which dictates the size of the beds (Nardozzi, n.d.). One should know how big plant beds need to be to grow a successful garden (Rexford, 1912). When selecting plants to go in the beds, short plants should not be placed behind tall plants that will prevent the short plants from getting sunlight needed to grow (Rexford, 1912). One should arrange plants in a way that are beneficial to each other, which can include planting companion plants in the same box, utilizing plants with natural predator protection, or plants that utilize different soil nutrients to prevent competition. Walkways should be planned beforehand to create access for machines, tools, and multiple users. When planning a garden, a to-scale map is the best way to manifest ideas on paper (Rexford, 1912). With a physical picture of all the garden ideas, it becomes easier to locate beds, walkways, and spot errors. Mapping ideas is also an easy way to observe the physical limitations of a garden. Once the final map is created, the garden can be evaluated as a whole and progressively made better.

5c. Water

Reduction of hard surfaces in the garden like stone and packed earth allow for better water retention. Hard surfaces allow water to run off as opposed to being absorbed into the soil, where it will keep plants hydrated longer. Proper watering is necessary to prevent both drought and drowning the plants (Missouri Botanical Garden, n.d.). When planning the garden, make note of naturally wet or naturally dryer areas and match these microbiomes to suitable plant types.

One way of increasing the water capacity of the garden is in situ water harvesting. In situ water harvesting is the practice of rainwater uptake in soils through increasing the soil surface area (Climate Technology Centre & Network, 2017). By preparing the planting area ahead of time with peaks and valleys of soil, one can create natural reservoirs for water deeper in the ground (Dos Anjos, Nelson Da, Franca Ribeiro, 1998). These natural reservoirs refill during rainstorms while transferring water to crops at a steady rate naturally. However, in situ water harvesting will not work on the ground with a grade of 5% or higher as the water will run out of the reservoirs (Dos Anjos, Nelson Da, Franca Ribeiro, 1998). Since a raised bed garden is ideally level, with a grade of 0, in situ water harvesting may not be beneficial to the new garden.

5d. Pest management

Pest control occurs directly or indirectly. Direct pest control involves discouraging pests from staying in the garden area. Indirect control involves attracting predators to the garden to kill the pests (Parker et al., 2013). Chemical pesticides are not required when natural direct and indirect pest control methods are used effectively.

Fences are generally used to deny mammals access to garden areas (Grande, 2010). Fences comprise of two main parts, posts and a wire wrap. Typically, fence posts for seven to ten foot fences are driven three feet into the ground. The post are often concreted into the ground to provide added stability. These posts should be no less than 5 inches in diameter and be spaced no more than 10 feet apart to maintain structural stability. A wire mesh wrap is then applied around the posts to deny access to to various mammals (Grande, 2010). The size of the mesh and post depend on the target pests. Larger mammals like deer require strong posts, but the wire mesh can be of a larger diameter. For smaller animals like squirrels, a much smaller mesh netting is required. Typically a ¼ inch wire mesh is required to keep the squirrels out and a 2 inch by 4 inch mesh is used for deer. Additionally, this mesh must be buried several inches below the ground level so that small mammals can not burrow under the fence (Ghidiu, 1992). Multiple options for bird control has been previously mentioned. A net that physically prevents birds from entering the garden will be the most effective means of deterrence. This is because these nets provide a physical barrier between the open sky and the garden area (Gardener's Supply Company, 2019).

6. Methods

The section below describes our project plan and how we expect to be of assistance to our sponsor and Turn Back Time.

6a. Determining the Best Garden Layout

To determine the best garden layout, several factors were considered. These factors included locating shade and light areas, the ideal bed dimensions, accessibility for children and equipment, and pest management. Together, these factors were used to create a comprehensive garden plan. Data was collected through primary and secondary sources. Design matrices were then created to evaluate the various potential solutions.

6a.i. Shade and light

To accurately determine the shade and light areas, we collected data through three main primary sources. First, we analyzed a satellite map of the garden and its surrounding area in order to create a working map of the farm including current placements of garden fencing and structures. Second, we took measurements of the garden to refine and accurately scale our map. These measurements were also used to place the garden areas on the map in order to ensure they receive adequate amounts of sun and optimized the growing conditions of the garden. Third, we conducted interviews with the staff at TBT to gain an understanding of what areas in the current garden received full sun and what areas received partial or no sun. For secondary sources, we read gardening books, journal articles, and blog posts on optimizing garden design for shade and light. The results of this research enabled us to place the raised beds in areas that will optimize plant growth. We also used this research to create a garden layout that shows how much sun each box will receive.

6a.ii. Determining Optimal Bed Dimensions

Three main primary sources were consulted when determining the optimal height. These sources included farmers and gardeners with experience in growing vegetables in raised beds, measurements taken of existing beds at Turn Back Time, and interviews with Mrs. Burris. Additionally, we read gardening books, journal articles, and agricultural websites to further educate our decision.

6a.iii. Pest Management

The designs for a pest management system were made through the collection of data from both primary and secondary sources. Primary sources included interviews with members of Turn Back Time's staff about current pest problems, as well as interviews with people who have experience or expertise in agricultural pest management. Secondary sources included agricultural extension reports that deal with pest management, gardening handbooks, and journal articles regarding animal control measures.

6b. The Design of Two Unique Feature Gardens

Information on feature gardens using alternative gardening methods was obtained through primary and secondary research. For primary data collection, the team conducted interviews and spoke with local children's museums and gardens on how to make feature gardens attractive and engaging to children. For secondary research, we utilized online gardening journals and gardening books. After our research and interviews were completed, we presented the best options for the feature gardens to Mrs. Burris. These options were presented to Mrs. Burris using a design matrix that analyzed the benefits and limitations of each feature garden, with decision criteria informed by the literature and by Mrs. Burris.

6c. Acquisition of Materials and Garden Construction

The physical implementation of our garden plan included the design and building of raised beds, an improved fence, and an aerial enclosure. The implementation of the garden layout served as the culmination of the project. Gathering materials included acquisition, as well as the prefabrication work, which was completed at the farm. Physical work on the farm began April of 2019.

6c.i. Material Acquisition

Gathering materials included purchasing or manufacturing the necessary supplies for the fencing, netting, and raised beds. Design matrices determined what materials were used in the garden. The criteria for bed construction, fencing, and ariel enclosure came from the primary and secondary sources in objective one. Additional secondary sources including gardening manuals and assembly guides that helped guide the criteria.

Our materials list was created by breaking down each aspect of the garden fencing enclosures and features. The fence was designed assuming a standard post-separation of 8 feet

(McCarthy, Pers. Com.). With the garden area map, posts were input into the computer program AutoCAD.

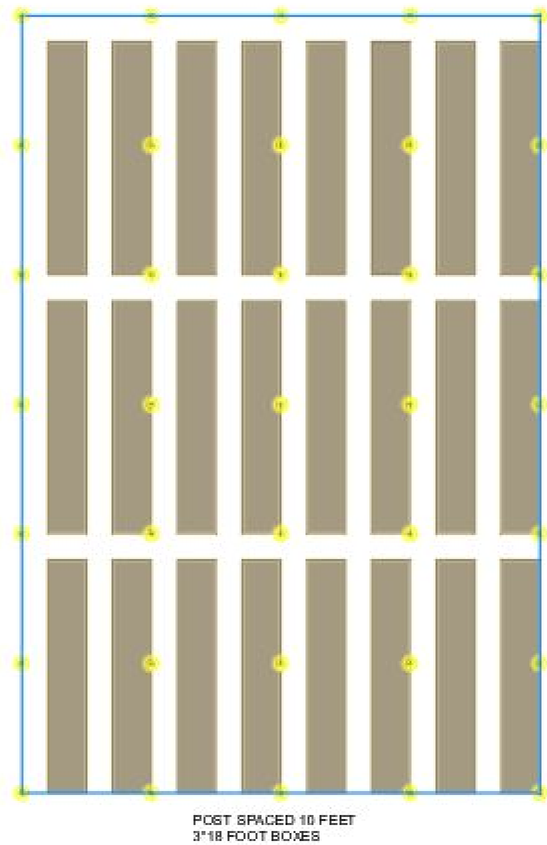

Figure 6c.i: AutoCAD layout of the enclosed garden area with proposed post and bed locations (Zimak, 2018).

Once all of the posts were placed in the program, door placement was selected. All of the posts were counted up and placed on a master materials list. The amount of mesh netting assuming an 8 foot high fence and 1 foot underground section were added to this list. The doors were also designed on AutoCAD assuming the construction would be with 2X4's.

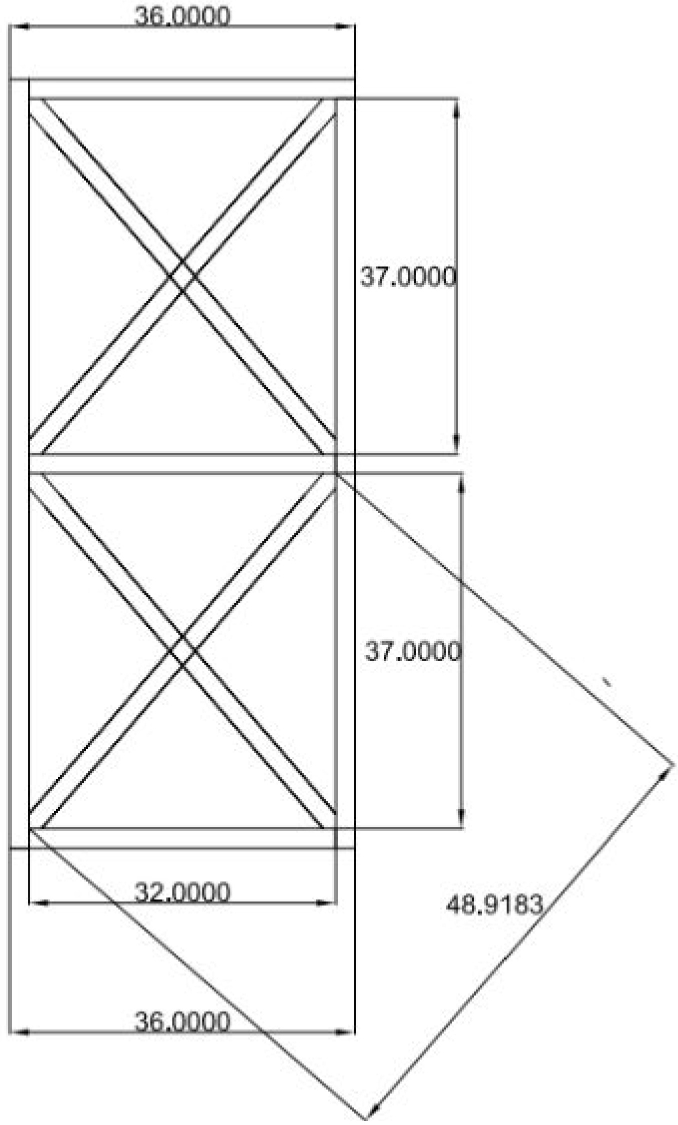

Figure 7c.ii: The AutoCAD blueprint for the garden door (Zimak, 2018).

These doors were designed to be 4 feet wide and very sturdy. The total amount of wood required for these doors was also added to the list.

The aerial enclosure was designed first by a PVC lattice and support posts on the interior of the garden. We then decided to utilize steel cables to hold up the bird netting. The amount of cable was calculated, and the necessary hardware included turnbuckles and end clasps were added to the list. Garden Beds were assumed to be designed with 2x4's to a height of 20 inches. Garden Beds were originally going to be 16 feet long and three feet wide. 16 feet was selected because it would originally allow walkways of 2-3 feet around the beds and would maximize growing area while preventing excessive bed sizes. As the garden area changed from 60 to 55 feet long, the beds changed to 13 feet long so that they could be constructed with one 8 foot piece and another 5 foot piece left over from the 3 foot wide section. The total number of beds was calculated to be 21. The total amount of lumber was then calculated using 8-foot boards to be 510 2x4s. This was then added to the final list. Concrete was selected in 80-pound bags. We rationed that each of the roughly 60 posts would need 2-3 bags of concrete, meaning a total of 200 bags of concrete was added to the list.

We first contacted multiple local suppliers of lumber and building materials. These Suppliers included TS Mann Lumber, Lowes, and Home Depot. We received a 25% discount from Lowes, saving our sponsor $3,000.

6c.ii. Construction

Garden bed, fencing, and ariel netting construction was led by the farm's foreman, using our designs. Construction took place during April, May, and June. We participating in digging and installing the fence posts, putting up fencing, and building the garden beds. We had support from several WPI athletics teams, WPI fraternities and sororities, as well as several WPI clubs, including Engineers without Borders. Support from other volunteer groups, including The United Way, led to the completion of the 16 garden boxes, bird netting, the second garden area, and the feature gardens.

7. Results

This section reviews the outcome of our three objectives, determining the best garden Layout, The design of two unique feature gardens, and the acquisition of materials and garden construction.

7a. Determining the Best Garden

Determining the best garden layout based on shade and light areas, bed dimensions, accessibility for children and equipment, and pest management. Below we discuss our results for each part of this first objective.

7.a.i. Shade and light areas

Shade and light areas were determined through semi-structured interviews with Mrs. Burris in the farm's garden. We considered assessing shade and light areas by creating a sun chart. These charts are a collection of sun/no sun measurements taken over 12 hours at multiple points evenly dispersed in the garden area (Andrychowicz, 2018). When averaged, an overview of total daily sunlight exposure can be calculated for each subsection. However, we chose to interview Mrs. Burris regarding the sun areas. This avoided any discrepancies caused by a difference in season and still accomplished our goal. Mrs. Burris was able to point out general areas that received full sun or 6 hours of sun a day. Mrs. Burris stated that the barn side of the garden received the most sun, while the forest side of the garden received the least sun (Burris, personal communication, December 13, 2018). The northeast corner of the garden was also noted to soon receive more sun than the current 6-hours a day, due to upcoming tree trimmings. Measurements were taken from the boundary lines that Mrs. Burris walked indicating the change in sun exposure. These dimensions were then used with satellite imagery from google maps to create a simplified sun chart that can be used when selecting plants. The simplified sun chart subdivides the garden into subsections that receive the same amount of daily sun. This chart was then applied to the new garden design, and an overall garden sun model was created. The sun model is a modified map that shows the garden area and daily sunlight in a single image. This is then used to optimize crop selection and growing conditions. The initial garden sun model and the model for the existing garden are shown below in Figure 7a.i.

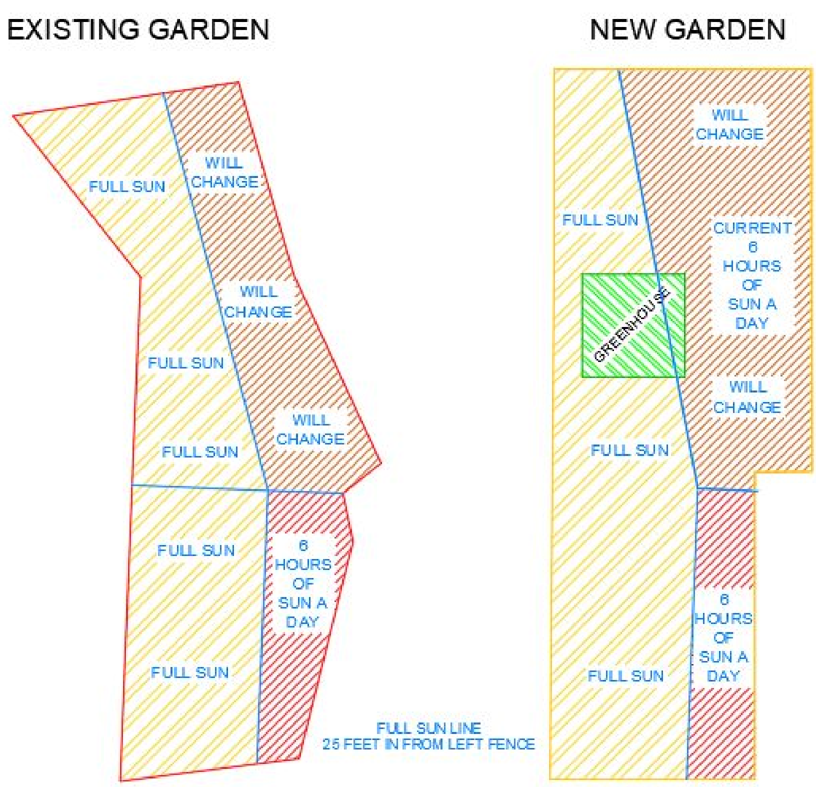

Figure 7a.i: Sun model for the original garden (left) and the newly built garden (right) (Zimak, 2018). These charts will be used when selecting plant locations and feature garden locations.

7.a.ii. Bed dimensions

Raised beds provide control over the health or quality of the soil by separating your growing soil from the surrounding dirt. Keeping the plants separate from the soil outside of the bed helps to reduce weeds or wild grasses (Lamp'l, 2018). The beds also should not be made on uneven ground, as this could cause the beds to not be level, which does not look appealing and can cause warping and beds to shift around in the soil. The beds should be located near a clean water source for convenient watering, and to give the plants water that you know will not harm them (Lamp'l, 2018). For dimensions the ideal height is between 12 to 18in, this is because any higher and the weight of all the soil could cause structural damage to the beds. If you go higher than this, the sheer weight of the soil will cause the sides of the bed to warp and push the walls out and could cause the bed's walls to break. Also, the width of the beds should be no longer than four feet to allow easy access to the plants in the center of the bed. The length can be whatever suits the individual's needs (Lamp'l, 2018).

As for materials, raw woods that have natural rot resistance are preferred like cedar, redwood, and oak. The only downside is that these raw woods can be hard to come by and can be nearly double the price of treated wood. This cost increase is because some types of wood are not readily available in certain areas and because they may need to be replaced more often than treated wood, upping the cost of raw wood to treated wood (Lamp'l, 2018). Treated woods can also be used but are not recommended for a vegetable garden because the wood could contain harmful chemicals, such as Micronized Copper Azole. This compound used to treat wood can leach into the soil and has been linked to being a cause of cancer (Civardi et al., 2016).

7a.iii. Pest Management

The primary purpose of our project is to prevent animals from entering the garden that would damage a harvest, so the farm can retain more produce. We only focused on keeping out animals from the garden because that was what our sponsor requested, as opposed to focusing intensely on insects and weeds. Pest management solutions were determined through traditional semi-structured interviews and researching gardening books and blogs. The farm's main pests are rodents due to the garden's location adjacent to heavily wooded areas. Mrs. Burris wants the garden bird proof as well (Burris, personal communication, December 10, 2018). Therefore, pest solutions need to cover a wide range of pests and entry methods to ensure the garden stays secure.

Garden fabric (pictured below in Figure 7a.ii) is a sufficient bed by bed solution for pest management. As it is a fabric that is used to cover plants to keep birds, bugs and other small pests from being able to get to the plants. The most common implementation of garden fabric is as a row cover. Row covers mainly prevent new insects from entering garden beds, which cause the majority of problems (Pilch, personal communication, February 8, 2019). These covers can be extended to also prevent birds (Gardener's Supply Company, n.d.). Other methods of keeping birds out of the garden such as hanging CDs or periodic loud noises, which can frighten birds, but they typically only work for a couple of days (Gardener's Supply Company, 2019). Birds are quick to realize a lack of consequences to such static deterrents. Netting is the most efficient and long term method of keeping out birds.

Figure 7a.ii: Garden Fabric (Gardener's Supply Company, n.d.)

Fences are the best way to manage rodents and other animals from the nearby woods out of the garden by preventing a means of entry. Deer are best kept out using an 8 ft electrified fence. A safer alternative to an electric fence is a double fence, which creates an in-between fence area deer do not want to land in (Schoff, 2018). Small rodents do not need a particularly tall fence to manage them but require small openings. Rodents can fit through spaces the size of their heads, as well as simply burrow under a fence. To prevent burrowing, simply extend the fence below ground a foot (Schoff, 2018). The mesh of the fence should be no larger than ¼ of an inch to protect against smaller rodents, while also allowing pollinators to pass through (Pilch, personal communication, February 8, 2018).

When building a fence, the posts are to be no more than 6 ft apart to uphold structural integrity (Lowe's, n.d.). All posts need to be concreted at least 2 feet into the ground, as per farm policy (Burris, personal communication, February 8, 2018). However, the rule of thumb with fencing is to bury one third the depth of the post underground to ensure strength.

With this information and taking into account the needs of our sponsor, we came up with an initial plan for pest management solutions. Our sponsor wanted a fully enclosed garden. From our research we designed an 8-foot high enclosure (Figure 7a.iii, below) using a mesh netting to prevent small pests from entering through the gaps in the mesh. We also proposed to bury sections of fence so that animals could not burrow underneath. Bird netting would be attached at the top of the fence to prevent birds from getting into the garden from above. Our initial designs were looked over by an industry expert, Ann Marie Pilch from Tower Hill Botanical Gardens, and Neil McCarthy who has 20 years of construction and carpentry experience.

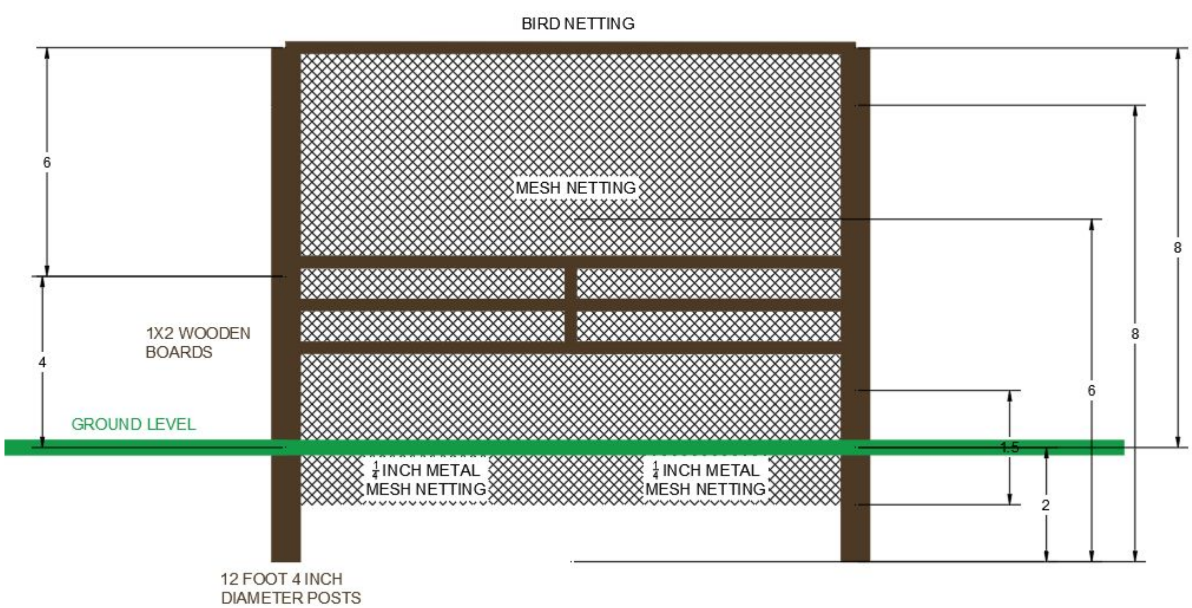

Figure 7a.iii Segment of the proposed fence (Jon Zimak, 2019)

7b. Designing Feature Gardens

For our second objective, we aimed to design two unique feature gardens that are engaging to children and get the kids excited about gardening and to grow herbs and flowers for Turn Back Time's new CSA. Feature gardens were determined using gardening books and websites, as well as through semi-structured interviews Mrs. Burris and Ms. Pilch. Burris and Pilch have years of experience introducing children to gardening. After receiving an estimated design and budget of $5000, the feature gardens had to be under 50 dollars and easy to implement (Burris, personal communication, December 10, 2018). The feature gardens aim to provide an introduction to alternative methods of growing food, herbs and flowers. The feature gardens also have to leave enough area in the garden for play and learning activities.

Another potential feature garden is the straw bale garden. Straw bale gardens introduce children to the composting process, serve as play devices, and are low cost. Straw bales work as a natural raised bed, which provide their own source of compost (Gardening Channel, 2018). Additionally, a straw bale is low cost, with a 24x42x18-inch bale typically costing around $5 (Tortorello, 2013). Purchasing enough bales would not be a substantial financial burden for the farm, and while the bales ferment the children may use them like large building blocks. The idea was discarded however due to input by Ms. Burris. The farm has already tried straw bale gardening with minimal success (Burris, personal communication, December 10, 2018). Additionally, it was deemed too similar to raised bed gardening to have sufficient educational value.

Figure 7b.i: and example straw bale garden (Times Publishing Group, 2017)

Tower Gardens, Figure 7a.ii, are pots of decreasing diameters stacked on top of each other, creating multiple levels for plants to grow on. Tower Gardens could help support the farm's projected Community Supported Agriculture (CSA) program on a minimal footprint, teach children responsibility, and are low cost. A tower garden's footprint is the size of the largest pot in the tower, typically only 14 inches (Grace, 2018). Despite the small footprint, the multiple levels allow children of various heights to take responsibility for different areas (Nickleson, 2015). The multiple levels allow different herbs and flowers that augment the CSA to thrive in the same small area (Nickleson, 2015). The farm also has an abundance of leftover pots, driving the cost of this garden down drastically (Burris, personal communication, December 10, 2018). A series of tower gardens will make up one of the feature gardens.

Figure 7b.ii Example tower garden (Grace, 2018).

Hanging gardens, Figure 7a.iii, are made of suspended pots from a structure, creating multiple small plots to grow plants. Hanging gardens offer the same benefits as tower gardens above but with a different profile physical profile. The hanging garden is great for a long narrow area as it is made from soda bottles suspended from a wooden frame by wood (Designing Idea, 2018). By tying a loop in the line at intervals, the soda bottles won't slip so multiple bottles can hang in a column(Stamper-Halpin, 2013). The variety of plots in a small footprint gives children the ability to practice management skills while growing herbs and flowers to support the CSA. The garden usually has wood lying around that can be used to build a frame, and older kids can help set up a hanging garden as a day project (Burris, personal communication, December 10, 2018). Plastic bottles are also easy to obtain, the cost of this feature garden should be zero.

Figure 7b.iii: An example of a hanging garden (Designing Idea, 2018)

7c. Materials Acquisition and Construction

The third objective was the acquisition of materials for the proposed garden plan, along with the construction of the proposed garden. To stay under our budget, we asked local hardware stores for donations. The construction of the garden was completed by this IQP team, farm employees, and various volunteer groups.

7c.i. Materials acquisition

Materials were originally sized and selected through Home Depot online. Several other groups were offered a 25% discount at a local Home Depot. However, due to the size of our project, they were not able to extend us the same offer. We visited 4 other similar stores searching for a discount and was offered 25% off at Lowes on Lincoln Street in Worcester.

At the store, each item was hand selected based on our materials list and placed in a contractor invoice. All of the parts had to be reselected and sized at lowes to match the new item codes. This involved going through the physical inventory of Lowes and marking down each item code number. These codes were then added to the contractor invoice for Mrs. Burris. She was then able to go to the store, place the entire materials list in her cart, and get them delivered to the farm with no tax and a 25% discount.

7c. ii. Garden Construction

We planned to construct the garden in five phases. Phase one was to clear and level the garden. RJ Burris, a member of the Turn Back Time family, took the primary lead with the farm's tractor in addition to several volunteers. Any old fencing, garden boxes, or infrastructure was removed from the garden area and recycled. The south end of the garden area was raised an additional foot and a half in order to make the area more level.

Phase two was to dig in and set the posts for the enclosure. A one-foot deep by two-foot wide trench was dug along the perimeter of the garden area. Post locations were marked with duct tape flags on mason line that stretched the length of the trenches. The back face of the square post would be flush with the mason line and directly line up with the flags. Holes for the posts were dug another foot and a half into the ground where the terrain allowed. RJ and a contingent of helpers on farm service day set the initial half the total amount of posts. RJ later was able to set the remainder of the posts in the following week. Each post was set with at least one 80 pound bag of concrete to help with structural integrity.

Phase three was the setting of the fence to the posts. The ¼ inch wire mesh was attached to the fence posts by three inch deck screws topped with a washer. Fencing was attached from the top down. A level line was first drawn one foot above the highest ground of the garden. This line was then extended 7 feet up and marked with a sharpie. The eight-foot height marker on each post was used as a guideline for the top ends of the wire mesh. Two three-foot-high sections of mesh were used from the top down followed by a four-foot section that went into the ground.

Phase four was the attachment of the overhead netting to the fence posts. Three lengths of 3/16 inch wire were used to span across the garden attached to the top of the posts with an O-hook lag bolt. A one-inch diameter bird netting can then be hung over the garden enclosure. 1X4 inch boards were attached at the top of the posts to form a box around the top of the fencing. Eye hooks can then be attached to the boards on the top of the enclosure to hold the netting in place. The eye hooks would support the edges of the bird netting and the wires would prevent the netting from sagging. This work would primarily be completed by Matt and his boy scout troop.

The final phase five was the building of the garden boxes for the enclosed garden. The 3 by boxes could be constructed by 3 people in 2 hours. Many volunteers and farm staff assisted in making the boxes, including Habitat for Humanity, WPI fraternities, as well as local groups and organizations. The final timeline for construction is below, Figure 7c, and lays out all of the major for the garden enclosure construction.

Date	**Task**
March 11	Finalize Garden Design
March 17	Garden area cleared
April 1	All materials purchased
April 6	Mark final garden Areas
April 14	Holes for posts dug
April 28	Posts set
May 6	Set door
May 7	Finish fencing
May 8	Attach guide wires and hooks for bird netting
May 11	Hang bird netting
May 31	all garden boxes built

Figure 7c: Timeline for project completion

8. Recommendations

Our recommendations based on our findings and results are presented below. Additionally, we make some predictions to our sponsor for the yearly required maintenance for the garden enclosure.

8a. Garden Layout

The goal of this project was to develop and then implement, a garden design that improved productivity, labor efficiency, and pest management at Turn Back Time, in order to increase the quality and quantity of educational opportunities at the farm. In this section, we will discuss our recommended garden layout, recommended feature garden designs, and our recommended building plan.

In figure 8a.i below, you will find our recommended layout for the garden based on shade, light, and accessibility. The garden boxes in area one, are placed three feet apart from each other. This spacing between boxes provides pathways wide enough for people to work comfortably, access for tools, and play area (Burris, personal communication, December 2018). The garden boxes are three feet wide, thirteen feet long, and 18 inches high. This creates large areas of raised gardens while providing enough paths for children to not climb over the boxes.

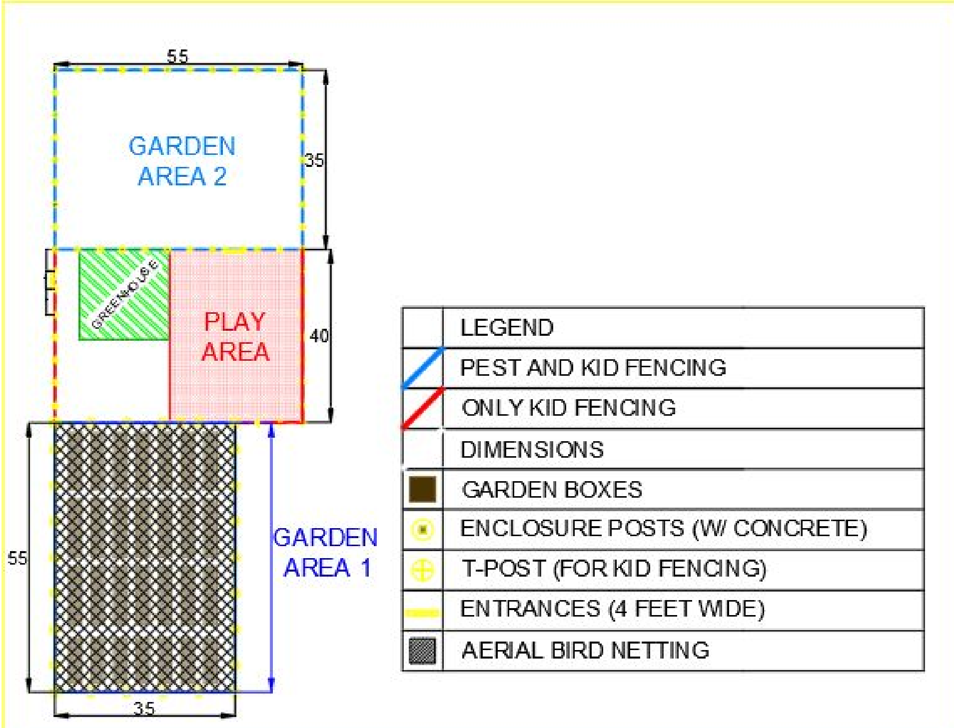

Figure 8a.i: Proposed to scale garden plan for Turn Back Time (Zimak, 2019)

Figure 8a.ii below is the fence we recommend for pest management. 1/4 inch metal mesh netting pests from slipping in through the gaps in the mesh, while allowing pollinators to pass through. The mesh continues two feet below ground to prevent animals from burrowing under the fence. The fence is 8 feet above ground level so that when netting is stretched across the top of the garden area the net is high enough so that it does not feel cramped to be inside the enclosure.

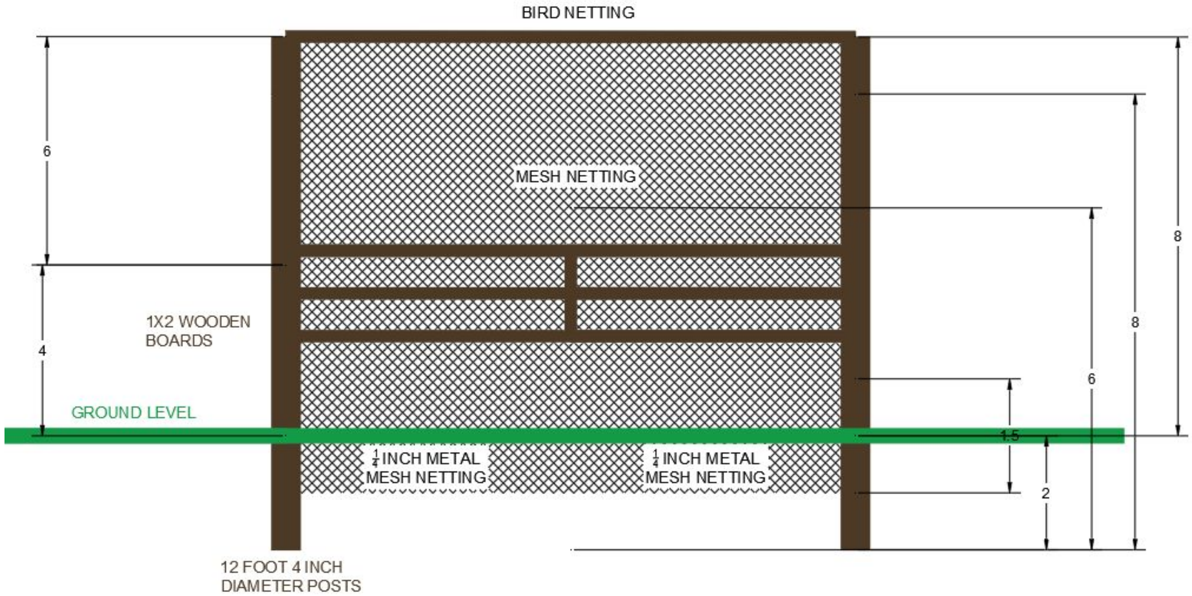

Figure 8a.ii Segment of the proposed fence (Zimak, 2019).

8b. Feature gardens

Based on the available space and budget, we recommend erecting two different types of vertical gardens to act as feature gardens. This is due to the low cost and small footprint of vertical gardens. We believe that building towers and hanging gardens will be engaging and educational for children, while still producing produce the farm can sell or offer through their new CSA program.

A tower garden's footprint is the size of the largest pot in the tower, typically only 14 inches (Grace, 2018). Despite the small footprint, multiple levels allow children of various heights to take responsibility for different areas(Nickleson, 2015). The multiple levels allow different plants that support the CSA to thrive in the same small area (Nickleson, 2015). The farm also has an abundance of leftover pots, driving the cost of this garden down drastically

(Burris, personal communication, December 10, 2018). A series of tower gardens will make up one of the feature gardens.

Figure 8b.ii shows an example of a hanging garden. The hanging garden has a slightly higher cost and larger footprint. The small nature of the individual pots that make up the hanging garden lends itself to growing smaller plants such as flowers and herbs. Hanging gardens open more garden management options to children. A younger child can be responsible for one plant, while older children can manage rows or columns of pots. Using spare cable, concrete, and posts from the garden enclosure reduces the cost of building this garden to $0.

Figure 8b.ii: an example of the proposed hanging garden (Designing Idea, 2018)

8c. Garden Construction

Figure 8c below shows the final proposed garden. Garden Area 2 is a 55 by 35-foot area that will contain the feature gardens and other gardening methods. A greenhouse is being concurrently built by a Major Qualifying Project team. The play area in the garden is an open area that the children can play, learn, and explore next to the garden. It can also serve as a gathering area for garden lessons, experiments, activities, and workshops . Garden Area 1 is a 55 by 35-foot area that is the proposed enclosed garden. The enclosed garden will be enclosed by a fence with a 1/4 inch diameter mesh that is eight feet above the ground and buried a foot deep underground, extending a foot away from the garden underground. The garden will contain 21 3x13 foot garden boxes and another 7 3x10 foot boxes to maximize the production of the garden so it can support the upcoming CSA.

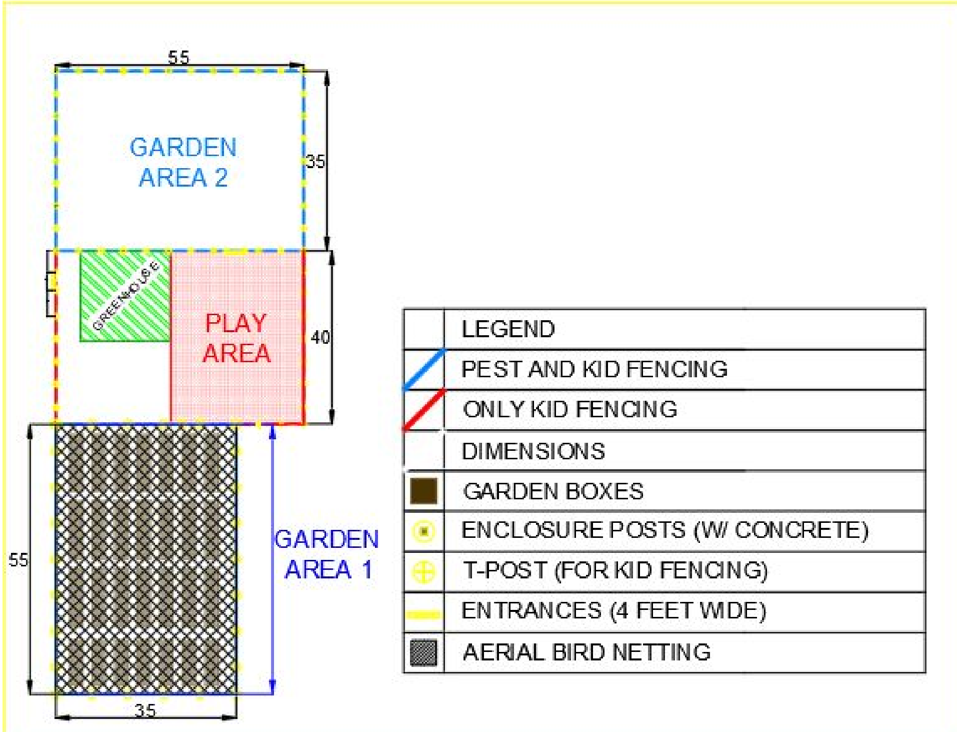

Figure 8c: Proposed to scale garden plan for Turn Back Time (Zimak, 2019)

8d. Garden Maintenance Plans

For our sponsor, we have three phase maintenance plans based on the age of the garden infrastructure. We expect there will be minimal maintenance required for the fencing during the first four years on the farm. During this time, the most probable maintenance will be required on the overhead netting and making sure that the support wire stays tight. Turnbuckles attached to the system should be able to handle the yearly tightening for the first couple of years. We expect the overhead netting to last two sessions if kept on during the winter and around 5 sessions if removed and reinstalled when needed.

We suggest that the overhead netting be removed each fall and reattached each spring. This task is expected to need four or more assistants and will likely take an hour or two. Holes in the netting can be fixed with paracord, zip-ties, or twine. Larger holes can be patched with leftover netting or with the donated mesh netting from WPI's campus by selecting a piece two to three times the size of the opening and attaching it over the full sized netting with zip ties.

After the four year mark, the gate may need to be releveled, some of the mesh fencing may need to be patched where there is heavy wear and tear. A few posts on the downhill side of the garden may need to be replaced or reset. We expect no major repairs will be required on the garden enclosures until the eight year mark. At that time, new fencing may need to be brought in to fix larger gaps, posts may need to be releveled or altogether replaced, and the overhead netting system may require a major renovation.

We expect that the garden beds will last roughly 8 sessions. After that time the wood still may be suitable for growing, but we expect the general structure to start to reach a point of deterioration. Yearly bed maintenance includes fixing any broken boards, replacing support trusses, and rebracing beads if they start to bow. The bowing of the beds will severely compromise their structural integrity and can potentially lead to broken boards.

9. Conclusion

Our project experience was limited by poor weather, scheduling conflicts and time. Weather conditions in early spring delayed initial construction about 2 weeks as the ground was still partially frozen. Further, there were several workdays that had to be canceled or rescheduled due to rain. Scheduling conflicts prevented our entire team from being present at farm service day, the farm's biggest workday, due to ROTC commitments. Our team was mainly limited by the WPI timeline. Officially our team had until April 29th, but we decided to participate in an additional 1/6th credit to further help the farm achieve its mission.

Our project was a great springboard for future improvement at Turn Back Time. This includes instructed TBT staff on how to construct more beds, and discussing our methods for applying the wire mesh on to the enclosure fence posts. Moving forward, other GPS, IQP, and MQP teams can pick up on our research and assist the farm in creating additional opportunities for educational development.

With their new enclosures, the farm was able to start it's first CSA and farm stand in June 2019. The enclosures provides plenty of predator protection and the new beds should provide a great image to help promote the farm. In addition to the increased growing capacity, the farm now will be able to support their educational programs, using the gardens for unique STEM and other learning opportunities. This will not only support the farm's mission of educating children but should also bring in significant revenue for the farm. It is our hope that the work we did for the farm makes a lasting impact and significantly improves the Turn Back Time experience for both the staff and students.

All three group members were able to utilize this opportunity as a major learning and growth environment. Not only were we able to grow and develop our general writing skills, but we all were afforded the opportunity to practice small group leadership tactics and tasks such as scribe, meeting leader, and key personnel liaison. We have all grown significantly as project leaders, professionals, and teammates. While we may not have been able to travel to a far off country, we are very thankful for being able to experience the joy of the farm close to WPI.

Matt advanced his skills in expectation management and communication. When working with the staff at Turn-Back Time, Matt learned not to assume a common base level of knowledge amongst a group, and to have information prepared from the ground up so everyone can have a shared understanding. This helped in Matt's communication skills, as he was then learned to explain concepts and ideas to people of various backgrounds. This helped him explain the project to donors to effectively secure donations and subject matter experts to get precise feedback.

Michael McCarthy took many leadership and supervisory rolls around writing aspects of the project. Additionally, Michael was able to gain practical knowledge of basic construction through his partnership with his father as a subject matter expert. He also learned and implemented techniques for the installation and leveling of fencing on an inclined surface. Michael was able to implement his SolidWorks knowledge to create assemblies of garden boxes to show our sponsor to get input from them and to show those assembling them how they should look when built. Along with this, he worked on his organization skills for meetings by helping create agendas for the team for their weekly meetings, on a rotational basis with the team. As well as his skills involving running meetings to discuss project goals and give updates to our sponsor and advisor.

Jon was able to practice many literary, communication, and engineering skills throughout the project. During the writing process for this report, he was able to develop his non-technical professional writing skills. As the main contact for many of the subject matter experts, he was able to grow in his communication skills and management skills, through scheduling meetings and interviews. As the representative sent to acquire materials, Jon had to communicate with contractors, Lowes' Pro Department staff, and store managers to ensure the materials were correct and at the right price. Finally, he was able to gain a better understanding of the engineering design process. The garden started out as a CAD drawing and was changed many times to become the gardens that now stand at Turn Back Time. Many of these revisions were made on-site, but affected the overall design and layout. Other changes were sponsor mandated or were required to be made due to differences in design materials. The team is incredibly grateful to Turn Back Time for the opportunity to learn, fail, and grow.

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