THREE PEAS IN A POD: COMPOSTING SQUAD!

Project Compost!

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E215: Introduction to Design

Table of Contents

1 Problem Formulation

1.1 Introduction

The problem formulation includes sections 1.1-1.3, and provides information regarding the problem this project aims to solve, which is the need for a composting system at Zane Middle School.

1.2 Background

Catherine L. Zane Middle School in Eureka, CA focuses their curriculum around science, technology, engineering, art, and math (STEAM), and caters to a diverse group of children. Zane and the Environmental Resources Engineering department at Humboldt State University have a rich history of partnership around the STEM programs. As of spring 2017, the school had tried a couple of composting systems in the past, but were faced with a variety of problems including rats, the need for excessive maintenance, and destructive children, so they removed the compost altogether. Bernie Levy is a teacher at Zane and facilitates student interactions with the garden located at Zane. He is interested in implementing a compost system that works for the school.

1.3 Objective Statement

The objective of this project is to develop a cost-effective composting system that will be educational and safe for middle-school aged gardeners to use. This composter will be low-maintenance, simple to use, and will accommodate a variety of garden waste, woody debris, and the occasional organic waste from the cafeteria. The design will ensure the compost is free of pests such as rats and raccoons, and will be sturdy enough to stand up to the test of rowdy middle-schoolers. Figure 1.1 is a visual representation of the project, where the input in the state of the world before the design process, and the output is the state of the world when the project if complete. The black box itself represents the design process itself, which is detailed in the remainder of this document.

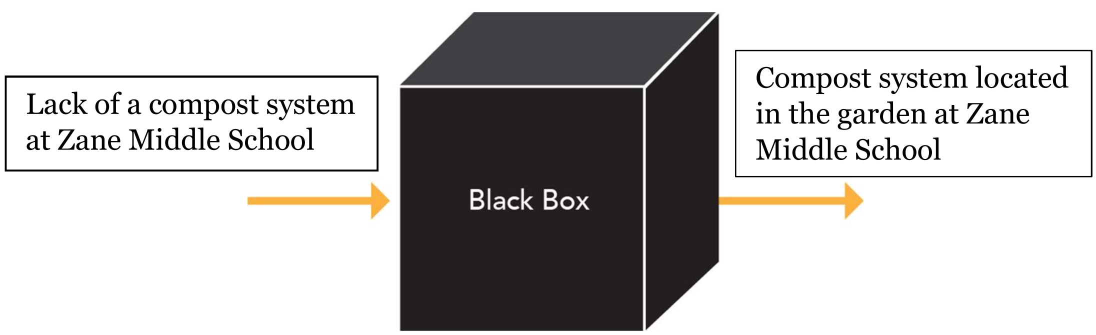

Figure 1-1. Black box diagram for this project. By Ronnel Yabut and Kelsey Burrell.

2 Problem Analysis and Literature Review

2.1 Problem Analysis

The problem analysis provides a detailed summary of considerations taken into account during the design process for the composting system at Zane Middle School. This section details quantifiable and qualitative specifications and criteria, as well as considerations regarding the usability and product volume.

2.1.1 Specifications

The design for the composting unit must fall within several specifications in order to fulfill the needs of Zane Middle School. The following list details those specifications.

- Location of the composter:
  Catherine L Zane Middle School garden
  2155 S St, Eureka, CA 95501

- The system must be safe for student interaction. Any wood must be sanded to avoid splinters, and no exposed sharp metal edges may be present.

- The school must be able to add food and garden waste on a daily basis.

- The system must be low maintenance and designed simply.

- The structure must be contained within an 8’ x 3’ area of the garden.

2.1.2 Considerations

The following considerations should be included in the design process. These considerations were developed through individual research and personal communication with the client.

The general aesthetics of the composting system should fit the overall motif of the school. The materials and construction must be able to withstand the climate of Humboldt County, which is described as a temperate rainforest which averages between 40 and 100 inches of rain each year (Humboldt County, n.d.). The composting system should have educational value, and be easily accessible to middle-school aged children.

2.1.3 Criteria and Constraints

Criteria help define the scope and quality of the project, while constraints clearly define parameters which must be met in order to satisfy the specific needs of the client. Table 2-1 delineates criteria and constraints applicable to this project. These criteria and constraints were developed through communication with the client.

Table 2-2-1. Criteria and constraints for the composter design.

Criteria	Constraints
Rodent-resistant	Must be rat-proof
Maintenance	Maximum of five hours of maintenance each week
Durability	Must not be easily altered or destroyed by middle-schoolers
Safety	Must not be sharp or splintery
Educational Value	Includes an appropriate display for middle-schoolers
Simplicity	Compost must be easily accessible to the middle-schoolers
Cost	Maximum cost is not to exceed $425
Aesthetics	The aesthetics must agree with those of the school and garden

2.1.4 Usage

The compost system is meant to be used year-round with the exception of during the summer when school is not in session. Students and faculty of Zane Middle School will add to the compost daily, and generate an approximate volume of 5 gallons of compostable matter every two weeks (Levy 2017). Students and school faculty and will have five hours each week to perform upkeep operations. During the summer, activities will be limited due to school not being in session. Since there will be no available children to help manage the system, faculty members may need to help manage the system during the summer.

2.1.5 Product Volume

One composting unit will be constructed, tested, and installed at the school.

2.2 Literature Review

The Literature Review is the culmination of the preliminary research conducted for the purpose of generating solutions to satisfy the need for a composting system at Zane Middle School.

2.2.1 Client Interview

Two client contacts from Zane Middle School were interviewed and provided information necessary for the design processes. The main client contact was Bernie Levy, a teacher and Garden Coordinator, and useful information was also provided by Trevor Hammons, the Counseling Services Director.

2.2.1.1 History of composting at Zane Middle School

Zane Middle School has undergone two attempts at establishing a permanent composting system. The first was a vermiculture system, which required maintenance during the summer, which the adults can't provide. The school closes for 10 weeks each summer, and the worm population suffered when left alone for that amount of time. The second time they tried a composting system, the school used a covered pit. The students enjoyed the process of digging and working with the composting pit. The compost wasn't rodent-proof. It eventually became infested with rats and was removed (Levy 2017).

2.2.1.2 Types of materials to be composted

Much of the compostable material at Zane comes from the garden, although occasional produce from the cafeteria will be composted. The school generates about 5 gallons of food waste from the cafeteria every other week (Levy 2017), which translates to 0.67 cubic feet. The garden has several raised beds, where fava beans, onions, garlic, kale, lettuce, and chard grow. The foliage from the fava beans supplies the bulk of the greens going into the compost, in addition to weeds and other garden greens. The garden houses a pile of alder branches that the client wants to possibly compost. Some of these twigs are in a pile of decomposing matter in the garden, which also consists of foliage and grass clippings, and the rest is in a pile with a diameter of about two feet.

2.2.1.3 Design specifications

The composter design must include a safe-guard against rats, and be contained within a 15' x 22.5' area inside the garden fence. The garden coordinator averages about five hours each week in the garden (Levy 2017), so the upkeep required for the compost needs to fit within that allotment. An additional requirement is that the composter be resilient when left alone for ten weeks at one time.

2.2.1.4 Design Criteria

The school is in need of a composter that can't be broken or altered significantly by the middle-schoolers. The compost itself should be easily accessible to the students so they can be active participants in the process. The client wanted a professional, educational composting system, which would be easily accessible for the kids. The soil should be easy to remove from the structure as well (Levy 2017). In addition to a professional aesthetic, the client requested that the school colors, red and gold, be considered when selecting colors (Hammons 2017).

2.2.2 Types of composters

This section gives an overview of various compost systems for small- to medium-scale use.

2.2.2.1 Rotating barrels
Rotating barrel composting employs a barrel shaped device which rotates on a central axis. to go through the composting process. The barrel itself is fully sealed but includes vents to allow gas exchange with the atmosphere, as seen in Figure 2-1.

Figure 2-1. An example of a rotating barrel bin. (BassetFran)

The fact that rotating barrel composters concealed from the outside helps keep pests out, and helps the compost retain its temperature. The combination of high temperatures and ease of mixing makes the rotating barrel composting process much faster. Batches of compost made by this method have an average of 6-8 weeks from start to finish. A negative aspect of the rotating barrel is it can be hard to rotate when it is full. Additionally, they can be expensive to buy or build (Seaman n.d.).

2.2.2.2 Bin
Composting bins are simple structures that sit on the ground. Fresh compost material is placed inside the bin, and left to decompose. Once every week or two the pile is turned with a shovel or

rake. Figure 2-2 shows a slatted compost bin with an open side to reveal the multiple layers of fresh materials that will soon decompose.

Figure 2-2. An example of a slatted wood composting bin. (DIY Network 2015)

This is one of the most used ways to compost because it's straight-forward and reliable, but they can have the big problem of attracting pests. Rats and mice in particular are known to make a home in compost bins because of the supply of food and the warmth that the compost pile is emitting (DIY Network 2015).

2.2.2.3 Turning unit bin

A turning unit bin, shown in Figure 2-3, is used as a multistep composting system. More than one batch of compost can be brewing at the same time, resulting in mass amounts of compost. (Rodale 1975). The structure is a series of bins that are at different stages of the composting cycle. One bin houses fresh materials, the next contains compost farther along in the decomposition process, and the final bin contains the soil. and as it reaches further stages of decomposition it gets moved into the successive bins.

Figure 2-3. An example of a turning unit bin composter. (WordPress 2015)

2.2.2.4 Worm bins/ vermicomposting

Worm composting is the process by which organisms like bacteria, worms and insects help turn fruit and vegetable waste into compost. In the process the worms eat their way through the waste, and the worm castings are collected in a bottom container, as seen in Figure 2-4. The

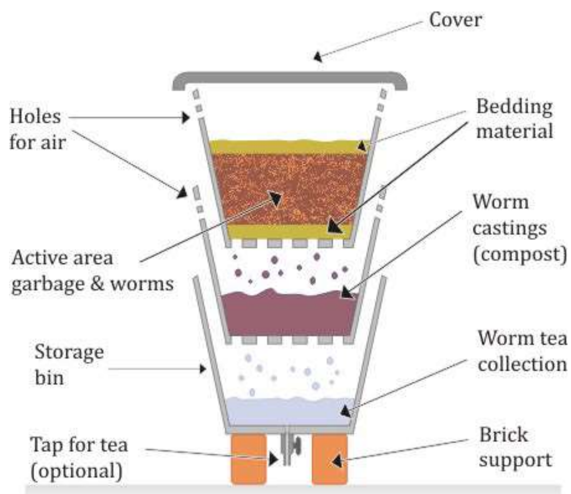

Figure 2-4. A diagram of a worm bin composter. (Working worms n.d.)

worm castings are called vermicompost, which is higher in nutrients than the average compost. Worm bins should be kept at temperatures between 55-80 degrees in Fahrenheit. A downside to worm bins is that it's high maintenance. The worms need food, bedding, moisture and air. If balanced wrong the whole composting system could be ruined (Nancarrow 1998).

2.2.2.5 Soil Composting

Soil incorporation is a simple method for composting food waste. A hole is dug around one foot deep, and the food wastes are chopped and mixed into the soil. After that more soil is put on top of it. Depending on soil temperature, number of micro-organisms in the soil, and the carbon content of the wastes, decomposition will occur in one month to one year (supercompostingtips.com n.d.).

2.2.2.6 Pit/ Trench composting

Pit/ trench composting is a three-year process rotation of composting kitchen waste, growing crops, and path making. In the first season a trench is dug, filled with food wastes and covered. At the same time, another row is used to grow crops and a third is used as a path. (Shell 2005) In the second year the fertile soil of the former compost trench is used to grow crops, the former crop row is used as a path, and the path is dug as a new trench. After a third year of rotation, the cycle starts over. This form of composting keeps the garden perpetually fertile with small organizational effort. This is shown in Figure 2-5 below.

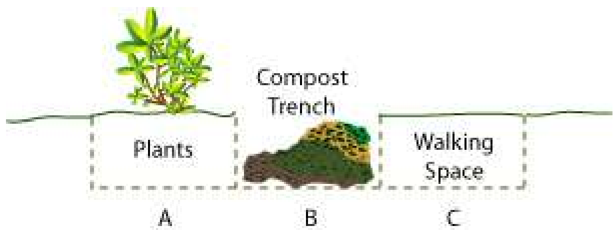

Figure 2-5. An example of trench composting. (University of Illinois n.d.)

2.2.3 Chemistry and Biology of Composting

This section details physiochemical and biological parameters which are involved with compost.

2.2.3.1 Compostable Materials

In a composting system one has a lot of variety in the process of choosing what to compost. Organic matter is the main component, and consists of everything from a corn cob to animal waste and all that's in between. This includes plants, vegetation, and paper based items like newspaper and coffee filters. It's good to have variety in a compost pile because it increases the types of microorganisms that'll work on the pile of compost (University of Illinois Extension n.d.).

2.2.3.2 Microorganisms and Macroorganisms

Microorganisms are important in a compost pile because they do the bulk of the decomposition. Bacteria, fungi, and actinomycetes are chemical decomposers. Chemical decomposers change the chemistry of organic wastes. Macroorganisms such as mites, centipedes, sow bugs, snails, millipedes, springtails, and earthworms are all physical decomposers. Physical decomposers bite, tear, and chew materials into smaller pieces, which increases the surface area available for chemical decomposition (University of Illinois Extension n.d.).

2.2.3.3 Oxygen

The organisms which are most beneficial to compost require oxygen. The anaerobic bacteria which form under limited oxygen conditions release compounds which can be toxic to plants. Too much exposure to the air can reduce the temperature of the compost, however, which would slow the process of decomposition. If turned 3-5 times each week, compost can generally decompose in a few weeks to months. (Writer 2011).

2.2.3.4 Temperature

The optimal temperature range for compost falls between 30°C and 60°C. The thermophilic stage of decomposition is the fastest, and occurs at temperatures between 40°C – 60°C. The compost should not exceed 60°C, however, as such high temperatures kill beneficial microorganisms. In addition to the fast rate of decomposition, it is ideal to bring compost up to this temperature range in order to kill fly larvae and weed seeds. To kill pathogens, The U.S.

Environmental Protection Agency recommends maintaining a temperature of at least 40°C for five days, during which temperatures of at least 55°C should be maintained for a minimum of four hours. If the temperature drops during thermophilic decomposition, it can be brought back up through aeration (mixing) (Trautman 1996).

If the compost gets too hot, it can be moistened and aerated to bring the temperature down (University of Illinois, n.d.).

After the thermophilic decomposition stage is finished, mesophilic processes occur. During this stage, temperatures will be lower than they were previously during thermophilic decomposition. The compost becomes more mature, and chemical processes yield a stable, relatively homogenous mixture that is suitable for use in the garden (Trautman 1996). Figure 2-6 shows a graphical representation of the average temperature of a compost pile versus the time it has been left to decompose.

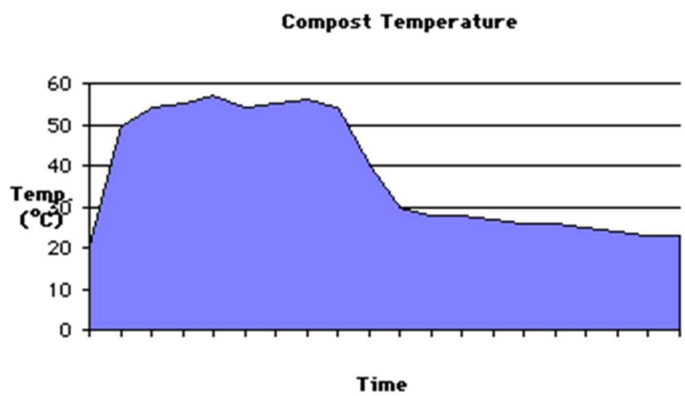

Figure 2-6. Graph of temperature versus time for an average compost pile (Trautman 1996).

2.2.3.5 Carbon/Nitrogen Balance

Many items can be composted, but for a good, successful compost there must be a balance. This is called the carbon to nitrogen balance or better known as the green(nitrogen) to brown(carbon) balance, shown in Figure 2-7. A good carbon to nitrogen ratio is between 25:1 and 30:1. With this ratio the compost pile will decompose faster. (Master Recycling Program n.d.). Ratios above 30:1 (carbon) cause the pile to become inefficient, as they don't heat to a high enough temperature for decomposition to occur at a rapid pace. If nitrogen is in excess the pH of the compost pile will rise, which will cause the pile to become too toxic for some microorganisms.

Figure 2-7. A table showing carbon-m and nitrogen-rich compostable materials. (Mclaughing n.d.)

2.2.3.6 Weather Considerations

Eureka's climate can prove to be a factor in what building materials we decide to use. Eureka's annual high temperature is 59.6°F and its low is 46.2°F but we are not so much worried about temperature as much as we are worried about how much rainfall Eureka gets. Annually, Eureka gets about 40 inches of rain and receives most of that rain during the months of October to May. Summers are not so hot either with highs reaching mid 70s°F. (US Climate Data) When building our compost, we want to take in consideration the weather conditions so we could decide if we need to treat the materials we use to resist weathering. The moisture and the amount of rainfall the area gets will be a main component to why we choose certain materials so our compost will last longer.

2.2.4 Material Considerations

This section details the materials that were considered for use in building the composting system.

2.2.4.1 Wood

When specifically looking at wood, decay and fungal invasions are its main problem. Higher nitrogen content can cause the wood to decay faster but little is known about fungal invasions and how they affect wood. There is little published that talk about wood degradation in agricultural environments and but we do know it happens typically in agricultural environments. To prevent decay, treating the wood with an emulsion will help protect it from decay. Polyethylene and oxidized polyethylene wax was found to be most effective when tested. (Belie, N. De 2000). Wood is particularly prone to instability in moist environments. When wood gets wet, the material tends to expand and then contract once it dries. This causes the molecules inside to flex and shrink which leads to loss of structural integrity over time. When choosing this material, it is important to consider how long our structure will last and if we could do anything to resist these environmental conditions. Unless treated with some sort of emulsion, wood will not last as long and will be needed to be replaced once rotting has occurred (Belie, N. De 2000).

2.2.4.2 Steel and other metals

Steel is a very valuable building material in that it is very durable. It is resistant to termites and handles well in extreme environments. The main downfall of steel is that it is a costlier building material compared to wood. Steel is also susceptible to corrosion and rusts easily. When considering steel, we could be considering designing a rotating composter because the specific design requires some sort of steel barrel. There are places that sell repurposed steel barrels and would be ideal in this situation. Barrier coatings of paint is readily available and can be used to isolate the metal from water and oxygen. Without the availability of water and oxygen, the metal cannot corrode. Steel is also mold resistance since it is in organic and does not provide food for mold to grow. Ventilation can be easily designed into our steel by drilling holes and will not compromise the integrity of the material too much. Steel is also vermin resistant because they would be unable to penetrate through the metal and we would not need to worry about termites eating at the wood. Steel will provide long-term, consistent performance and will not expand or contract with moisture. It will not warp split, or crack when exposed to environmental conditions since it is isotropic. Isotropic means that the dimensional properties are all the same in all directions of the material (Durability of Steel,2017).

2.2.4.3 Plastics

When considering plastic, there are several benefits that could be integrated into our design. Typically, plastics are made of hydrocarbon monomers that are linked together. Plastics are usually lightweight and can vary in strength from type to type. They can be classified as durables or non-durables plastics in that durable plastic will last more than three years and non-durables typically will not last long. When considering plastic into our design, its strength and resistance to moisture is important. Plastic will not expand and contract like wood and will act like steel when considering structural integrity. Plastics will expand when exposed to high temperatures and contract in low temperatures but our environment will not yield this problem so temperature will not be considered. Plastics however are not as rigid as steel and can flex when force is applied. When looking at our design, plastic can be used as a mesh to contain our compost and can act as a barrier to keep rodents out. Similarly, when looking at the tumbler design, we can also buy repurposed plastic barrels (J H. Greenwood, 2002).

2.2.5 Compost in Schools

This section details examples of composting in primary schools in the United States, and provides examples of educational activities related to compost. This section also details the California science standards for 6^{th}, 7^{th}, and 8^{th} grade.

2.2.5.1 Zane Middle School

Zane participated in the Humboldt Environmental Ambassador Pilot Program (HEAPP), which in part resulted in the retired worm bin composting system. Seventh-graders were directly involved in establishing the worm bins. They also conducted waste audits, during which they gained an understanding of the amount and kinds of waste generated by the school (CalRecycle).

2.2.5.2 Connecticut Schools

Various schools across Connecticut compost. At these schools, all students can be involved in composting in some capacity, whether it be scraping their waste into the proper containers at the end of lunch, or take a leading role helping younger students. Schools employ the volunteer system or work study (for-credit) to compile groups of student compost monitors. Under adult supervision, the monitors help other students dispose of their lunches properly, ferry compost from the lunch room to the main pile, assist with turning and upkeep.

Daily upkeep tasks include collecting and weighting food scraps, transporting them to the compost, monitoring compost temperature, spreading food scraps, layering them with bulk material, and cleaning up after these activities. Weekly tasks include maintaining observance of the structural integrity of the compost bin(s), turning the pile, acquiring bulk material, and trouble-shooting any problems which might arise regarding the effectiveness of the composting system.

To gain scientific experience through composting, students can weigh the daily additives to the pile, keep good record of the temperature (read on a compost thermometer), and make general qualitative observations. They can track the volume changes over time as well. All of these qualities can help students determine the stage of decomposition, and whether the processes are working correctly.

Adults are involved in many different facets of the composting program. The cafeteria workers are consulted for input regarding a manageable and effective food disposal system in the kitchen. Parent volunteers spend time with students, training them to monitor the bins in the cafeteria, helping them transport food waste, and assisting with turning and upkeep processes (Walton et. al n.d.).

2.2.5.3 Promotional Activities

Some schools choose to sell plants from their garden to bolster community involvement and fund related activities. Compost is sometimes packaged and labeled and included as merchandise at these events (Walton et. al n.d.).

Some schools choose a week during the first or second month of school to promote compost awareness and help kids get used to the cafeteria sorting system. Awards are given for compliance with the system (Walton et. al n.d.).

When schools choose to make students a central part of the compost operation, they can help maintain motivation in a variety of ways. Student volunteers may get special recognition at events, earn class credit, or earn points towards rewards. Rewards can be community-based, and acquired in the form of gift certificates or small items solicited from business by parent volunteers (Walton et. al n.d.)

2.2.5.4 Pedagogy

The culmination of 20 years of research has shown that students learn best in environments which stimulate passion and interest in both teachers and students. When new concepts are directly connected to the real world, students take more interest and therefore retain more information (Hoffman et. al 2007).

A 2007 study at a Los Angeles community college found that when students participated in a voluntary gardening program at the school, their language and science scores improved in their classes. Students of various ethnic backgrounds became more vocal an interactive with each other, and self-reported higher self-esteem and lower ethnocentricity after their involvement with the garden than before (Hoffman et. al 2007).

2.2.5.5 California Science Standards for Sixth Grade

Sixth-graders focus on earth sciences. Among the concepts introduced at this level is thermal energy, to the extent that heat energy is released when fuel is consumed. Radiant energy is introduced as well. Students learn that solar energy reaches the earth, mostly in the form of visible light, and that plants use light to make energy though photosynthesis. Students are expected to understand that organisms are categorized by the functions they serve within their ecosystem. They learn that the sizes and types of populations an environment can support has to do with physical factors such as temperature, moisture, and growth media composition. They study natural resources, and learn to classify things as renewable or non-renewable. Scientific inquiry is introduced, and students learn to develop and test hypotheses (California State Board of Education 2003).

2.2.5.6 California Science Standards for Seventh Grade

Seventh-graders focus on life sciences. They learn to distinguish plant and animal cells, are introduced to photosynthesis in chloroplasts (energy storage) and respiration in mitochondria (energy release). Basic genetics is introduced, along with sexual and asexual reproduction (including humans and angiosperms), heredity, and DNA. Students learn about the structure, function, and organization of organ and tissue systems. They look at skeletal features such as joints and sockets, and make comparisons to machinery. Students explore evolution and extinction, and understand how to use fossil records. They connect life to earth sciences by studying geologic cycles and the movement of continental plates, and learning the role these phenomena play in the distribution of organisms on earth. The seventh-grade curriculum includes a study of light, detailing the visible spectrum within the electromagnetic spectrum, and the properties of absorption, reflection, refraction, and transmittance. Seventh-graders are introduced to the concept that objects are visible due to light they emit or scatter. They study ocular devices, such as microscopes, magnifying glasses, cameras, telescopes, and eyes. They further their understanding of scientific inquiry by forming hypotheses, selecting instruments to test their ideas, researching those ideas, and communicating their results through written and oral reports (California State Board of Education 2003).

2.2.5.7 California Science Standards for Eigth Grade

Eighth-graders focus on physical science. They are introduced to speed and velocity and their connection to the rate of change of position, and learn to interpret graphs of position or speed versus time. They consider mass, and learn that unequal masses require proportionally unequal forces to be moved the same distance. Forces are discussed, including gravity, tension, compression, friction, density and buoyancy. The curriculum includes chemical concepts such as the periodic table, the structure of an atom, properties of elements, and that properties of compounds. Eighth-graders learn about the states and structure of matter, including the movement of atoms in solids, liquids, and gasses. Conservation of matter is introduced. Students explore chemical reactions, the differences between physical and chemical processes, and that heat is either liberated or absorbed during the latter. They learn about pH, acidity, basicity, and neutrality. Chemistry is connected to biology. Students learn that carbon, nitrogen, phosphorus, sulfur, and oxygen are central elements to living structures, and that water, salts, carbohydrates, fats, proteins, and DNA are all molecules essential for life. In addition to formulating and testing hypotheses, eighth-graders learn to recognize whether their experiments are accurate and reproducible. Their analytical techniques are expanded to include detection of linear and non-linear relationships, interpretation of the slope of a line, and development of quantitative relationships between known, unknown, constant, and variable parameters (California State Board of Education 2003).

2.2.5.8 Compost-Related Activities

Educational, compost-related activities for grade levels 2-6 include identifying objects that are or are not biodegradable. This can be accomplished though taking a survey of items thrown away at home and school, discussing which materials are recyclable, and then identifying the remaining materials which are appropriate for the compost.

To gain personal experience and understanding of the compost process, kids can create their own tiny composts in the classroom. To start, they can cut small scraps of fruit and vegetables into tiny pieces and place them in their cups, which would be covered with a screen. Each day, they can moisten the mixture slightly and stir it around. By making daily observations of the scent, darkening, shrinking, and general composure of the decomposing matter, students can foster an understanding of the process of composting. If they plant an easily-germinated seed (such as bean or corn) in their concoction, they can also develop a deeper understanding of the relationship between life, death, and re-birth (Wilson 1995).

Another activity appropriate for middle school is performing an experiment which involves growing triplicates of the same plant. The kids can plant one in compost, one with half compost and half soil, and one with only soil. They can watch their plants grow while taking measurements and making observations (ACMASR and RB 2007). This experiment can be expanded to include additional soil/compost ratios and plant species. An example set of observations includes temperature, scent, and texture. After a few months, students can construct a graph of the compost temperature versus time, which they can compare with their qualitative observations. The teacher can lead discussions including topics such as the necessity of measuring temperature at a constant depth and location, the role of decomposing organisms, and the relationship between odor and stages of decomposition (Cronin Jones 1992). An example of a compost worksheet is located in Table 2-2.

Table 2-2. Compost worksheet, middle school level (Cronin Jones 1992).

KEY COMPONENT	FUNCTION
1. Soil	Contains microorganisms (bacteria) that help decompose organic materials.
2. Organic wastes (e.g. leaves, fruit and vegetable scraps, egg shells, and grass clippings) containing both carbon and nitrogen Meat scraps, fats, and oils inhibit decomposition and their strong odors can attract dogs, rats, raccoons and other animals. They should not be used in compost piles.	Alternating layers of high-carbon and high-nitrogen wastes creates good environmental conditions for decomposition to occur. 
3. Fertilizer containing nitrogen or manure or green grass clippings containing nitrogen	Many of the organisms responsible for decomposition need extra nitrogen for rapid and thorough decomposition.
4. Earthworms	Eat the waste and help break it down; Make droppings which enrich the soil; Tunnel through and aerate the waste thus aiding decomposition; Eventually die and become part of the compost.
5. Water	Essential component of the decomposition process; Too much water can make the compost pile soggy and slow decomposition by reducing needed oxygen.
6. Air	Fungi, bacteria, small insects, and other decomposing organisms require adequate amounts of oxygen to survive and function.
7. Time	Decomposition takes time; aerating the compost pile every few days can speed up decomposition.
8. Heat	Heat is a by-product of the chemical reactions occurring during decomposition; A properly functioning compost pile can reach a temperature of 150° Fahrenheit; These high temperatures help sanitize compost by killing weed seeds, pathogens and harmful insect larvae.
9. Mass	In order to generate enough heat for optimal decomposition, a compost pile should contain at least one cubic meter of organic material.

Students can investigate the effects of surface area to volume ratios by performing a composting experiment involving a variety of sizes of plant matter to be composted. While holding parameters such as temperature, light, and type of compostable material constant, they can compile and observe small-scale compost samples which each consist of uniform and uniquely sized organic matter. After several weeks, the students can make inferences as to the effectiveness of the compost process in relation to the different samples (Cronin Jones, 1992).

An activity which can be adapted to a wide variety of grade levels is identifying the decomposer organisms that reside in compost. Students can obtain samples of compost and identify organisms in groups, with the aid of a worksheet. A discussion can be facilitated regarding the role of decomposers, adapted to grade level (ACMASR and RB 2007).

Cornell University presents a bench-scale bioreactor project that is appropriate for middle school. To construct the bioreactor, students need two plastic 2- or 3-liter bottles, one small container (about 5 sm high) that fits inside the bottles, a nail or drill, tape, a utility knife, two Styrofoam plates, insulative material (such as Styrofoam peanuts or foam rubber), a fine meshed screen, a thermometer, green waste and bulking material (brown waste), and tubing for ventilation (optional). After following the construction procedure detailed on Cornell's website, students can make variations of the bioreactor itself and the compostable materials to be added. Making daily observations, the class can compare different variables such as green to brown ratio, types of green and brown waste, air flow, moisture level, and insulation, and make inferences regarding the viability scale of different components of the system. A diagram of this bioreactor is located in Figure 2-8, and Figure 2-9 depicts an example student project.

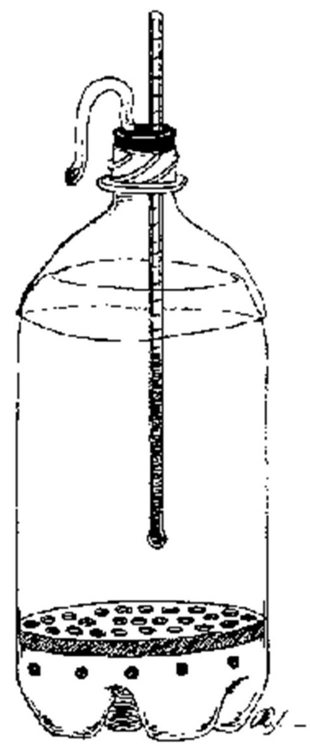

Figure 2-8. Bioreactor diagram (CWMI n.d.)

Figure 2-9. Example student bioreactor (CWMI n.d.)

3 Alternative Solutions

3.1 Introduction

Section III is composed of the brainstorming process which led to the alternative solutions to satisfy Zane Middle School's need for a composting system. The solutions are described generally, with the formation of specific details reserved for the adopted design.

3.2 Brainstorming Process

Our informal brainstorming process was conducted over the course of a few weeks. It began when met our client and heard his ideas and previous experiences with compost. Our formal brainstorming process was a popcorn-style conversation that extended for half an hour. We collected as many ideas as we could, and then selected our top 9 solutions for further consideration. We recorded our raw ideas with pencil and paper. Our alternative solutions cover a wide variety of different designs that each have their perspective pros and cons. We focused on different ways to achieve the specifications and considerations in Section 2.1. Our notes from our brainstorming session can be found in the Appendix of this document.

The alternative solutions we generated are listed below. Detailed descriptions follow.

- The Tin Man
- The Class Can
- The Roll-Around
- Trashy Bins
- Bag it Up
- Go Escargot
- Woody
- The Pit
- The Barrel

3.3 The Tin Man

The Tin Man employs metal barrels or trash cans, either of which have removable lids that uncover the entire diameter of the top of the receptacle. These are placed outside in the garden. As indicated in Figure 3-1, the bottoms are cut out and replaced with hardware cloth or hardware cloth, which is secured in place with epoxy or welds. The hardware cloth helps fulfill the rodent-resistant criterion, while allowing leachate to drain and giving worms access to aid the biodegradation process. As depicted on the right side of Figure 3-3-1, these bins can be insulated during the winter months with a couple of layers of corrugated cardboard or foam rubber, which would be wrapped with a fitted rainfly or heavy plastic held in place with a strong duct tape. Alternatively, the cans can be partially buried, which would make them much less prone to toppling (or being pushed) over and meet our durability constraint. For this system to work properly the compost is added to the bins in rotation, just as with a traditional 3-bin system. The upkeep constraint would be met, as the upkeep demand extends only to the compost being turned several times each week.

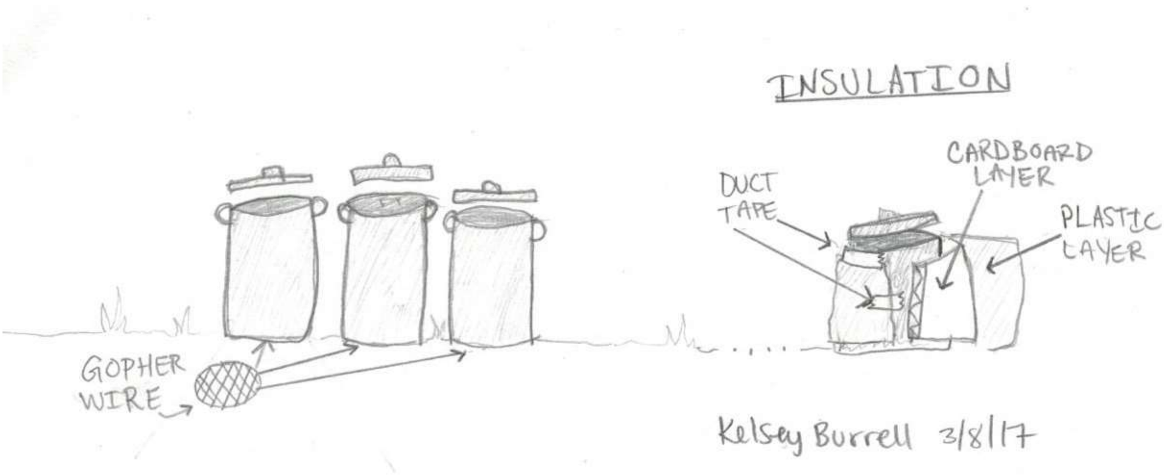

Figure 3-3-1. Tin Man diagram.

3.4 The Class Can

The Class Can is a small-scale composting system that can be implemented in a classroom or outside. The benefit of having this in-class version is the students could be more consistently and actively involved with the compost process, which could result in the design meeting or exceeding its educational value constraint. The system is fairly simple to build. Holes are punched through one garbage can (10 or 20 gallons), which fits into another, larger can (20 or 35 gallons) with a tight-fitting lid. The holes should be large enough to allow leachate to run through from the compost into the outer can, but not so large as to allow compost through. As depicted in **Error! Reference source not found.**, a brick or similar object should be placed inside the outer can to elevate the inner can, and allow ample space for leachate runoff. To reduce the odor of the composting matter, wood chips, soil, or other absorbent organics can be placed inside the outer can. Alternatively, the bottom of the outer can could be equipped with a spigot to allow for leachate extraction. This latter method would provide the opportunity for the leachate (or "compost tea") to be extracted and used as a nutritive addition to the garden. This system was developed by the Cornell Waste Management Institute (Cornell, 1996).

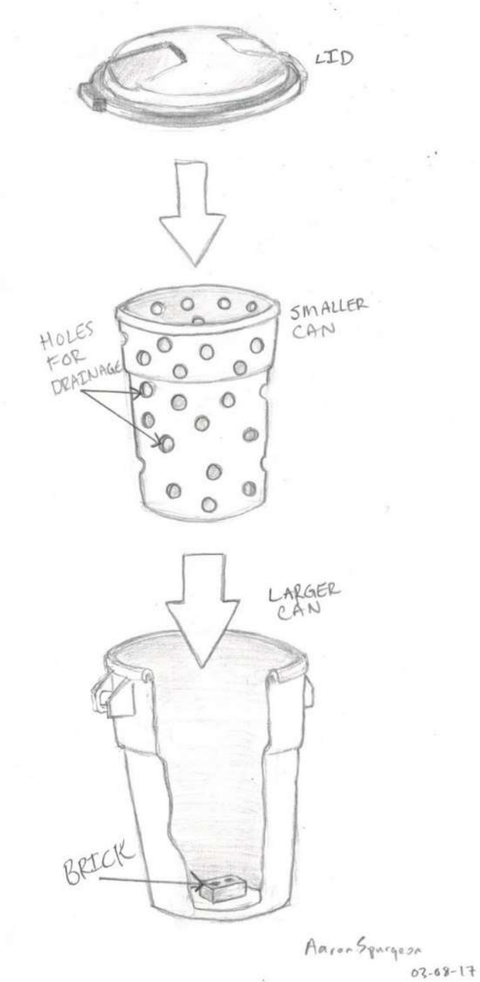

Figure 3-2. The Class Can diagram.

3.5 The Roll-Around

The Roll-Around composter is inexpensively constructed from one or more cylindrical 10- or 20-gallon plastic garbage cans, similar to the one depicted in Figure 3-3. The can is rolled around the garden for the purpose of mixing the compost. The compost should be mixed by children or adults every week or two. For the sake of ease of rolling, the handles cannot stick out from the main cylindrical body of the can. The handles either fold to lay flat against the can, or are removed without puncturing through the can. The diameter of the lid is as small as possible, to create a cylindrical shape rather than a conical one. If the shape of the overall vessel is more conical than cylindrical, rolling it in a straight line is more difficult. The lid is securely fastened with bungee cords, as shown in Figure 3-3. The bungee cords are necessary to secure the lid so it won't fall off when the can is rolled around the garden. The children could remove the bungee cords and access the compost easily. The can is punctured to allow for airflow and leachate runoff. To encourage maximum compost retention, the diameter of the holes should not exceed 1/8". The holes should not be smaller than 1/16" or so, so they will have less of a chance of becoming blocked with solid matter. The runoff may get on the shoes or hands of users, but the volume of liquid in total will be small and easy to rinse off if necessary. The rodent resistance constraint may be compromised by this design, since rats can chew through plastic. The educational opportunity of the structure itself may be lacking as well, as there isn't a good location to attach a display.

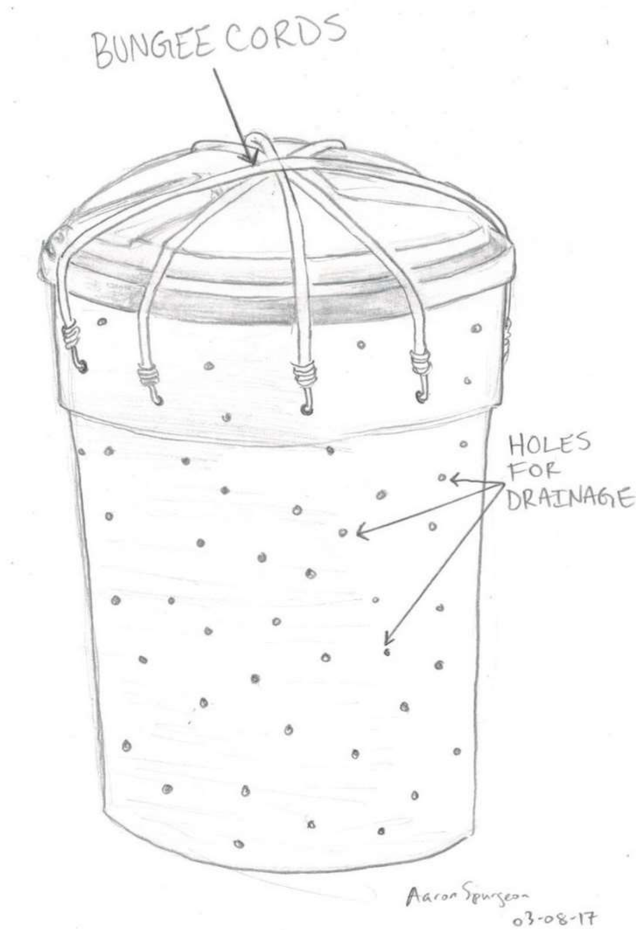

Figure 3-2. Roll-Around diagram.

3.6 Trashy Bins

Trashy Bins is a 3-bin composter intended for indoor composting. The sizes of the bins can scale with the user's compost volume, but it's best to keep them small for indoor use to avoid smell and flies. As seen in Figure 3-3-3, Trashy Bins employ three plastic trash bins, which are tied together so they can't be kicked over by small children, pets, and clumsy people. The materials are easy to get and is well under the budget of $425. With this system being an indoor system rodents shouldn't be a problem. This meets the criteria of the system needing to be rodent resistant.

Fresh composting material is put into bin #1 and receives a weekly turn, which gives the compost time to warm up and begin the decomposing process. After a couple of weeks in bin #1, the material should appear slightly more homogenous than raw compost. When the matter has decomposed past the point of obvious color and rigidity, it will be transferred to bin #2 for the remainder of the composting process. After several more weekly turns, the matter will be blended and decomposed past the point of recognition, and that is the point when it's ready to be moved to bin #3. The prepared compost will be stored in bin #3 for use in the garden.

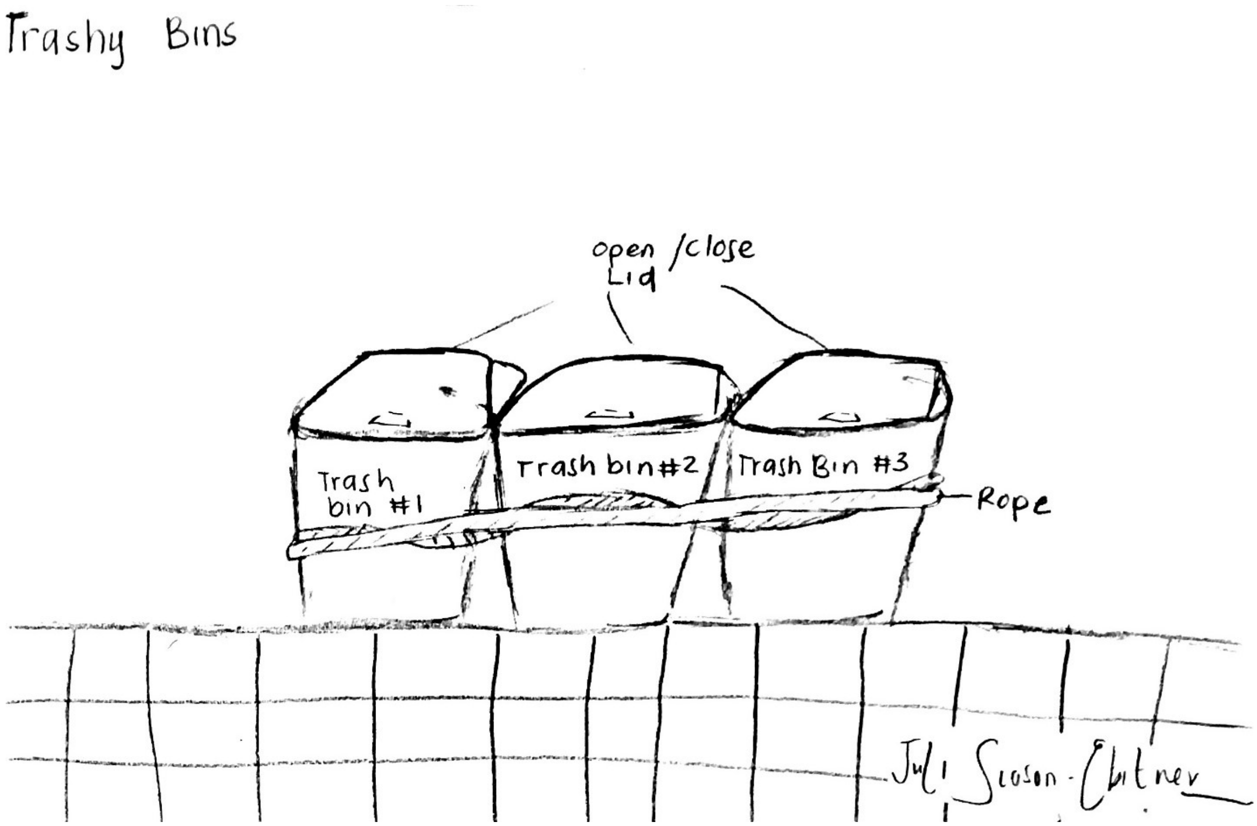

Figure 3-3-3. Trashy Bins diagram.

3.7 Bag it Up

The Bag it Up composter is an example of anaerobic composting. It's also a contender for the least labor-intensive composting method. Necessary materials include a plastic bag, composting materials, and a bucket to hold the bag of compost. This is displayed in Figure 3-3-4. With the materials being items can be found around the house Bag it Up meets the criteria of cost and the constraint that it has to be under $425. The fresh compost materials are placed in the bag, which is placed in the bucket. The bucket is left out in the sun for several months. This anaerobic process takes at least 6 months to kill off the pathogens and dangerous micro-organisms, but after the 6-month period the compost will be nicely blended. A warning about this method: the contents of the bag will be stinky due to the methane produced by the bacteria during respiration. Additionally, the compost must be put through an aerating phase after it's removed from the bag because its pH will be too acidic for plants. The aerating process takes about a month, and can consist simply of compost being left in a bin to interact with open air, and turned every few days (Planet Natural 2016).

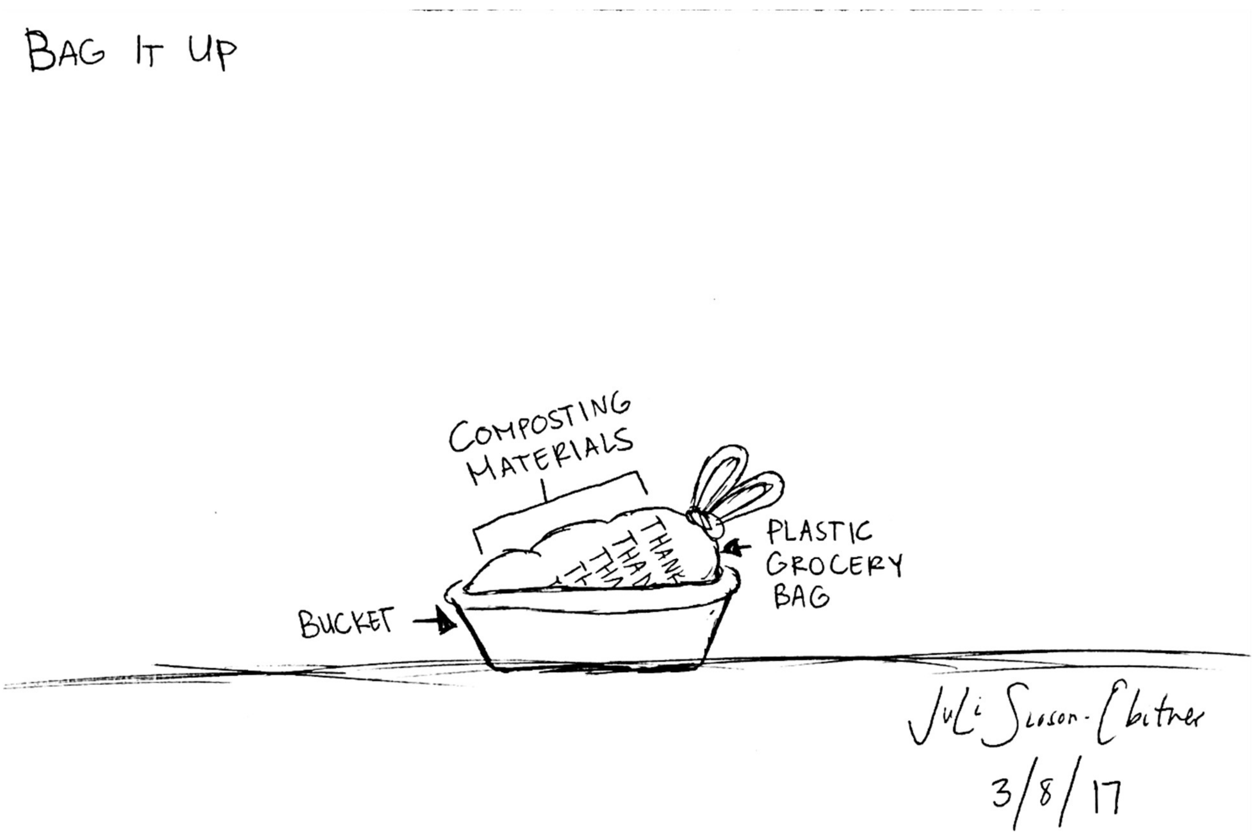

Figure 3-3-4. Bag it Up diagram.

3.8 Go Escargot

Go Escargot is similar to a worm-composting system, but instead of worms the process uses snails. As shown in Figure 3-3-5, Go Escargot is housed in a metal trash can, and includes distinct layers of compostable material. The system is closed with a lid which helps keep the warmth in and also keeps the pests out. Since rodents can't chew through the metal can, Go Escargot meets the criterion of being rodent-resistant. The top is the bedding layer, which consists of shredded newspaper or other paper materials. This layer provides insulation for the snails so they don't get too cold and die. Beneath the bedding layer are the compost and snails. The snails digest the compost, which helps speed up the decomposition process. The decomposed material and snail excrement falls through a filter (which is attached to the inside of the trash can) and into a drawer that is inserted into the bottom of the can. The filter can be made from hardware cloth or chicken wire. The drawer pulls out for quick and easy access to prepared compost. For this design to be adequate for use in a garden, the snails have to be restricted to the inside of the can. They would eat through the vegetables in the garden if left to have free access in and out of the compost.

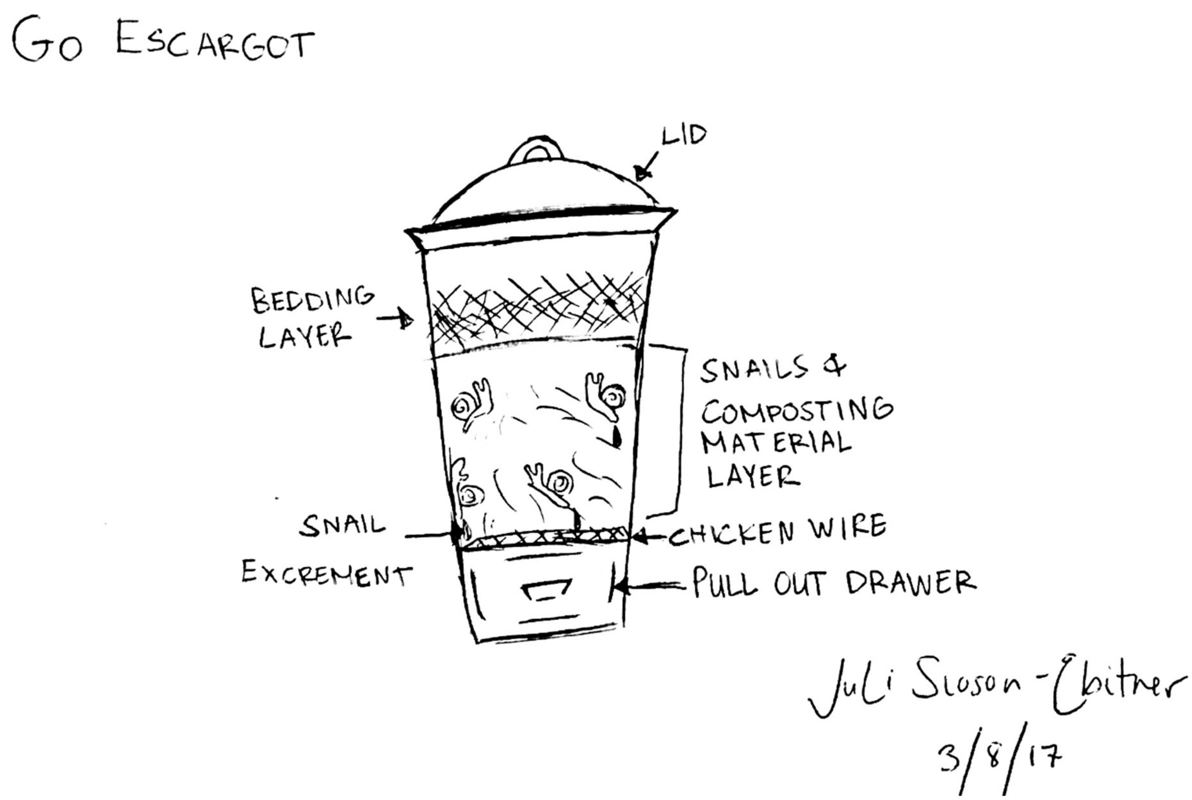

Figure 3-3-5. Go Escargot diagram.

3.9 Woody

The design with a hinged cover allows for easy access to the composting material, and allows students to visually track the composting process. Due to the wet climate in Eureka, it is very important to control the amount of moisture that infiltrates the compost. The features of the design are shown in Figure 3-7. This is designed with a **A** metal lid that will help enclose our compost, prevent unwanted moisture from entering, and will provide ease of access to the piles. Eureka gets about 40 inches of rain per year, so allowing the compost to be exposed to the elements would be severely detrimental to the biodegradation process. **C** Wood is fairly cheap and easy to work with during construction. Since the compost is more exposed from the sides where there is **B** wire mesh, retaining the pile's core temperature and moisture levels may be a problem. To turn the material, it is required to grab a shovel and mix. This could provide a great activity for students and will allow them to understand the system a little better. This design may prevent some unwanted pests like rats from getting into the pile but they may be able to chew through the wire mesh or wood. It may be a good idea to apply some sort of deterrent or use thicker wire to prevent unwanted pests. **D,E,F** are sections where the compost is added and acts as stages when turning the material. The initial material will start on the **D** and will be transferred to **E** and then finally end at **F** depending how decomposed the material is. (Eartheasy)

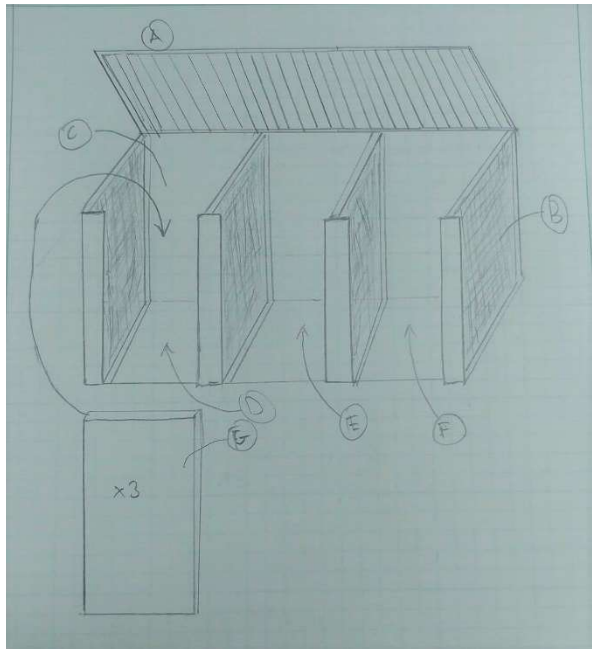

Figure 3-6. Woody diagram. ***A****. Metal Closeable Lid,* ***B.*** *Wire Mesh* ***C.*** *Wood Material* ***D,E,F.*** *Sectioned Compost Piles.* ***G****. Slidable Wood Walls. By Ronnel Yabut.*

3.10

3.11 The Pit

As shown in Figure 3-8, The Pit is a trench dug into the ground. Compost is placed in the pit, and covered with hay, wood chips, or sawdust. It is simple to start requiring only a shovel, it retains moisture well, it directly feeds worms or other organisms that live in the soil, it improves drainage, and the site is essentially in one place. As in Figure 3-8, label **A,** the pit will act as an enclosure for our layered compost (label **B**) and will need to be mixed with a shovel from time to time. When considering safety, this design becomes a hazard and may need to be (label **C**) fenced off to prevent students from falling in. It also does not retain temperature well and would result in cold composting. Unwanted creatures may also dig around the site and get into the pile since the compost is not contained within a bin or structure. If Zane Middle School decides that the compost is not needed anymore, it would require more work to dig out its contents and then fill the hole back up with new soil. New soil is required because this type of compost will deplete the nitrogen levels in the soil and will not be a good place for new plants to grow if you wanted to plant a tree in place for example. Lastly, since this design favors cold composting, the material will take a while to break down (Dryer).

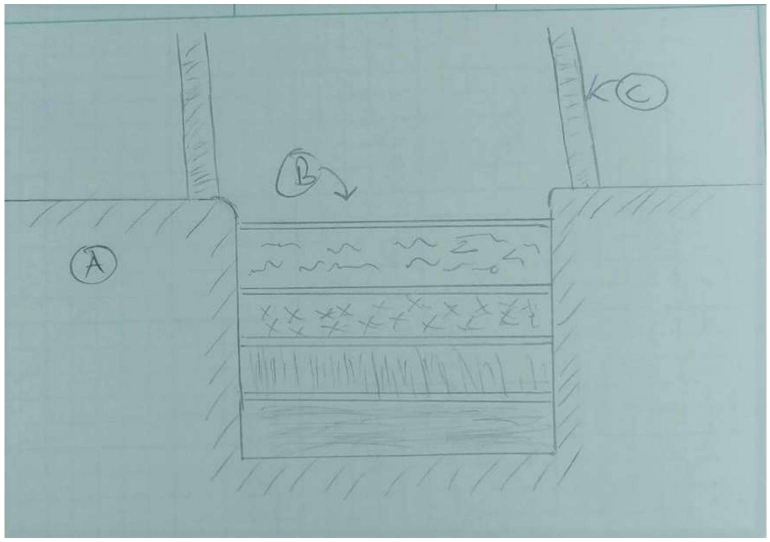

Figure 3-7. The Pit Diagram. ***A.*** *Ground Enclosure,* ***B.*** *Layered Compost,* ***C.*** *Wood Fencing. By Ronnel Yabut.*

3.12 The Barrel

The Barrel provides an easy way to turn the material by mounting the barrel on four wheels. By mixing, it allows the material to be exposed oxygen and moisture throughout and is much easier than getting out a shovel and turning the material by hand. By using a repurposed metal barrel, it eliminates worrying about the compost being exposed to the elements. Reusing metal and barrels can also help reduce the general footprint of the design. Drilled holes (shown in Figure 3-9 label **E**) are needed so air can get inside. The enclosed compost also allows the material to cook and retain its internal temperature. By mounting the barrel on the wheels, the kids will have a lot of fun turning the material. It is however really hard to see what is going on inside the barrel without some sort of trapdoor, which is shown in Figure 3-9 label **B**. If the school wanted to compost bigger items or just have a bigger volume of material, the barrel may get too full or the material may need to be broken down into much smaller pieces. The design is more complex than the other designs and will require a more thoughtful approach to measurements. If more than one is made, different types of compost can be made and can prove to be an educational experience in that students can differentiate between the different types of compost. (Eartheasy)

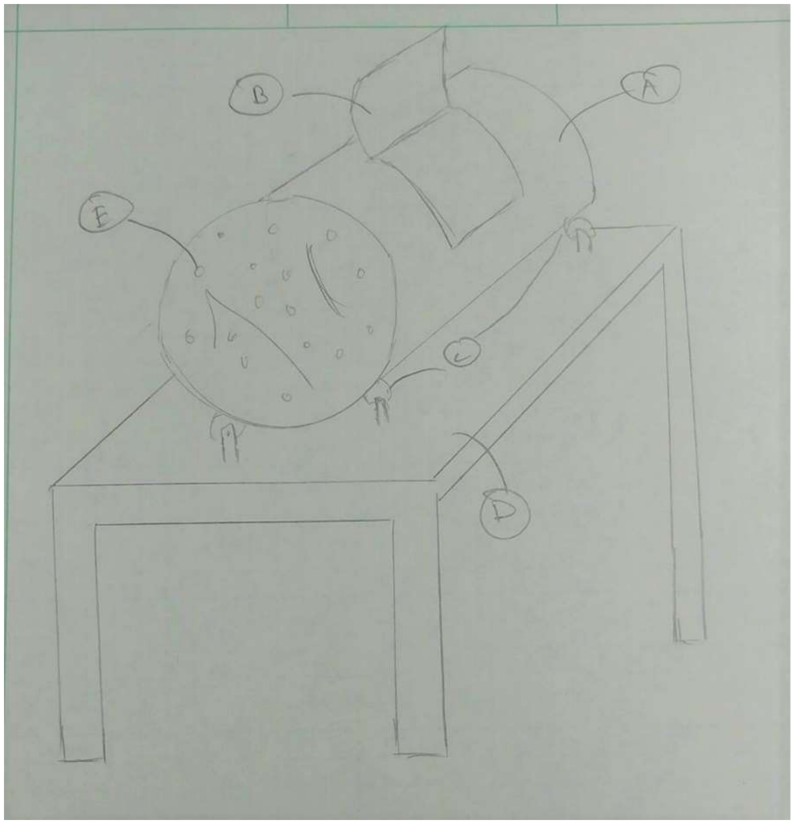

Figure 3-8. The Barrel diagram. ***A.*** *Metal Repurposed Barrel,* ***B.*** *Trapdoor,* ***C.*** *Wheels,* ***D.*** *Wood Table,* ***E.*** *Drilled Holes. By Ronnel Yabut.*

4 Selection of the Final Design

Section 4 presents the analysis of the alternative solutions, and the process of selecting the final composter design. The elements which influenced this selection process were client feedback regarding the alternative solutions, the design criteria, and the benefits and drawbacks of certain instruments explored in the literature review. A Delphi matrix is located in Section 4.4, and presents the synthesis of the alternative solutions with the design criteria. The result of the Delphi analysis is a set of numerals, which are interpreted to assign a sliding scale of the ability of the alternative solutions to satisfy the needs of the client.

4.1 Criteria

The following criteria are defined in Section 2.1.3. They are based on the specific needs of the client, and were considered when choosing the final design.

- Pest-resistance: the ability of the structure to protect the compost from pests like rats and raccoons.
- Maintenance: the amount of work required to maintain the compost system.
- Durability: the ability of the structure to withstand wet weather and rowdy humans.
- Safety: the freedom from anything sharp or otherwise harmful to people.
- Simplicity: the ease of use and maintenance.
- Cost: the total amount of money spent on building materials and other needed tools to complete the design.
- Aesthetics: the ability of the design to match the overall motif of the school and the garden.
- Educational Value: the ability of the design to provide learning opportunities to all students at the school.

4.2 List of Alternative Solutions

The alternative solutions presented to the client for consideration are as follows:

- The Tin Man
- The Class Can
- The Roll-Around
- Trashy Bins
- Bag it Up
- Go Escargot
- Woody
- The Pit
- The Barrel

4.3 Decision Process

The decision process consisted of presenting the alternative solutions to the client, receiving and considering his feedback, and accounting for each criteria and constraint. Nine alternative solutions were presented to the client. After the client meeting, each criterion was placed on a scale of 1-10, where 1 is least important and 10 is most important. The weighted criteria are shown in Table 4-1.

Table 4-4-1. Criteria and weights.

Criteria	Weight (0-10 high)
Safety	10
Educational Value	9
Pest-resistance	8
Simplicity	7
Durability	6
Maintenance	5
Cost	4
Aesthetics	3

A Delphi matrix was used to assess the ability of each alternative solution to meet each criterion. The scale used was 1-50, where 1 was associated with the design being extremely unlikely to meet the criterion, and 50 was used when the design was extremely likely to satisfy the criterion. The values for each design were added at the bottom of each column, with higher numbers signifying designs that were more likely to satisfy the design criteria. The completed Delphi matrix is shown in Table 4-4-2.

Table 4-4-2. The Delphi matrix used for the design selection process.

Criteria	Weight (0-10 high)	Alternative Solutions (0-50 high)								
		Bag it Up	Go Escargot	Trashy Bins	The Pit	Woody	The Tin Man	The Class Ca	me Roll Aroun	The Barrel
Pest-resistance	8	5 / 40	40 / 320	30 / 240	2 / 16	45 / 360	45 / 360	40 / 320	20 / 160	45 / 360
Maintenance	5	50 / 250	15 / 75	20 / 100	45 / 225	40 / 200	35 / 175	20 / 100	35 / 175	35 / 175
Durability	6	10 / 60	25 / 150	30 / 180	45 / 270	45 / 270	45 / 270	40 / 240	40 / 240	40 / 240
Safety	10	15 / 150	30 / 300	35 / 350	5 / 50	40 / 400	35 / 350	40 / 400	30 / 300	40 / 400
Simplicity	7	45 / 315	15 / 105	30 / 210	45 / 315	35 / 245	28 / 196	20 / 140	40 / 280	20 / 140
Cost	4	45 / 180	20 / 80	40 / 160	50 / 200	20 / 80	20 / 80	35 / 140	40 / 160	20 / 80
Aesthetics	3	5 / 15	15 / 45	25 / 75	10 / 30	50 / 150	30 / 90	25 / 75	25 / 75	40 / 120
Educational Value	9	10 / 90	20 / 180	40 / 360	20 / 180	45 / 405	25 / 225	40 / 360	20 / 180	20 / 180
	Total	1100	1255	1675	1286	2110	1746	1775	1570	1695

4.4 Final Decision

As shown in Table 4-4-2, the Woody received the highest Delphi score. The design scored high for each criterion, with the exception of cost. Cost was not weighted heavily, as the client requested that the final product be constructed with high-quality materials. The Woody scored the highest of all designs on aesthetics, and although it is more expensive than other designs, the necessary materials were still acquired within the budget of $425. The Woody has excellent pest-resistant qualities, as it is lined with hardware cloth which rats can't chew through. It is safe and durable; it's heavy, painted with weather-resistant paint, and the biggest safety concerns are splinters and exposed wire ends inside of the structure. The design can provide many educational opportunities to the school, including use of the educational posters, activities involving temperature monitoring, and experiments discussed in Section 2.2.5.8. Finally, although the design received a middle-of-the-road score for simplicity, the maintenance it requires is minimal, and falls entirely within the scope of reason according to the client.

The Woody design was altered slightly from the description in Section 3-9. Two bins were constructed instead of three, and the entire structure has dimensions of 7' x 3'. The original design included doors that sat in slots and slid vertically in and out of the front panels. Hinged doors that fold down the front were used instead. This helped the design be more accessible for the kids, and doesn't present the danger of the door paths becoming blocked by composting matter. Educational posters are prominently displayed on each bin. The posters describe the types of organic matter to be composted, and a little about the physical, biological, and chemical processes occurring within each bin.

5 Specification of Solution

5.1 Introduction

Section 5 describes in detail the composter which was implemented at Zane Middle School. This section contains a complete description of the design, along with instructions for implementation and use of the composting system. Analyses of the capital costs, labor, and the projected cost of maintenance are included in this section as well. The results of testing can be found at the end of this section.

5.2 Description of the Final Product

As introduced in Section 4.6, a modification of the "Woody" alternative solution was selected for Zane Middle School. The structure is made of wood, and has a corrugated metal roof and two compartmentalized bins. The left-side bin is where fresh material is added, and the right-side bin is where maturing compost is moved and let to turn into soil. In total, the design is 8 feet wide, 3 feet and an inch deep, and 4 feet high at its highest point. The overall shape of the structure is depicted in Figure 5-1.

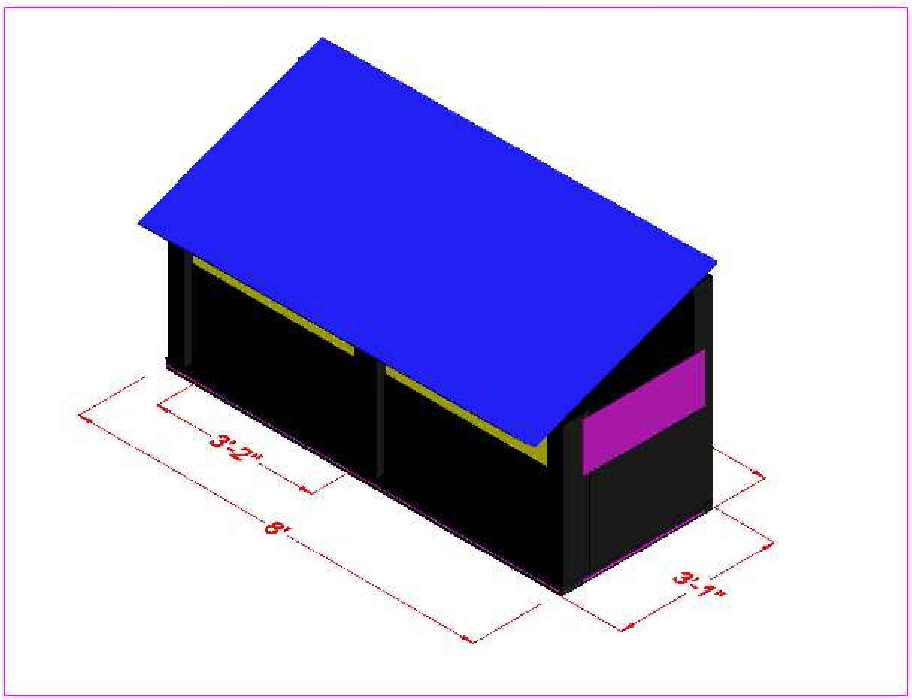

Figure 5-1. Whole composter featuring the tin roof (blue), pull down doors (yellow), hardware cloth (pink), and wood (black). By Juli Sioson-Ebitner

One door is located on the front of each of the two bins, and each door is 35" wide and 15" tall. When the doors are down and the roof is up, space is created for the compost to be mixed by adults or middle-schoolers. Figure 5-2 illustrates the composter with the roof open and one door ajar.

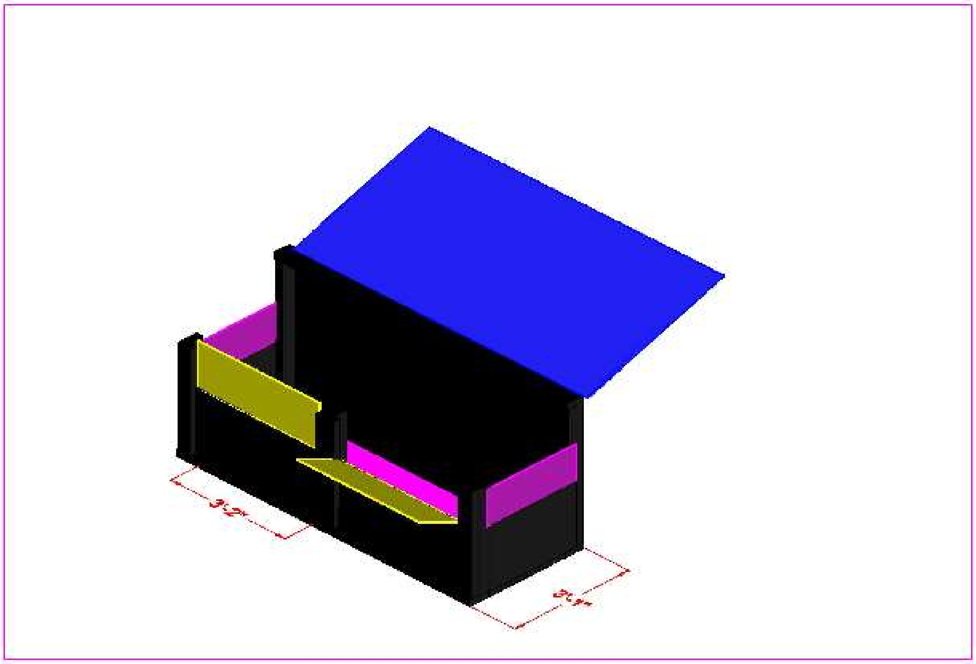

Figure 5-2. The whole composter with open tin roof (blue) and slightly opened door (yellow). By Juli Sioson-Ebitner

5.2.1 The Doors and Educational Posters

Each door is supported by two hinges at the bottom and two eye-hook closures on the top. The general layout of the hardware on each door is shown in Figure 5-3. The doors on the composter are a key component to its ability to meet the project criteria. They are 3' off of the ground at their highest point and are held up by simple eye-hook closures. This configuration allows for the compost to be easily accessed by pre-teen aged children, and helps the overall structure meet the simplicity criterion. The original design included educational posters on the doors, to help meet the educational value criterion. Figure 5-3 shows this original configuration. The posters were moved to the inside of the compost bins at the request of the client, so they are visible when the doors are down and the compost is being accessed. The new configuration is shown in Figure 5-4.

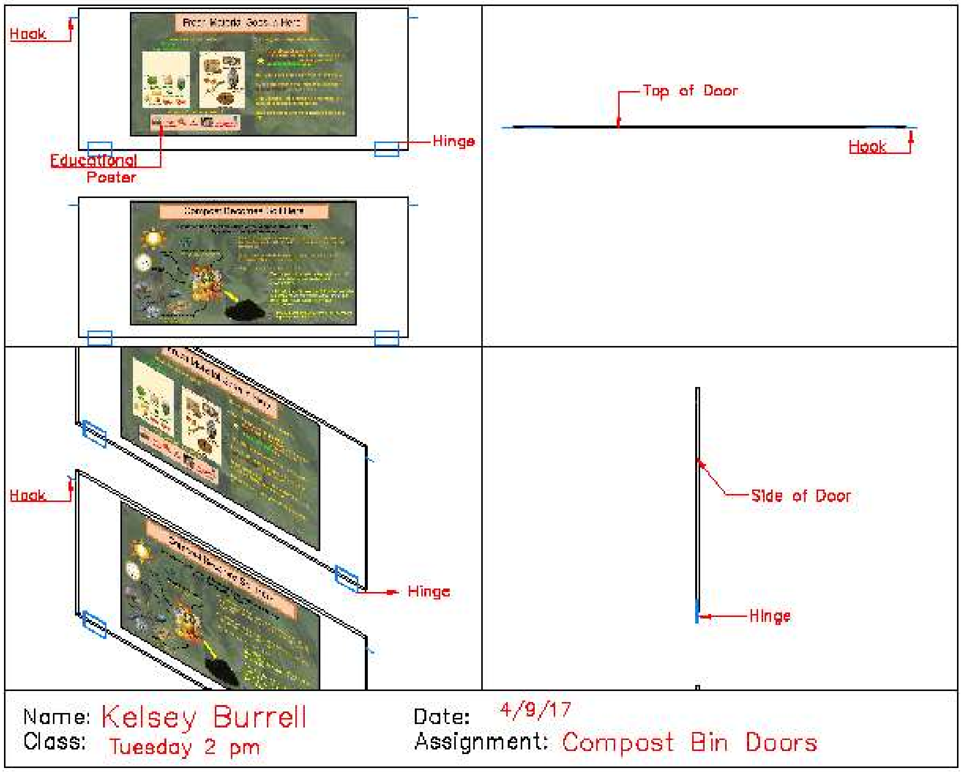

Figure 5-3. The layout of the hardware and educational posters on the doors. The posters were moved to a different location, shown in Figure 5-4. By Kelsey Burrell

Figure 5-4. The completed composter structure, with doors down and roof up. The educational posters are located on the back wall, as shown. By Kelsey Burrell.

Each poster is laminated to protect it from the weather, and each contains information which is unique to the processes in their respective bins. The poster on the left-side bin (shown in Figure 5-5) teaches users about the types of material that should and should not be composted. It also contains information on the difference between carbon- and nitrogen-rich materials, and how to balance those elements properly in a compost. The right-side bin poster (shown in Figure 5-6) contains information on biodegradation and temperature, and tips on how to properly maintain the compost.

Figure 5-6. The poster on the left-side bin, with descriptions of what can and can't be composted. By Kelsey Burrell.

Figure 5-5. The poster on the right-side bin, with information about decomposition and compost maintenance. By Kelsey Burrell.

5.2.2 The Roof

The composting unit includes a corrugated steel roof, which protects the compost from weather and larger critters like raccoons. The roof helps meet the pest-resistance criterion, and also helps maintain the heat and overall chemistry of the compost by reducing water infiltration. The roof is 8' long, 4' deep, and is supported by the body of the structure, which has a height of 3' in the front and 4' in the back. This creates an overall slope of 18.4° with the horizontal. The corrugations run parallel to the slope. The roof includes an overhang past the front of the composter, and funnels water away from the compost. As shown in Figure 5-7, the corrugated metal is bolted to a wooden frame. The frame attaches the roof to the body of the composter, and also provides support for the roof so it lifts and closes smoothly. The metal edges were smoothed by sanding, and covered with Plasti Dip.

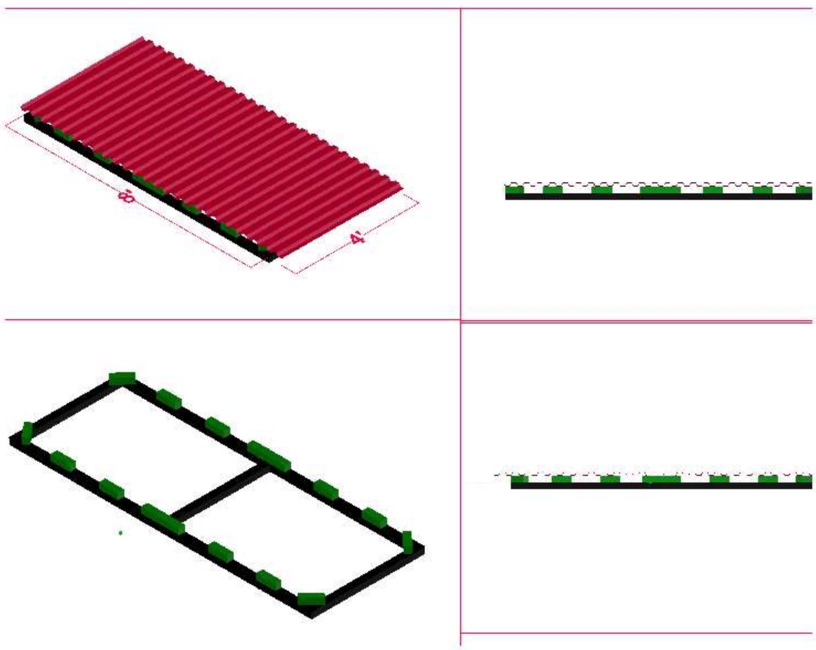

Figure 5-7. The metal roof (red) and wooden frame (black and green). By Ronnel Yabut.

5.2.3 The Base

The bottom of each bin is exposed to the ground, with the slight barrier of ¼" galvanized mesh hardware cloth. This configuration (an open base with a hardware cloth barrier) is beneficial for a number of reasons. First, the mesh extends about 8" up the inside walls of each bin, which creates a barrier that is impenetrable to rats. This helps fulfill the pest-resistance criterion for the design. Second, the fact that the base is not completely closed off to the surrounding environment allows for the exchange of organisms between the compost and surrounding environment. Notably, this design allows for worms to take residence in the compost and expedite decomposition.

The frame of the base of the structure is 8 feet long and 3 feet and an inch deep, as shown in Figure 5-8. The hardware cloth was cut from a 2-foot-wide roll, and was layered along the bottom to cover gaps. The mesh wire covers the entire bottom of each bin, and spans the lower perimeter of the walls. The total length used was 50 feet.

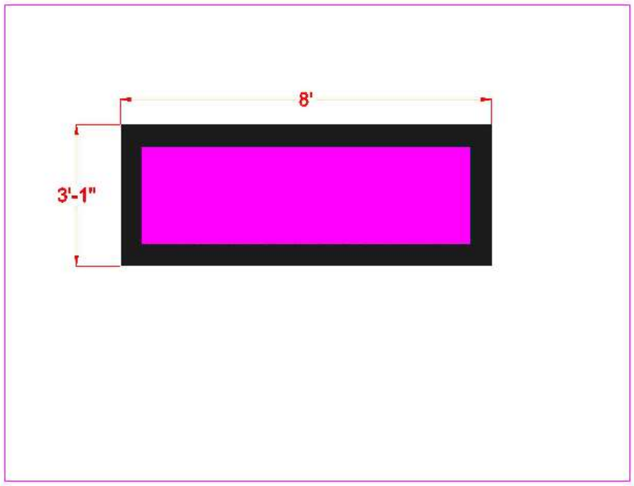

Figure 5-8. The bottom of the composter with the wooden frame (black) and hardware cloth (pink). By Juli Sioson-Ebitner

5.2.4 The Paint

An Ace Hardware exterior paint, colored Tulip Red, was used on the composting structure. The exterior paint will help preserve the wood and the color fits with the general motif of Zane Middle School. Three quarters of paint was used and covered about one coat.

5.2.5 The Sides

The bottom half of the compost system was covered with wood panels and the top half was covered with wire mesh. The wire mesh helps create a barrier so rodents can't get into the compost, and also provides area for air exchange between the contents of the bins and the atmosphere.

5.2.6 The Thermometer

A compost thermometer is essential to the composting process because it tells the user if the compost needs to be turned, to cool down the compost, or not. A Planeko compost thermometer

Figure 5-10. An image of the model of a Planeko compost thermometer obtined for the compost (Planeko n.d.).

was selected for use in the compost, as shown in Figure 5-9. The thermometer is a composed of stainless steel, has an extra thick probe, and has a 20" stem. The 20 inch extra thick stem is there so that the thermometer is long enough to stick into the compost pile and won't easily snap or break (Planeko n.d.). The compost thermometer also has an easy to read dial. The compost thermometer will show the temperature, but there also is color coordinated areas; yellow is warm, grey is ideal, and red it too hot. This will make it easier for the users to understand if the compost is too hot and needs to be turned, if venation needs to be less when it's in the yellow, or if the compost pile is just right (Planeko n.d.).

Figure 5-9. The sides of the composter are a combnination of wood and hardware cloth. (Ronnel Yabut)

5.3 Cost Analysis

This section provides an analysis of the cost of designing and implementing the compost system at Zane Middle School. The final cost is the culmination of the total hours and capitol spent on research and designing the system, acquiring materials, and prototyping and building the final design.

5.3.1 Cost of Labor

A total of 204 hours have been spent working on this project. During the overall process of designing and implementing the composting system, most of the labor hours were spent on conceptualization. This included the problem formulation and analysis, research and literature review, alternative solution generation, and the final decision process. Implementing the solution consisted of building the structure and starting the compost, and required less than half of the labor as the conceptualization process. Prototyping (detailed in Section 5.4) was the least time-intensive process. The visual breakdown of labor hours spent on this project is located below in Figure 5-9.

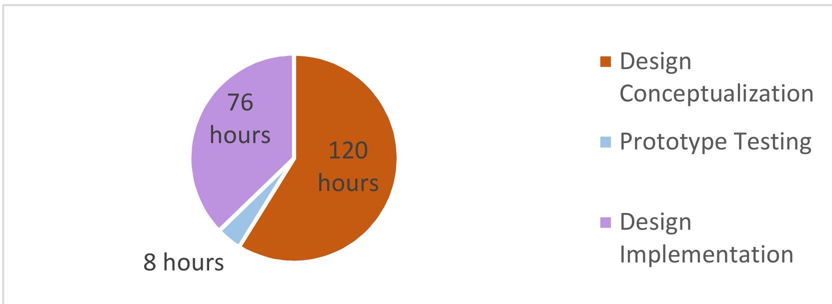

Figure 5-11. Breakdown of the total hours spent on the project.

5.3.2 Cost of Implementation

The total cost of materials for the composting system was $391.73. The total came out to be less than the budget of $425, and so the cost criterion was met. The itemized breakdown of materials used and the respective capital costs is located in Table 5-1.

Table 5-1. Breakdown of all of the materials and capital costs associated with implementing the composting system.

Quantity	Material	Source	Cost ($)	Total ($)
1	Corrugated metal, 73 sq. ft.	Arcata Scrap and Salvage	$ 17.00	$ 17.00
2	Weather-Resistant Paint (quart)	Ace Hardware	$ 14.37	$ 28.74
1	Wood Glue	Ace Hardware	$ 3.99	$ 3.99
2	Hinge (small)	Ace Hardware	$ 4.59	$ 9.18
1	Hinge (large)	Ace Hardware	$ 5.99	$ 5.99
1	Corner Brace	Ace Hardware	$ 5.99	$ 5.99
1	Mending Brace	Ace Hardware	$ 7.99	$ 7.99
2	Hook & Eye Closures (2-pack)	Ace Hardware	$ 2.59	$ 5.18
4	2 x 6 (Doug Fir)	Pierson's	$ 6.00	$ 24.00
2	4 x 8 (Cedar)	Pierson's	$ 38.89	$ 77.78
7	2 x 2 (Cedar)	Pierson's	$ 2.00	$ 14.00
6	2 x 4 (cedar)	Pierson's	$ 3.84	$ 23.04
1	2 x 2 (pine)	Pierson's	$ 6.98	$ 6.98
20	Wood Screws	Pierson's	$ 0.33	$ 7.16
1	Compost Thermometer	Amazon.com	$ 22.84	$ 22.84
1	Galvanized Mesh, 2'x50' 1/4"	Ron's Home and Hardware	$ 42.37	$ 42.37
1	Staples for staple gun	Ace Hardware	$ 4.49	$ 4.49
1	5/32" Drill bit	Ace Hardware	$ 2.59	$ 2.59
1	1/4" Nut driver	Ace Hardware	$ 4.59	$ 4.59
1	Gasketed screws	Ace Hardware	$ 9.29	$ 9.29
1	Mending brace	Ace Hardware	$ 8.59	$ 8.59
1	Hinges	Ace Hardware	$ 13.98	$ 13.98
1	Plasti Dip	Ace Hardware	$ 10.08	$ 10.08
1	Poster lamination	Ace Hardware	$ 19.98	$ 19.98
1	1/2" Hardware cloth	Ace Hardware	$ 18.98	$ 18.98
			Total Cost	**$394.80**

5.3.3 Cost of Maintenance

The overall cost of maintaining the compost structure is projected to be extremely low. Care was taken to select materials that would support the lasting integrity of the structure, and it is possible that years will pass before anything needs to be replaced. The itemized list of maintenance costs and projected time periods for replacement of components is located in Table 5-2.

Table 5-2. Itemized and temporal list of upkeep expenses.

Item	Expected rate of replacement	Cost
Compost Thermometer	Every 5 years	$ 23.00
Paint + Sandpaper	Every 5 years	$ 16.00
Plasti Dip	Every three years	$ 10.00

Plasti Dip is very flexible, and is expected to perform well in a variety of weather conditions for up to three years (PlastiDip n.d.). One can was used for this project and

The entire two-bin unit was covered thoroughly with weather-resistant paint. This paint will weather and need to be touched up every few years. The cost of sandpaper and one quart of paint is expected every five years.

The compost thermometer is made of steel, and its gauge is protected by a moisture-resistant coating. It is expected to perform well left in the covered compost over an extended period of time. The conservative estimated period for replacement is five years.

5.4 Implementation of the Design

This section contains implementation instructions for the construction of the two-bin compost system.

5.4.1 Two-Bin Compost

The two-bin compost system was constructed in the area and size agreed to by the client as well as certain design considerations presented in Section 2. The area of the garden was initially marked and prototyped by cardboard boxes. The two bins are used for the different stages of compost. The first bin on the left would be used for the first stage of compost where the second bin would be used once the material has reached a later stage. The later stage would have ready to use soil in the second bin. The general frame was made by cutting and screwing of wood according to our previously agreed upon design. The frame was the first thing built and were able to prototype the front doors with cardboard. Brackets were used in the design to provide structural support as well as connect the frame together. Doors have been constructed on both bins for ease of access to the compost as well as an openable roof. The doors were cut out of plywood and attached by small hinges. They also have small hooks on the front to secure them.

The roof was made of corrugated metal that had to be cut into three sections. The sections were then measured and screwed overlapping each other side-by-side. A frame had to be constructed for the roof and gasketed screws were used to prevent water leaking. The roof is able to be opened and balanced against the fence of the garden. Hooks are attached to the roof to be used to secure the roof against the fence of the garden. The edges of the corrugated roof proved to be really sharp so they have been grinded down with a metal grinder and painted with red Plasti Dip.

Inside, the bottom of the compost is lined with a layer of gopher wire to prevent pests from digging down and getting into the pile. The inside of the compost is designed to provide ease of access to the material and allow the transfer of material from bin to bin. The composting material is enclosed on all sides to maintain the ideal conditions of the compost pile, and to prevent unwanted moisture in. The openings where the frame and roof attach have also been lined with metal wire to prevent pests from climbing over and into the compost pile.

5.4.2 Building Steps

This section details each step of the building process. Pictures illustrate each of the building steps.

1. Buy materials. Prototype the desired building area by carefully measuring and marking

Figure 5-13. Some of the materials bought for the project. By Ronnel Yabut.

Figure 5-12. Assembly and prototype of frame. By Ronnel Yabut.

   out with cardboard boxes.
2. Once the general frame of the composter is built, prototyping the mixing heights as well as the two front doors is important. The pile needs to accessible to potentially more than one person at a time. Grab a shovel and an extra body to ensure that there would be enough space.

Figure 5-15. Prototyping doors and compost mixing heights. By Ronnel Yabut.

3. The front doors provide ease of access into the compost pile as well as helps enclose the pile. Cut doors out of the compressed wood panel and screw two hinges for each door.

Figure 5-14. Attached doors with hook latches. By Ronnel Yabut.

4. Eureka gets a lot of rainfall during the year so to further protect the wood from warping, weather resistant paint was applied. Three quarts of paint to cover the compost in one coat but more maybe be used if desired. To fit the general motif of the school, a tulip red color was selected.

Figure 5-16. Application of weather resistant paint by Ronnel Yabut.

5. A roof frame was constructed to hold the corrugated roof together as well as provide a way to attach hinges to the roof so it can be opened and closed. The frame and big hinges used also provides support to the heavy roof so it can be safely opened.

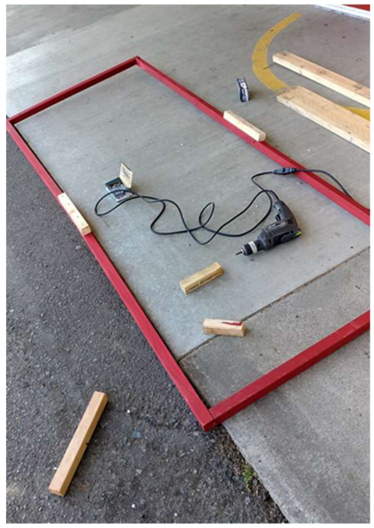

Figure 5-17. Assembly of the roof frame. By Ronnel Yabut.

6. Construct a wood frame to hold the corrugated roof together. This will also provide a way to attach hinges to the roof so the lid can be opened and closed. Use 2x2 wood pieces to build the frame and it should be 8 ft. long and 3 ft. wide. Cut two 1 foot pieces of 2x2 wood and screw to the top/bottom middle of the frame. 6 in. 2x2 pieces of wood are then cut and screwed along the edges of the frame evenly distributed. The frame and big hinges provides support to the heavy roof so it can be opened and closed safely. Screw in the corrugated roof with gasketed metal screws to the wooden frame. Gasketed screws would ensure that no unwanted moisture would seep into the pile through the holes they would create in the roof. The corrugated roof had really sharp edges. Grind down the edges and then apply Plasti Dip to further ensure that the edges are not sharp. Run your fingers along the edges to test and apply more Plasti Dip as desired.

Figure 5-18. Attachment of corrugated roof to wood frame. By Ronnel Yabut.

7. Pest control was a big concern. Use metal wire to line the bottom and top of the composter to prevent rodents from being able to get into the pile.

Figure 5-19. Lining the bottom of the compost bins with metal wire. By Ronnel Yabut.

8. With the ability to open the compost system, it allows for students to interact with the pile from all sides. Use heavy duty hinges were to ensure the weight of the roof will be supported.

Figure 5-20. Attachment of roof with hinges. By Ronnel Yabut.

9. Place educational signage inside of the compost bin. Students are to refer to the signage to learn about the compost and reference what items can be put into the pile. Signage can be viewed when opening the top roof of the compost and the two front doors.

10. 

Figure 5-21. Finished Product. By Kelsey Burrell.

5.4.3 Initial Setup of Compost Bin

At the start of the compost process, a 2:1 carbon to nitrogen ratio was used. Material was obtained from the Campus Center for Appropriate Technology (CCAT) at Humboldt State University (HSU) and from Zane Middle School to make the initial pile. These materials were layered on top of each other and a thermometer should be used to measure the pile's internal temperature over time. It should be known that the pile needs to be aerated every once and awhile by using a shovel to mix. New material can be incorporated into the existing pile as long they are broken down into smaller pieces.

5.4.4 General Maintenance

The compost needs to be thoroughly mixed at least once every 1-2 weeks. A shovel may be used for mixing and the doors and roof of the compost bin can be opened for ease of access. If during the summer no one is able to keep up with the compost system, it is recommended to empty the contents out or stop adding new material 3-4 weeks before the summer. This will allow adequate time for the pile to turn into soil. The already composted soil could be transferred and stored in the second bin and be can be used in the garden. When adding new material to the compost, making sure the correct material is added and is broken down into smaller pieces is important. Refer to laminated signage located on the inside of the compost bin for a list of allowable compostable materials.

5.5 Results of Prototyping

The prototypes used to develop the design were successful, and in one case inconclusive.

To prototype the pest resistance, half of a banana and half of an apple were placed into a bucket, and a length of ¼" hardware cloth was stapled to the bucket to enclose the fruit. This device is shown in Figure 5-21.

Figure 5-22. The device used to prototype the quality of pest-resistant of the hardware cloth. By Kelsey Burrell.

The bucket was placed on its side, and left outside in an open area. The other halves of the fruits were placed next to the bucket. Two days later, the fruit outside of the bucket was gone, and the fruit inside the bucket remained. This confirmed that the hardware cloth would be a suitable rodent deterrent.

The educational quality of the posters for the compost bins was prototyped in two different classrooms. One classroom was the special day class, and the other was a 7th grade science class. The poster content was displayed on two different cardboard posters, shown in Figures 5-22 and 5-23.

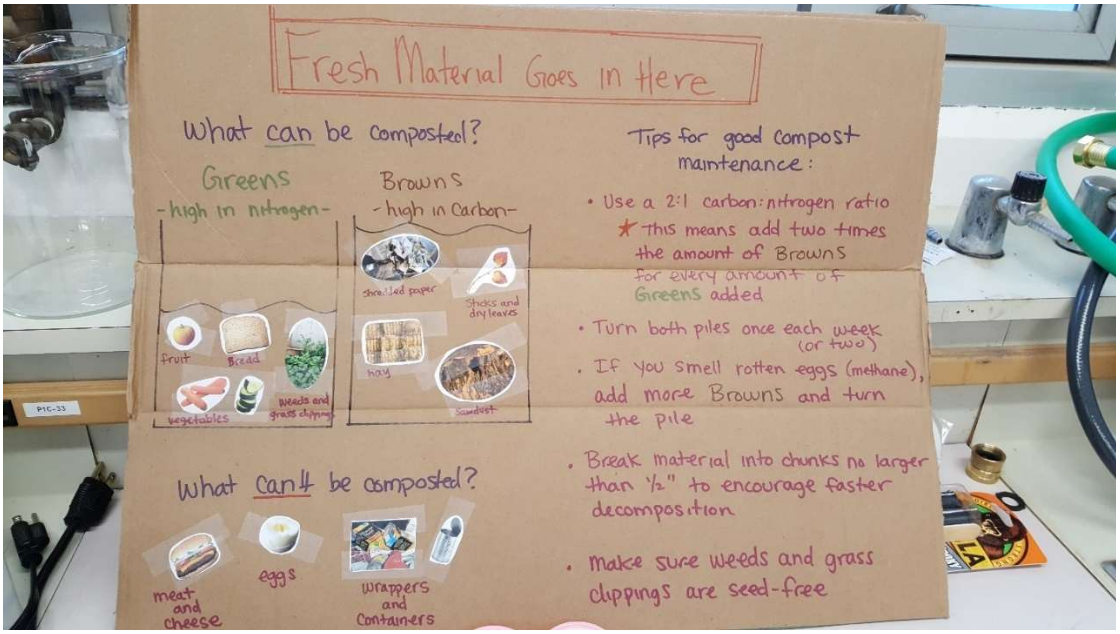

Figure 5-23. Prototype of the poster for the left-side compost bin. By Kelsey Burrell.

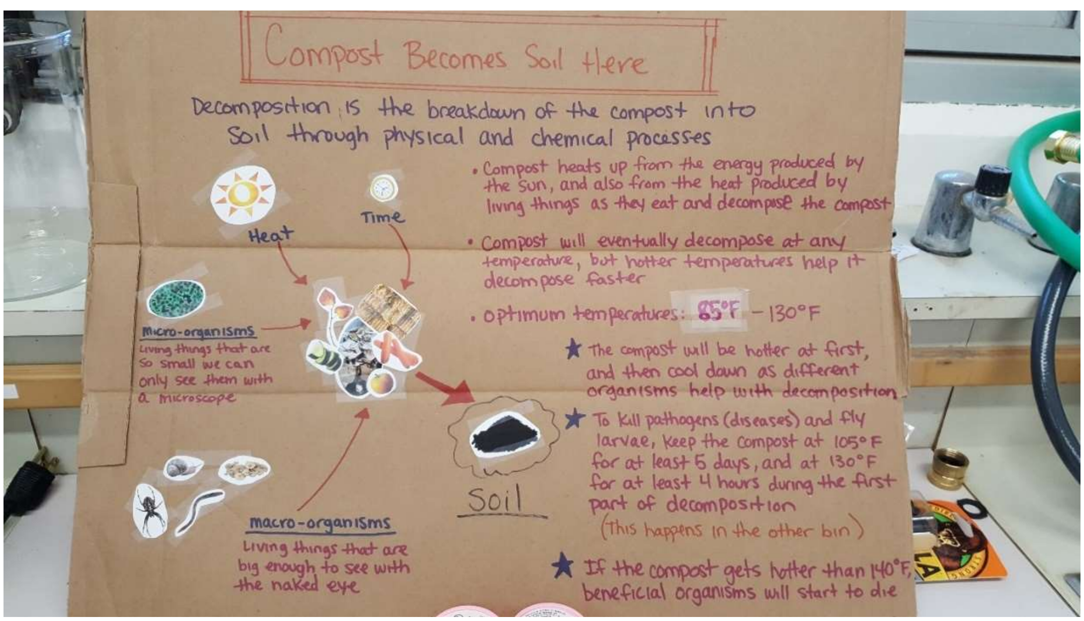

Figure 5-24. . Prototype of the poster for the left-side bin. By Kelsey Burrell.

Questionnaires were developed to test the educational quality of the posters. The intent was for students to answer the same set of questions before and after interacting with the poster prototypes. The "before" and "after" questions for each student were intended to remain on the same sheet of paper, but were severed from one another by the teachers. As a result, no correlation between any individual student's understanding of compost as affected by the posters could be made. Thus, the results of this prototype test were inconclusive. The question set is located below:

- What is compost? Does your family compost?
- What kinds of things can you put into compost?
- Circle the things that are ok to put into a compost pile:
  Oranges Slice of pizza Old newspaper A bag of chips Tomatoes
- What elements (from the periodic table) do we pay attention to in compost piles?
- What temperature range is good for compost?
- What happens if compost gets too hot?
- What happens if compost gets too cold?

Feedback regarding the quality of the posters was provided by the teachers, who were happy with the content and offered no suggestions for change. The use of bold lettering and pictures were especially beneficial for the students, in particular those in the special day class.

The doors of the system prototyping concluded that if it was to swing out that it would be too big, so the team decided on making them pulldown doors for easy access and little use of space.

Another section that was vital to test was the composter's durability. Humboldt has strong winds and a lot of rain. When constructing, the team painted the wood with a protective layer of paint. The wood that was painted was in good condition when the team came back for another building day after a couple days of rain, unlike the more water dense wood that was not painted. A problem that the team kept running into when building was that the wind kept knocking over the work that the team did the previous days. After it all was put together though, the composter became very sturdy and has yet to fall over.

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Appendix

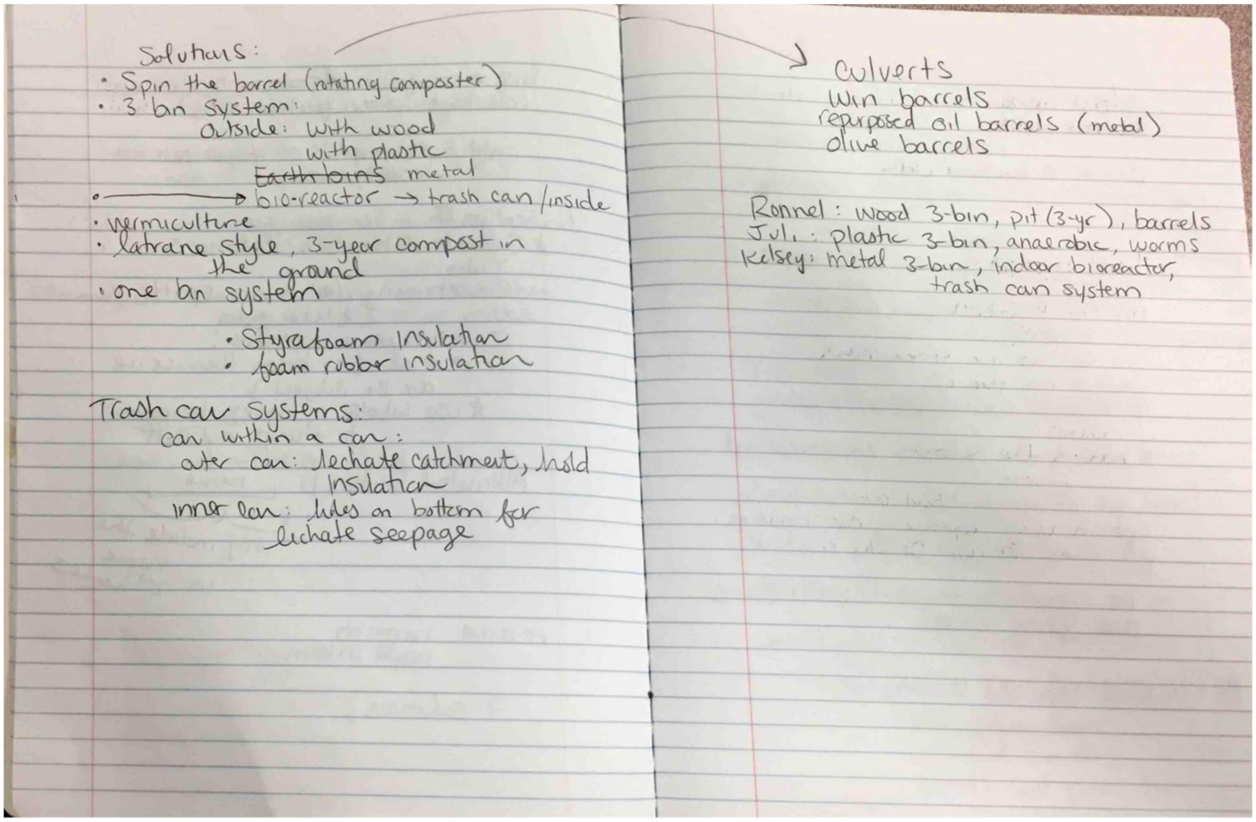

Figure 5-25. Brainstorming notes, referenced in Section 3.