MOVABLE INSTRUMENT STORAGE COMPARTMENT FOR ZANE MIDDLE SCHOOL

ENGR 215 – Spring 2017

HUMBOLDT STATE UNIVERSITY
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1 Problem Formulation

1.1 Introduction

Section 1 contains background information on how the project originated, team members, the objective statement, and the black box model.

1.2 Background

Team Strange was given the opportunity to design a moveable instrument storage compartment for violins and violas. This project was specifically for Mr. Bruce McCay, a music teacher at Zane Middle School in Eureka, CA. The music department at Zane was in need of storage renovation for years. The storage compartment was created during the spring semester of 2017 at Humboldt State University. Team members are: Alexis Clemente, Mason Davidson, Haley Isaacson, and Erik Kentfield.

1.3 Objective Statement

The objective is to design and assemble a durable, moveable storage compartment for violins and violas that does not impose a fire hazard and contains shelf depth to accommodate the length of the instruments in their individual cases.

1.4 Black Box Model

The black box model shown in Figure 1-1 depicts the impact of a completed moveable instrument storage compartment.

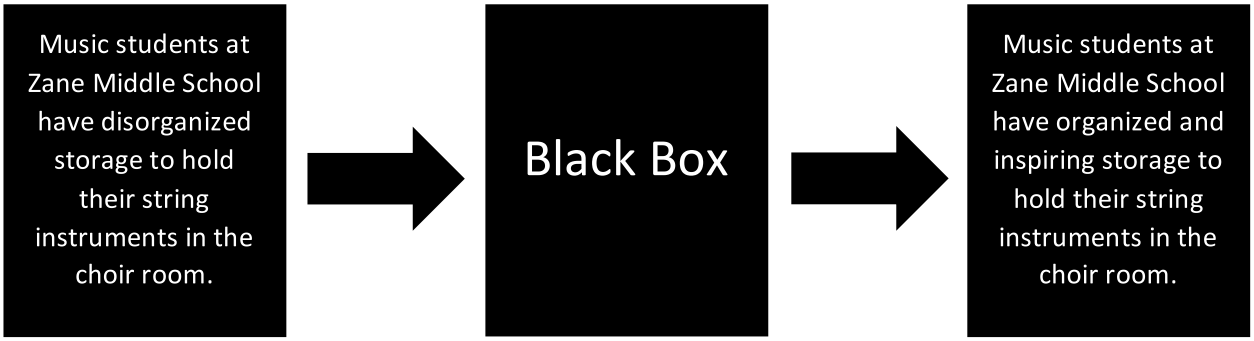


***Figure 1-1**: Black Box Model demonstrating how students at Zane Middle School will be effected by the completion of a moveable instrument storage compartment for their violins and violas.*

2 Problem Analysis and Literature Review

2.1 Introduction to Problem Analysis

Section 2 illustrates specifications and constraints of the project as well as criteria agreed upon by the client. The problem analysis discusses considerations that contribute to the design of the storage compartment, product usage, and production volume.

2.1.1 Specifications and Constraints

Specifications and constraints help to develop criteria. The instrument storage compartment cannot cause a fire hazard in the classroom. The instrument storage compartment has to meet minimum safety standards of furniture in a middle school classroom. The instrument storage compartment has to comfortably fit instruments and their cases on the shelves. Multiple children should be able to access their instruments at once. The storage compartment should be at a height accessible to the average middle school child. The storage compartment should have the capability to be moved in the classroom, by an adult, if so desired. Aesthetically, the storage compartment should appeal to children and adults alike. The storage compartment should cost no more than $400 to build unless otherwise funded from outside sources, should incorporate upcycled material, and should last a minimum of 10 years. Instruments should not shift while in storage and the compartment should be structurally sound. The storage compartment should be inspirational for musicians and non-musicians alike.

2.1.2 Considerations

Zane Middle School colors, red and gold, were considered for the design in order to represent the school with the instrument storage compartment.

2.1.3 Criteria

Criteria were based off the client’s needs and all criteria consider what is best for the user. The criteria are:

- Stability
- Safety
- Accessibility
- Cost of Materials
- Storage Space
- Aesthetics
- Inspirational
- Durability
- Sustainability
- Movability

2.1.4 Product Usage

The storage compartment will have instruments stored on it every day and will be accessed by multiple students taking music classes at Zane Middle School daily.

2.1.5 Production Volume

One instrument storage compartment was produced.

2.2 Introduction to Literature Review

The literature review is a summary of information researched to provide a foundation for the design process.

2.2.1 Client Interview

Mr. McCay’s specifications were quite simple. The storage compartment should be 8 ft. wide and tall enough to contain all of the instruments. Children should be able to reach their own instrument. Bruce did permit the design of a second compartment if necessary. The instrument storage cannot cause a fire hazard and the shelves must be deep enough to fit a full violin and/or viola. Also, the shelves must be wide enough so multiple children can access their instrument without complications. (Strange 2017).

2.2.2 Structures of Strength

Different structural designs were useful for the design of this instrument storage compartment.

2.2.2.1 Frame

A structure is called a frame if at least one individual member is a multi-force member; a member with three or more forces acting on it. Frames are usually joined together through jointing and/or bolting. Individual members can carry transverse loads. This generates shear forces, bending moments, and/or tension and compression forces (Meriam et al. 2007). Shear forces and bending moments will be discussed in detail later. Generic storage compartments are usually framed structures.

2.2.2.2 Truss

A truss is a framework of members connected at their ends to create a structure. Trusses frequently use pin joints to join members together. This enables members to rotate freely about the pin to prevent the transfer of moments. Instead, members are only subjected to tension and compression forces. Large trusses use slip joints to counteract expansion and contraction from temperature changes and to counteract deformation of applied loads (Meriam et al. 2007).

2.2.3 Internal Forces

Different internal forces can cause complications with the design of this instrument storage compartment.

2.2.3.1 Shear Force

Shear forces occur when parallel forces act out of alignment with one another. The shearing force represents the affinity of one portion of a beam to shear, or slide horizontally, when compared to the other portion. The shearing force is the sum of lateral components of each force acting on either side of the section. (CodeCogs 2011). Violins and violas will be creating shear forces on the storage compartment when stored with uneven load distribution. See Figure 2-1.

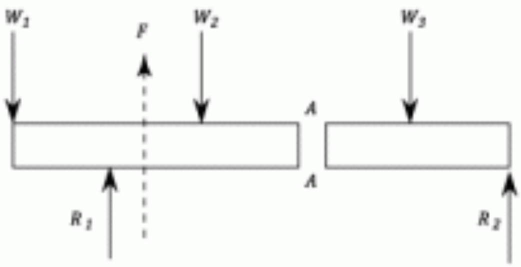


Figure 2-1*: Shear force diagram. Image from: http://www.codecogs.com/library/engineering/materials/shear-force-and-bending-moment.php.*

2.2.3.2 Bending Moment

The bending moment is a sum of moments about a section with respect to forces acting on either side of it. Bending moments are considered positive when the left moment is clockwise and the right moment is counterclockwise (CodeCogs 2011). Violins and violas will be creating bending moments on the storage compartment. If the moment created by the violins and violas is greater than the moment created by the storage compartment, the compartment will flip. See Figure 2-2.

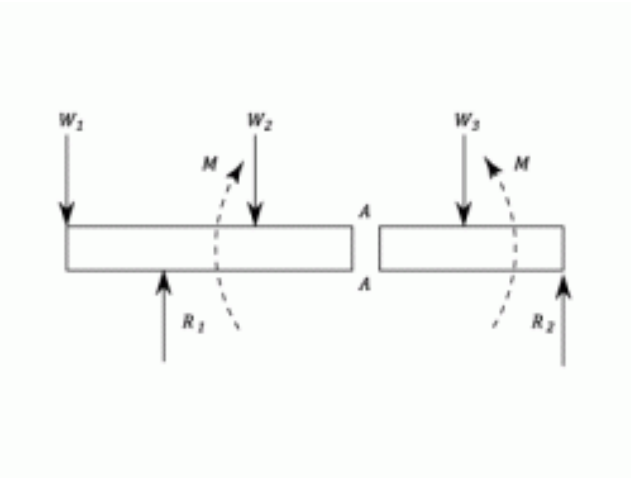


Figure 2-2*: Bending moment diagram. Image from: http://www.codecogs.com/library/engineering/materials/shear-force-and-bending-moment.php.*

2.2.4 Wood to Wood Joints

Most structures involve some form of jointing/bolting and/or connection. There are numerous woodworking joints. Some joints are innately stronger than others.

2.2.4.1 Butt Joint

A butt joint joins two pieces of wood by butting them together and gluing them. This is the simplest joint to make and is also the weakest unless coupled with some form of reinforcement (McCleary 2017). See Figure 2-3.

Figure 2-3*: Picture of a butt joint. Image from: https://www.wwgoa.com/article/woodworking-joints-which-ones-should-you-use/.*

2.2.4.2 Biscuit Joint

A biscuit joint is a reinforced butt joint and is designed to allow flexibility. A biscuit (wooden insert) is inserted into a mortise (hole) on each piece of wood being joined. This joint does not have perfect alignment which can cause complications when building (McCleary 2017). See Figure 2-4.

Figure 2-4*: Picture of a biscuit joint. Image from: https://www.wwgoa.com/article/woodworking-joints-which-ones-should-you-use/.*

2.2.4.3 Brindle Joint

The brindle joint joins two pieces of wood together forming a corner. This joint is used for housing a rail in uprights like the legs of a table. A brindle joint has good strength when in compression and can be moderately resistant to stress (McCleary 2017). See Figure 2-5.

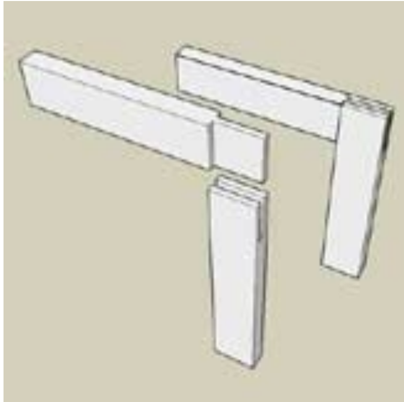


Figure 2-5*: Picture of a brindle joint. Image from: https://www.wwgoa.com/article/woodworking-joints-which-ones-should-you-use/.*

2.2.4.4 Dado Joinery

A dado is a slot cut into the surface of a piece of wood that usually has its ends open. Dados are used to attach shelves to bookcases (McCleary 2017). See Figure 2-6.

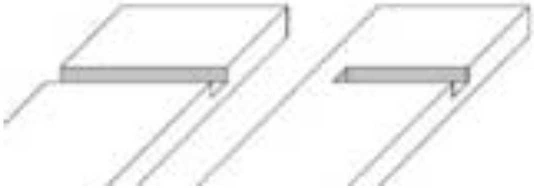


Figure 2-6*: Picture of a dado joinery. Image from: https://www.wwgoa.com/article/woodworking-joints-which-ones-should-you-use/.*

2.2.4.5 Dovetail Wood Joint

The dovetail is a strong wood joint and is revered for its tensile strength (resistance to pulling apart). These are usually used to connect the sides of a drawer to the front of a drawer. Pins and tails of trapezoidal shape interlock with each other and the joint becomes permanent once glued together (McCleary 2017). See Figure 2-7.

***Figure 2-7**: Picture of the dovetail. Image from: https://www.wwgoa.com/article/woodworking-joints-which-ones-should-you-use/.*

2.2.4.6 Finger Joint

A finger joint is fairly similar to a dovetail aside from the pins being squared and not trapezoidal. There is less mechanical strength in a finger joint when compared to the dovetail. The finger joint relies on glue to hold it together (McCleary 2017). See Figure 2-8.

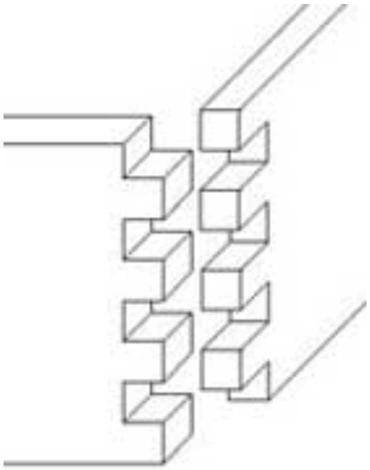


***Figure 2-8**: Picture of a finger joint. Image from: https://www.wwgoa.com/article/woodworking-joints-which-ones-should-you-use/.*

2.2.4.7 Mortise and Tenon Wood Joint

The mortise and tenon joint is one of the simplest and strongest wood joints. A tenon from one piece is inserted into a mortise in another piece. In Figure 2-9 the end being inserted is the tenon and the hole is the mortise. Glue is normally used to make this joint, but pins or a wedge can lock the joint in place. The tenon is usually taller than it is wide (McCleary 2017).

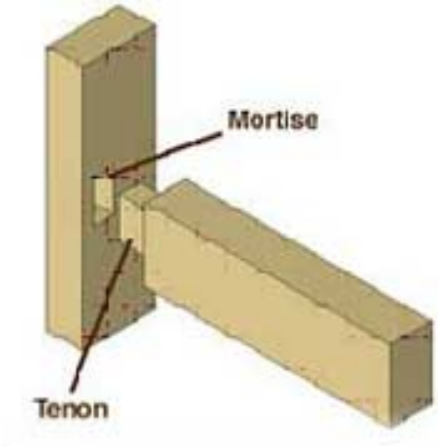


Figure 2-9*: Picture of a mortise and tenon joint. Image from: https://www.wwgoa.com/article/woodworking-joints-which-ones-should-you-use/.*

2.2.4.8 Pocket-Hole Joinery

The pocket-hole joinery is nothing more than a butt joint with pocket-hole screws. The process takes two separate drilling operations. One to create the pocket-hole itself and another to allow a screw to pass through one piece and into another. Glue is used to strengthen the joint. Pocket-hole joinery is more expensive and less effective than other wood joints (McCleary 2017). See Figure 2-10.

Figure 2-10*: Picture of a pocket-hole joinery. Image from: https://www.wwgoa.com/article/woodworking-joints-which-ones-should-you-use/.*

2.2.4.9 Metal to Wood Connection

Metal plate connected wood truss structures are often used because they have a high strength-to-weight ratio and they are extremely versatile. It is possible that their load carrying capacity can be hindered by the collapsing of truss members under compression. Although, recent tests have shown the lateral force ratio of certain metal plate connected wood truss structures adhering to the 2% rule. The 2% rule requires that the lateral bracing members resist at least 2% of the overall compression load in each compressed member (Song et al. 2012).

2.2.5 Wood

Wood is a naturally durable building material and its durability can be enhanced with preservatives. When forests are managed properly and consumers are buying from sustainable sources, wood can be a definitive resource. Relative to other building materials, wood does not cost as much energy to produce.

In return, wood leaves a small carbon footprint which adds to the sustainability of the building material. There are hard and soft wood types (Falk 2010).

2.2.5.1 Soft Wood

Although they are labeled soft, some types of wood in this category are actually stronger than hard woods and make a better building material for structures. The trees that provide soft wood generally grow at a faster rate than the ones that provide hard wood and because of this softwood is more likely to be grown sustainably in tree farms. Some common softwoods include: redwood, cedar, fir, and pine.

Redwood is a durable material that holds moisture well. Tannins in redwood provide natural protection from fire, insects, and rotting. Redwood works well with hand tools and machinery and accepts glues and finishes. Redwood has been noted as a sensitizer. Meaning the more you are exposed to particles of the wood, the more sensitive you are to its' allergic reaction. Reactions include: irritation of the skin, eyes, and the respiratory system; severe cases are uncommon (Meier 2016).

Douglas fir is an inexpensive building material that is moderately resistant to rot and decay but is vulnerable to attack by insects. Fir takes on stains, glues and finishes well. Fir has been recorded to cause nausea and irritation to the skin, but harsh reactions do not happen often (Meier 2016).

Northern white cedar is very durable with respect to resisting decay, termites, and powder-post beetles. Cedar works well with both machine and hand tools. Cedar is weak and does not hold screws well, but it does hold glues and finishes well. Cedar has also been noted to cause skin irritation along with symptoms similar to asthma, but severe reactions do not happen often (Meier 2016).

Soft pine has a low to moderate resistance to decay. Soft pine works well with both machine and hand tools and accepts glues and finishes. Some people experience symptoms similar to those of asthma and/or allergic skin reaction while working with soft pine (Meier 2016).

Hard pine also has a low to moderate resistance to decay. Hard pine works decently with most tools, but resins, excluding loblolly, can clog tools. Like soft pine, hard pine has also been noted to cause skin reactions and symptoms similar to those of asthma (Meier 2016).

Table 2-1 presents the strengths, stiffness, and hardness of the soft woods mentioned above.

Table 2-1*: North American Softwoods. Table from: http://workshopcompanion.com/KnowHow/Design/Nature_of_Wood/3_Wood_Strength/3_Wood_Strength.htm#top.*

Wood Species	Specific Gravity	Compressive Strength (psi)	Bending Strength (psi)	Stiffness (Mpsi)	Hardness (lb.)
Cedar, White	0.32	3,960	6,500	0.80	320
Fir, Douglas	0.49	7,230	12,400	1.95	710
Pine, Sugar	0.36	4,460	8,200	1.19	380
Redwood	0.35	5,220	7,900	1.10	420

2.2.5.2 Hard Wood

Trees that produce hard wood take longer to grow than ones that produce soft wood. This increases the price of the material and makes it less likely to be sustainably produced through tree farms. Some common types of hardwood are: birch, maple and poplar.

Birch has a low price relative to other hard woods and is good for turning, gluing, and finishing. Birch is prone to insect attacks, rot, and decay. Just like redwood, birch is a sensitizer with reactions including skin and respiratory irritation (Meier 2016).

Maple's fine grain provides stability, though it is considered non-durable. Maple is reasonably easy on both hand and machine tools, but high-speed cutters tend to cause maple to burn. Maple turns well and accepts glues and finishes, but may need a toner, pre-conditioner or gel stain in order to accept stains. Maple has been reported to cause symptoms similar to asthma and irritation to the skin (Meier 2016).

Poplar is not the most aesthetically pleasing wood, but it is cheap and easy to work with. Poplar is a moderately non-durable material and is prone to attack by insects. Poplar sometimes ends up with fuzzy surfaces/edges from sanding and cutting. Poplar has been noted as a skin, eye, and respiratory irritant, though severe cases are not common (Meier 2016).

Table 2-2 presents the strengths, stiffness, and hardness of the hard woods mentioned above.

Table 2-2*: North American Hardwoods. Table from: http://workshopcompanion.com/KnowHow/Design/Nature_of_Wood/3_Wood_Strength/3_Wood_Strength.htm#top.*

Wood Species	Specific Gravity	Compressive Strength (psi)	Bending Strength (psi)	Stiffness (Mpsi)	Hardness (lb.)
Birch, Yellow	0.62	8,170	16,600	2.01	1,260
Maple, Hard	0.63	7,830	15,800	1.83	1,450
Maple, Soft	0.54	6,540	13,400	1.64	950
Poplar	0.42	5,540	10,100	1.58	540

2.2.6 Plastic Lumber

Plastic lumber is a durable material that provides resistance to rot, insects, and moisture. It is not very flexible and when holding heavy loads in an environment with high temperatures, the material is likely to change form (Cirko 2017).

Plastic lumber has the potential to be a sustainable building material when it is produced by a company that uses high amounts of post-consumer recycled material. Products made out of high and low density polyethylene are preferred because their lifecycle produces less chemical hazards and has less negative impacts on the environment when comparted to other plastic resins (Platt 2005).

Plastic lumber can also serve as insulation. Plastic foam has a high R-value, or resistance to heat flow. The R-value of plastic foam does not change when exposed to different humidity. For instrument storage, this is an important feature. Under certain conditions creating this plastic lumber can result in the volatilization of chemicals, both harmful and neutral. Despite this possibility, when plastic is used as a laminate, it can prevent harmful materials from emitting volatile organic compounds (Kim 1998).

2.3 Alternate Methods

There are numerous examples of existing structures that were useful for inspiration in the design of this instrument storage compartment.

2.3.1 Cabinet

One option is to make a cabinet with an individual space for each violin or viola. Considerations are: how deep to make each space, the volume of each space, designing an adequate height for middle school children to reach their own instrument, and what materials to use. See Figure 2-11.

***Figure 2-11**: Cabinet example. Image from: http://www.melhart.com/images/schoolmusicequipment/1520.jpg.*

2.3.2 Rack

Another option is making a rack that would lay violins and violas side by side. Considerations are: the space between the dividers so instruments will stay firmly in place and how to optimize the space of the rack. This design would take up less space, it is more aesthetically pleasing, and the violins and violas will be easily accessible. See Figure 2-12.

***Figure 2-12**: Rack example. Image from: https://bandstorage.com/shop/violin-case-rack/.*

2.3.3 Rotating Circular Storage

The storage compartment could be rotatable. This would allow the structure to be stored in the corner of the classroom, out of the way, while also allowing students to reach their own instruments. Considerations are: the diameter of the circle, ways to stabilize the instruments, and how to accommodate a wide variety of violins and violas in the storage space. This design may be too big, the children might be tempted to play with it, and it might take too long to distribute the instruments.

Figure 2-13 is an example of a rotating circular storage rack for instruments. This is solely a representation of the rotating idea. It does not hold many instruments, but could be modified to accommodate more instrument storage.

Figure 2-13*: Example of a rotating circular instrument storage. Image from: https://www.guitarstorage.com/shop/rotating-multiple-guitar-stand/.*

Figure 2-14 does not serve the purpose of instrument storage, but is a more accurate representation of the structure Team Strange imagined for this design.

Figure 2-14*: Example of a circular storage unit. Image from: http://hative.com/creative-shoes-storage-ideas/.*

2.3.4 Wall Mount Storage

This storage option is composed of cylindrical rods, rivets, and a base that keep the instruments in place. Considerations are: how to make the rods safe enough for children to use and how to store instruments with their individual cases. This design would conserve a lot of space and would take minimal building material making it cost efficient. Zane Middle School may not have the wall space to accommodate this design. Figure 2-15 depicts the concept of this design.

***Figure 2-15**: Wall mount storage example. Image from: https://s-media-cache-ak0.pinimg.com/236x/4f/80/c5/4f80c51ba1d7bd0edd59cd584b0212f5.jpg.*

2.4 Instrument Requirements

Environmental conditions are important to violin and viola storage. Dimensions of the instruments were imperative to the design of a storage compartment.

2.4.1 Environmental Conditions

Environmental parameters that affect the sound of violins and violas are: humidity, temperature, and pressure. In varying degrees of severity, these parameters can cause the wood that makes up the instruments to change. Small changes in the wood causes the sound produced by the instrument to change as well. This is due to the damping; the damping of wood must be low for small changes in resonance to be perceived. The best way to keep internal damping low is to have instruments made from high quality wood and avoid significant changes in temperature and humidity. When temperature and humidity are not constant the damping of violins and violas goes up, making it harder for musicians to control the sound of the instrument. This phenomenon comes from wood's ability to absorb water. The more moisture the wood can absorb, the higher the damping and the harder the instrument is to control (Gough 2000). Changes to humidity and temperature must be minimized when designing an instrument storage compartment.

2.4.2 Size Constraints for Instruments

Violins and violas will both be stored in the storage compartment. The dimensions of both instruments were considered for the design.

Usually, the length of a violin is around 2 ft. not including the case, which can add several inches to both ends. The violin cases being used depends on the students and the depth of the storage compartment depended on the cases. On average, the width of a violin in the widest section is about 11 in. The height from the bottom wooden panel to the strings is about 1.2 in. (Vetter 2015).

Violas are larger than violins in most dimensions. On average, a viola is 2 ft. 3 in. from the end of the body to the top of the neck. The average widest point on a viola is 9.1 in. and the height of a viola is about 1.4 in. from the bottom panel to the strings. These measurements are without cases. The cases can add several inches to each end. This was considered when designing the dimensions of the instrument storage compartment (Vetter 2015).

2.5 Ergonomics

Heights of middle school children and the ergonomics of the environment affected the design of the instrument storage compartment.

2.5.1 Heights Specific to Middle School

Several factors affect how accessible an instrument storage compartment is for middle school children: height, weight/style of the doors (if any added), and width/depth of the storage system. The height had to be within range of an average child in middle school. If doors were added, the difficulty of handling them must have been in the favor of the children. The width of the compartment was not only important to the surrounding environment, but it was also pertinent to the design itself. The compartment had to be wide enough to allow multiple students to stand in front of it and access their instruments simultaneously. The depth of the storage compartment was designed to be shallow enough to pull out the instrument, but deep enough to contain the instrument with its' case. For square cases depth was crucial. For circular or some other shaped cases, height and width were more important. Instruments should have very slight, to no variation in position while in storage.

A major concern with designing this storage compartment for middle school children is the height of the unit. Research shows that the top shelf for a cabinet in a middle school setting should be no more than 6 ft. 2 in. tall. The height of a door knob (if any added) was also imperative. The lowest height for a door knob in a middle school setting should be 3 ft. 2 in. while the tallest height should be 3 ft. 5 in. (21st Century Schools 2012). These dimensions maintain reach capability of the average child in middle school.

2.5.2 Adjusting to Age

Ergonomics are normally related to the working environment. Principles of ergonomics can be applied to the "work day" of a student. Middle school children are not at the caliber of "working" college students, but they still face similar "workplace" challenges. Challenges include, but are not limited to, learning new material on a weekly basis and dealing with interpersonal behavioral issues. The challenges middle school children face stem from their age. Children who are in middle school have many advantages when compared to adults.

A common issue for people of all ages is work fatigue. Work fatigue effects different personalities in varying ways. Some people become aggressive while others simply withdraw themselves from work entirely. Fatigue comes from having to perform the same monotonous task for an extended period of time. This is the epitome of a middle school child's "work day". When children are forced to do mathematics for several hours at a time, it is only natural for them to get tired. Lighting and safety procedures affect performance in the workplace. Required lighting for middle school children is much lower than middle-aged and elderly people (Singleton 1972).

3 Alternative Solutions

3.1 Introduction

Section 3 covers 8 alternative design solutions for a moveable instrument storage compartment for violins and violas that adhere to all criteria discussed in Section 2. This section encompasses brainstorming techniques and topics used by Team Strange to develop different designs, as well as diagrams and descriptions of each unique design developed.

3.2 Brainstorming

Team Strange held a formal brainstorming session on Friday March 3, 2017 at 12:00 PM, in Sci D 17, on Humboldt State University's campus. All of Team Strange participated in the session. The team used a variety of techniques to aid in the innovation process. Some techniques used include: time travel, mind mapping, big dream, arbitrary constraint, and force fitting. All techniques were utilized in different ways during the session. Time travel was used to "warm-up" and mind mapping was used to get all the ideas down on paper. Big dream was used to cultivate the ultimate instrument storage compartment. Arbitrary constraint and force fitting were used to come up with more realistic designs. See appendix for all brainstorming notes.

3.3 Alternative Solutions

The following are 8 alternative solutions Team Strange developed during brainstorming sessions that adhere to all necessary criteria. These designs are uniquely named and include "Sliding Shelf", "Groovy Shelf", "Cozy Cubbies", "Pi-Olin", "Power Wheelie", "Ring-Around the Cubbies", "Floor Rack", and "High Violins". All of these designs are weighed against one another in Section 4 to determine the most suitable, effective, and efficient design for a moveable instrument storage compartment for violins and violas.

3.3.1 Sliding Shelf

Sliding Shelf consists of a series of 5 shelves inside a cabinet-like structure with 2 doors that open outward. The shelves are equal in depth, width, and height. The shelves have dimensions to support the length, width and depth of both violas and violins; 6 ft. 7 in. long, 2 ft. 6 in. deep, and 6 ft. 4 in. tall. Violas are longer, wider, and taller than violins. The dimensions of the shelves are large enough to accommodate violas. This design is made of heavy-duty plastic that is durable/strong enough to support the weight of the instruments. It is light enough to be moved by an adult. This design has a specialized sliding bottom on each corner of the base. The material for these attachments is a smooth plastic that helps minimize friction. This addition makes sliding the cabinet to different locations easier. The attachments will be cubes 9.5 in. long, 7.5 in. wide, and 4 in. tall. See Figure 3-1.

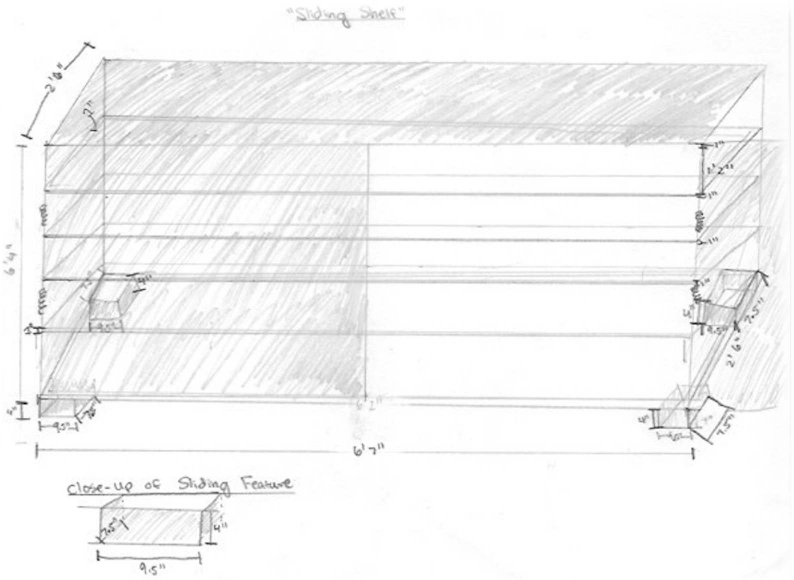


Figure 3-1: Sliding Shelf design. Image drawn by Haley Isaacson on 3/8/17.

3.3.2 Groovy Shelf

Groovy Shelf consists of 5 shelves with grooves. This design is similar to Slippery Shelf with a basic cabinet design. This design features doors that open outward. Grooves on the shelving are the main feature. They will be a viola-width apart from each other, with a few inches to spare on each side for easy access. The grooves will be made of sanded wood, will be 1 in. thick, 8 in. tall, and be flush with the back of the cabinet. There are enough grooves in the cabinet to accommodate every instrument that needs to be stored. Dimensions of Groovy Shelf are identical to Sliding Shelf, 6 ft. 7 in. long, 2 ft. 6 in. deep, and 6 ft. 4 in. tall. The sections instruments go into are 1 ft. wide. See Figure 3-2.

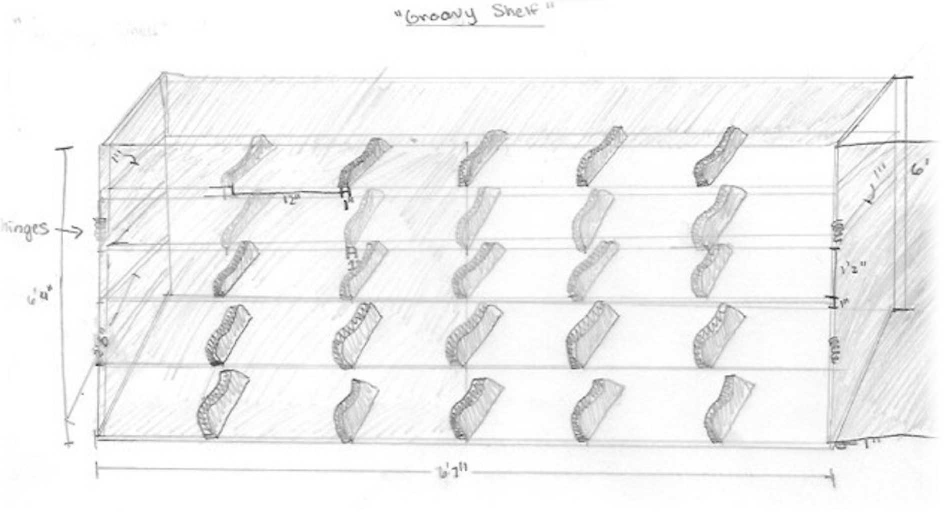


Figure 3-2: Groovy Shelf design. Image drawn by Haley Isaacson on 3/8/17.

3.3.3 Cozy Cubbies

Cozy Cubbies is a design capable of holding 42 instruments with their cases, while providing each instrument with an individual spot. Each cubby is designed to be more wide than tall. This allows the instruments to lay flat further preventing them from falling over. The entire design is 8 ft. 6 in. wide, 2 ft. 10 in. deep, and 4 ft. 9.5 in. tall. See Figure 3-3.

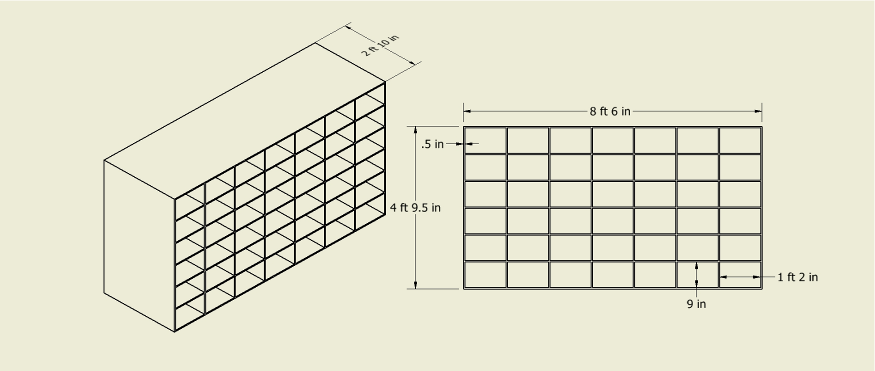


***Figure 3-3**: Cozy Cubbies design. Image done in AutoCAD by Mason Davidson on 3/8/17.*

3.3.4 Pi-Olin

The Pi-Olin design features 4 circular shelves that rotate. The corner of a room is an ideal spot for this unit. There are 4 in. walls on each shelf to prevent any instrument from falling off as it rotates. Each shelf can hold 13 – 14 instruments, totaling 52 – 56. See Figure 3-4.

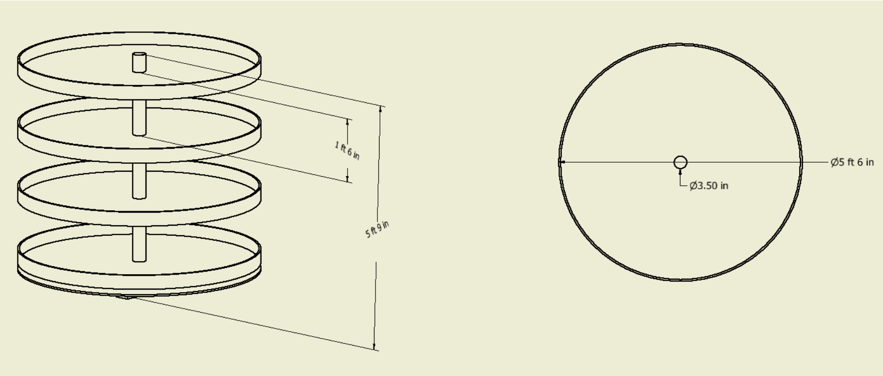


***Figure 3-4**: Pi-Olin design. Image done in AutoCAD by Mason Davidson on 3/8/17.*

3.3.5 Power Wheelie

Power Wheelie is a standard storage unit with lockable wheels. This design can commonly be found for purchase. The shelf stands 5 ft. tall and 6 ft. wide. The shelves are 3 ft. deep and 1 ft. apart from each other. These are ideal dimensions to make accessing instruments easy by everyone in the classroom. This design is made of metal rods and wired metal shelving. Wheels are fixed to the base of each metal rod. The 5 shelves can hold 6 – 8 instruments each. Having lockable wheels makes movement of the storage compartment on demand. See Figure 3-5.

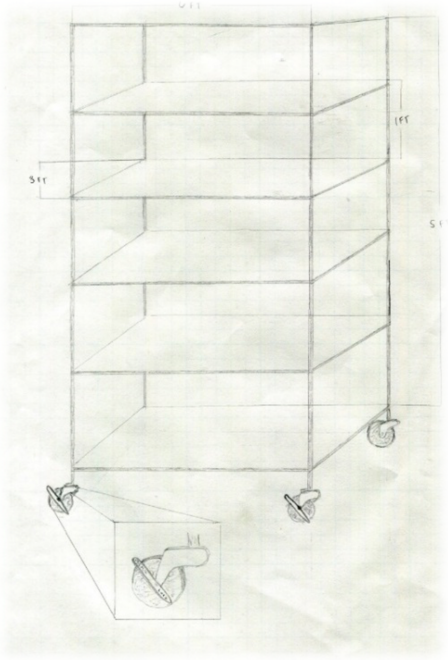


__Figure 3-5__: Power Wheelie design. Image drawn by Erik Kentfield on 3/8/17.

3.3.6 Ring-Around the Cubbies

Ring-Around the Cubbies is a circular design that stands 5 ft. tall with a diameter of 6 ft. The shelves are 1 ft. apart and are 3 ft. deep. 5 separate shelves can store 6 instruments. This design is made of durable, upcycled plastic. The shelves are designed to store a single instrument comfortably with ease of access. See Figure 3-6.

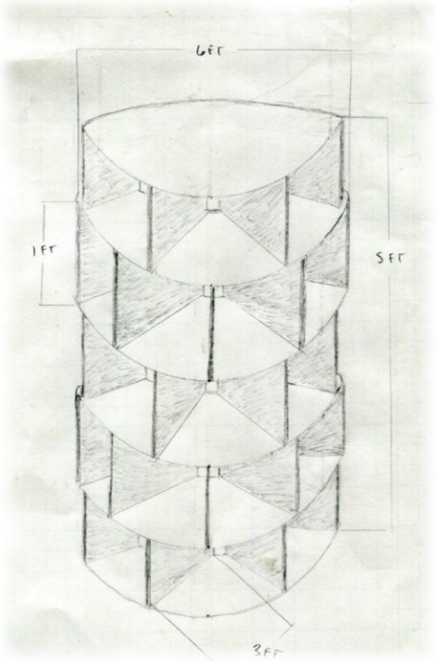


__Figure 3-6__: Ring-Around the Cubbies design. Image drawn by Erik Kentfield on 3/8/17.

3.3.7 High Violins

High Violins is designed to attach to a wall so instruments are hanging while being stored. The bottom is a few inches from the base of the wall and the top is no taller than 6 ft. 2 in. There are 2 boards stretching the length of the structure, 2 ft. apart. The bottom board has a lip attached to it so each instrument has something to rest on. The 2 boards have a peg mechanism to hold the instruments upright. There are 2 rows of 2 boards stacked on top of each other. This design is capable of holding 7 instruments per row. See Figure 3-7.

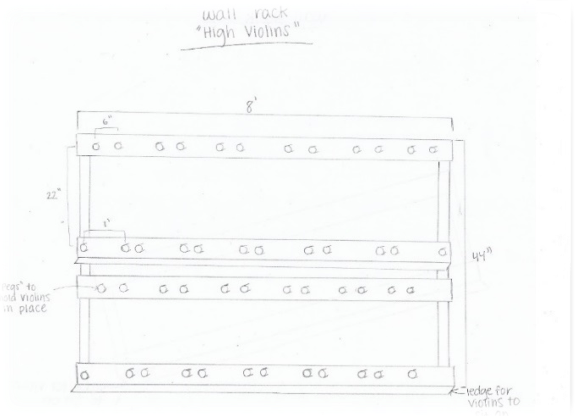


***Figure 3-7**: High Violins design. Image drawn by Alexis Clemente on 3/8/17.*

3.3.8 Floor Rack

Floor Rack is a design that allows safe storage of instruments and is similar to models that can be purchased. Floor Rack is a trapezoidal design that stores instruments vertically on each face of the trapezoid providing easy access for students. There are dividers on the shelves that prevent instruments from falling over. Dividers are spaced 6 in. apart. 2 rows of instruments rest on 2 planks that connect 2 side panels creating the face of a trapezoid. The planks are 8 ft. long and the trapezoid shaped side panels are 5 ft. tall. The bottom of the instruments rest on 1 of the 2 base planks and the neck of the instruments lean back to rest on 1 of the 2 top planks. Floor Rack has lockable wheels fixed to each of the base corners that allows easy movability. Floor Rack provides more space in the classroom from the vertical instrument storage. See Figure 3-8.

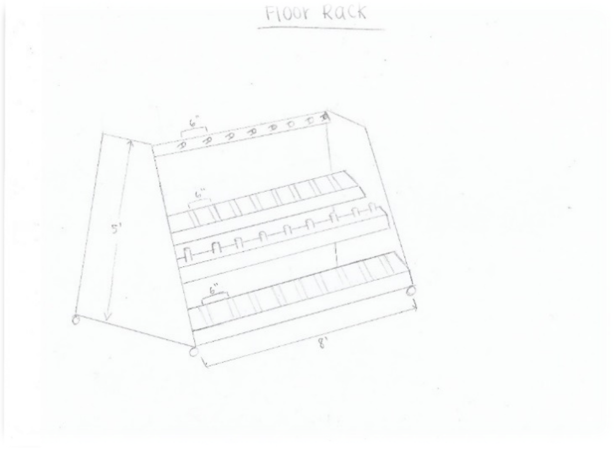


***Figure 3-8**: Floor Rack design. Image drawn by Alexis Clemente on 3/8/17.*

4 Decision

4.1 Introduction

Section 4 consists of the team’s decision process. The team utilized the Delphi matrix method to weigh alternative solutions against each other and received input from the client to find the best fit design.

4.2 Criteria

The criteria discussed in Section 2 were used for the decision making process that lead to the final design.

Stability refers to a structurally sound design and a design that supports all instruments, preventing them from falling over.

Safety refers to the protection of the instruments being stored and the students in the classroom without breaking any fire codes.

Accessibility is providing easy access for middle school students to access their instruments.

Cost of materials refers to the importance of not exceeding the $400 budget unless otherwise funded.

Storage space is the total number of instruments the storage compartment can hold.

Aesthetics refers to the final design being pleasing to the eye and having some musical aspect incorporated.

Inspirational refers to the inspiration created by the storage compartment for non-musical students to join the music program.

Durability refers to the shelves withstanding scraping, chipping, and breaking from the bottom of the instrument cases.

Sustainability refers to the design using upcycled materials.

Movability: Movability refers to the client’s capability to move the instrument storage compartment around the room.

4.3 Solutions

The following are the alternative solutions discussed in Section 3.

- Sliding Shelf
- Groovy Shelf
- Cozy Cubbies
- Pi-Olin
- Power Wheelie
- Ring-Around the Cubbies
- High Violins
- Floor Rack

4.4 Decision Process

Table 4-1 lists the criteria from Section 2. These criteria were primary factors in the team's decision. The team assigned weights to each criterion and then used a Delphi matrix to make the best decision. This process is described in the next subsection. The needs and desires of the client played a tremendous role in the final decision. Mr. McCay wanted a standard unit that meets the needs of the music students at Zane. He wanted a unit that is movable, easily accessible, and has the capability to store and protect all the instruments necessary.

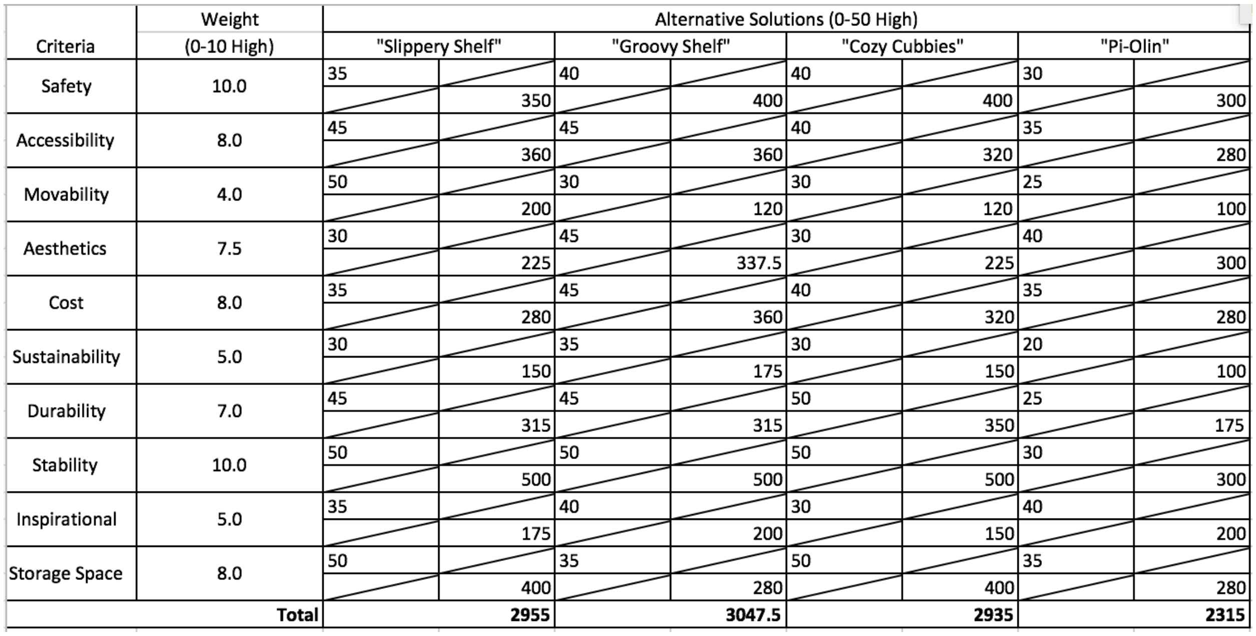
Table 4-1: *Weighted Criteria.*

Criterion	Weight
Stability	10.0
Safety	10.0
Accessibility	8.0
Cost of Materials	8.0
Storage Space	8.0
Aesthetics	7.5
Inspirational	7.5
Durability	7.0
Sustainability	5.0
Movability	4.0

4.4.1 Delphi Matrix

The weights of each criterion were multiplied by scores assigned to the 8 alternative solutions in each criterion category. The products were then summed for each design, giving each design a unique score. The resulting totals of each design determined the best final design. Each design satisfied the criteria differently and their respective scores reflect that. See Table 4-2 and Table 4-3.

Table 4-2: *Delphi matrix for final decision.*



Criteria	Weight (0-10 High)	Alternative Solutions (0-50 High)							
		"Slippery Shelf"		"Groovy Shelf"		"Cozy Cubbies"		"Pi-Olin"	
Safety	10.0	35	350	40	400	40	400	30	300
Accessibility	8.0	45	360	45	360	40	320	35	280
Movability	4.0	50	200	30	120	30	120	25	100
Aesthetics	7.5	30	225	45	337.5	30	225	40	300
Cost	8.0	35	280	45	360	40	320	35	280
Sustainability	5.0	30	150	35	175	30	150	20	100
Durability	7.0	45	315	45	315	50	350	25	175
Stability	10.0	50	500	50	500	50	500	30	300
Inspirational	5.0	35	175	40	200	30	150	40	200
Storage Space	8.0	50	400	35	280	50	400	35	280
	Total		**2955**		**3047.5**		**2935**		**2315**

***Table 4-3**: Delphi matrix for final decision.*

Criteria	Weight (0-10 High)	Alternative Solutions (0-50 High)							
		"Standard Shelf"		"Ring-Around Cubbies"		"Floor Rack"		"High Violins"	
Safety	10.0	45	450	30	300	40	400	35	350
Accessibility	8.0	45	360	25	200	40	320	45	360
Movability	4.0	35	140	30	120	50	200	25	100
Aesthetics	7.5	40	300	45	337.5	45	337.5	35	262.5
Cost	8.0	40	320	45	360	35	280	50	400
Sustainability	5.0	30	150	30	150	30	150	40	200
Durability	7.0	40	280	40	280	30	210	30	210
Stability	10.0	50	500	40	400	35	350	35	350
Inspirational	5.0	35	175	40	200	40	200	35	175
Storage Space	8.0	50	400	35	280	40	320	35	280
Total			**3075**		**2627.5**		**2767.5**		**2687.5**

4.5 Final Decision

Standard Shelving is a modified version of Power Wheelie from the Alternative Solutions in Section 3. This design scored the highest on the Delphi matrix and was Mr. McCay's most preferred alternative solution. Standard Shelving is a simple design, but easily adheres to all criteria while still providing space for inspirational creativity. Standard Shelving was designed to facilitate an extensive lifespan. Standard Shelving is 8 ft. wide, 6 ft. tall, and has a 3 ft. shelf depth. Standard Shelving can be moved if desired and the shelving is adjustable. See Figure 4-1.

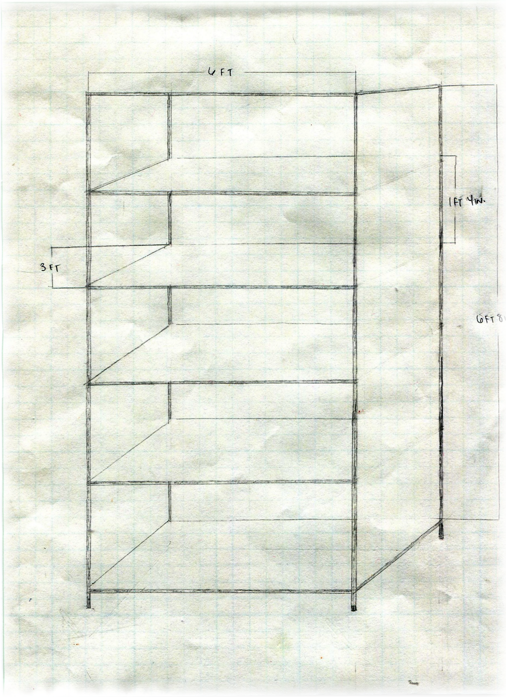


***Figure 4-1**: Standard Shelving design. Image drawn by Erik Kentifield on 3/8/17.*

5 Specification

5.1 Introduction

Section 5 includes a description of the design Team Strange chose for the movable instrument storage compartment. There is also a discussion of the cost analysis, instructions for use, and results of the project overall.

5.2 Description of Solution

Team Strange decided on a simple design. The main structure of the storage compartment is a U-Line storage unit that comes with adjustable shelving. Side panels have been retrofit onto the unit to prevent instruments from falling off the sides as well as providing space for a decorative, inspirational element. Magic Sliders have been used to make the unit easily movable. Figure 5-1 is an AutoCAD representation of a side panel added to the structure with a violin created from upcycled materials. Figure 5-2 is an AutoCAD representation of the frame of a U-Line storage unit that allows shelving to be adjusted by 1.5 inch increments. Figure 5-3 is an AutoCAD representation of casters being added to the base corners of the U-Line frame. This compromised the structural integrity of the unit and the team decided against adding wheels. The storage compartment is movable through the use of Magic Sliders. Figure 5-4 is an AutoCAD representation of the movable instrument storage compartment as a complete unit. Figure 5-5 is a picture of a finished side panel. Figure 5-6 is a before and after comparison of the choir room at Zane with and without the finished storage compartment. Figure 5-7 is picture of the completed storage compartment from a front view.

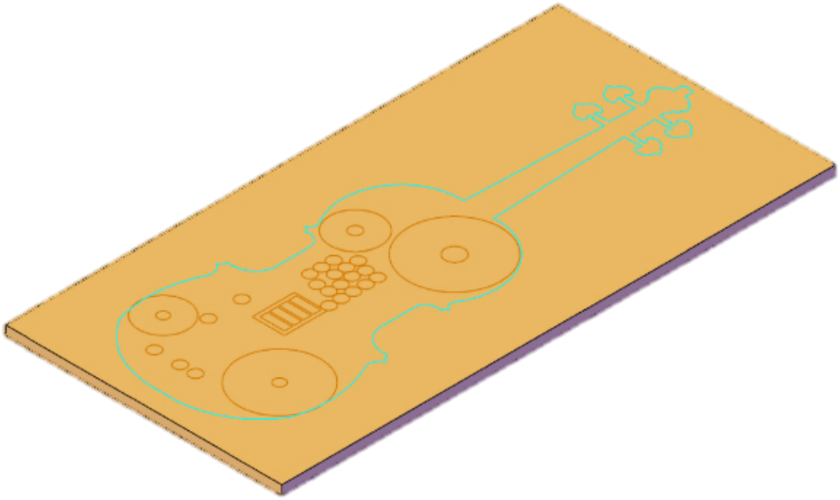


***Figure 5-1**: Side panel of instrument storage compartment. Image done in AutoCAD by Haley Isaacson on 4/9/17.*

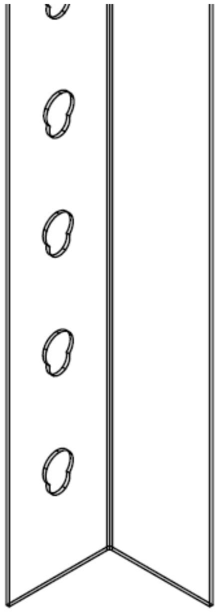


Figure 5-2*: Frame of U-Line storage unit that allows for adjustable shelving. Image done in AutoCAD by Mason Davidson on 4/9/17.*

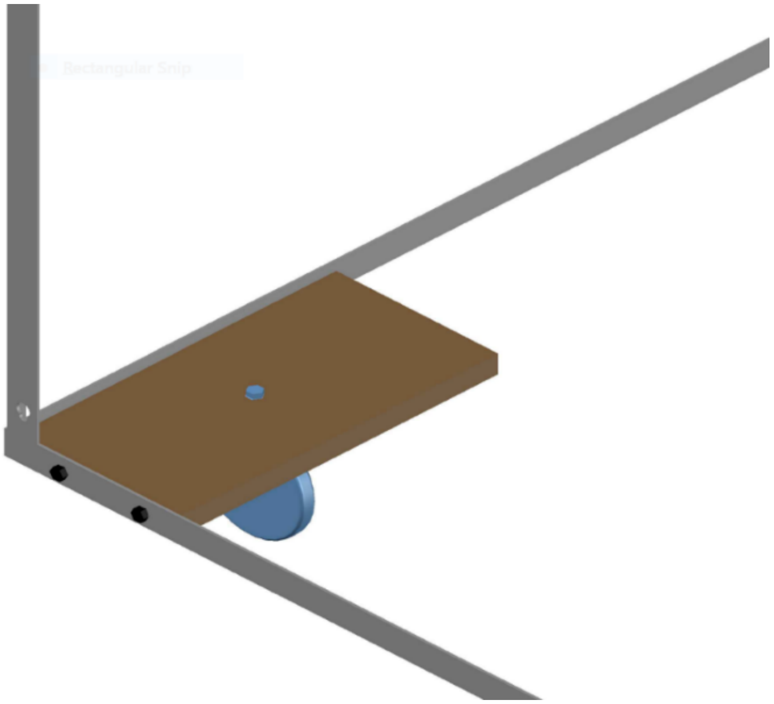


Figure 5-3*: AutoCAD representation of casters added to the base of the U-Line frame. Image done by Alexis Clemente on 4/9/17.*

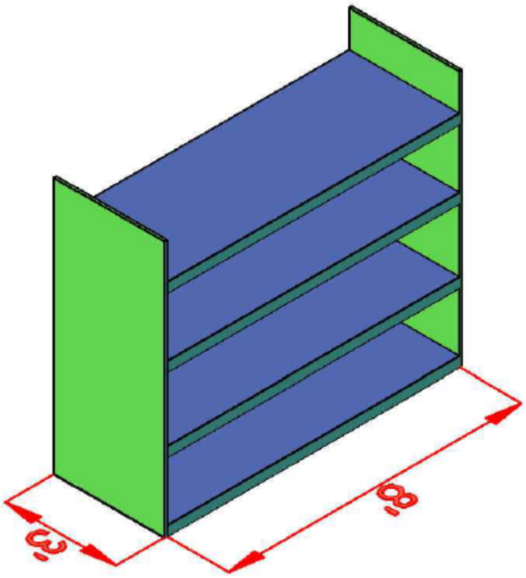


***Figure 5-4**: The complete movable instrument storage compartment. Image done in AutoCAD by Erik Kentfield on 4/9/17.*

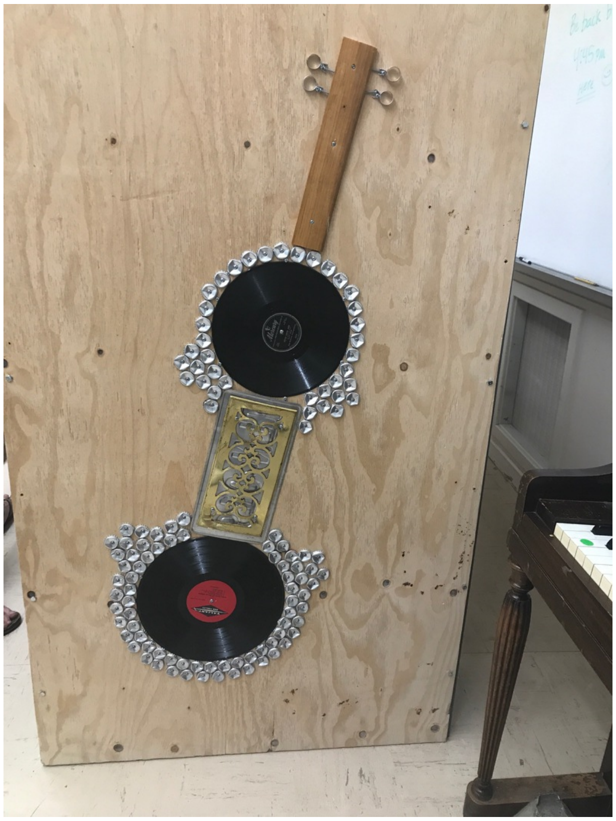


***Figure 5-5**: Picture of a completed side panel for the movable instrument storage compartment. Image taken by Alexis Clemente on 4/27/17.*

Figure 5-6: *Before (left) and after (right) comparison of the choir room at Zane. Images taken by Alexis Clemente on 4/27/17.*

Figure 5-7: *Front view of the completed movable instrument storage compartment in the choir room at Zane. Image taken by Alexis Clemente on 4/27/17.*

5.3 Costs

5.3.1 Design Costs (Hours)

The design costs is an indication of hours Team Strange exhausted designing and building the movable instrument storage compartment. Figure 5-8 is a graphical breakdown of hours spent on each phase/section of the design/building process.

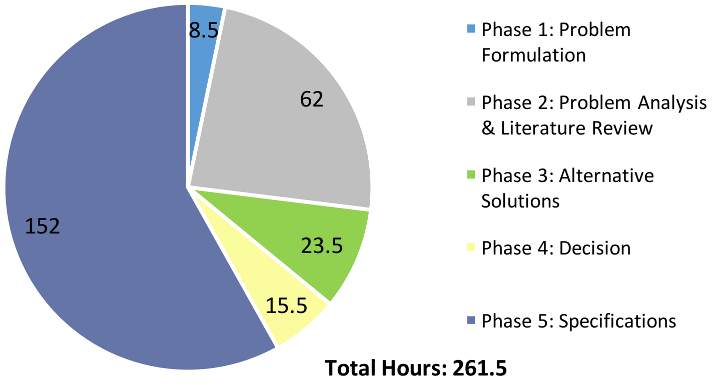


Figure 5-8*: Team Strange hour breakdown for the design/building process.*

5.3.2 Material Costs ($)

Table 5-1 is a breakdown of financial expenses Team Strange spent on materials and components for designing and building the movable instrument storage compartment. The total expense was $758.87.

Table 5-1*: Cost of materials/components for the movable instrument storage compartment.*

Materials	Use/Description	Price ($)
U-Line Storage Rack	Main Structure	$268.00
U-Line Shipping	Freight Delivery	$154.35
Additional Shelf	More Storage Space	$93.00
1/2" CDX Plywood (4' X 8') (2)	Side Panels (24.19 ea.)	$48.38
Tax	Sales Tax	$46.15
Polyurethane (2)	Particleboard Finish	$31.98
Upcycled Material from Scrap	Violin on Side Panels	$25.50
Wood Delivery	Too Large for Car	$20.00
Screws (3)	Attaching Violin Components	$14.67
Magic Sliders	Making Unit Movable	$10.94
Large Bolts	Attaching Shelves	$9.99
Small Bolts	Attaching Sides	$9.29
Nuts	Attaching Shelves/Sides	$7.49
Paint Brush (4)	Applying Polyurethane	$7.16
Spray Paint	Painting Bottle Caps	$6.99
Sanding Block (2)	Sanding Side Panels	$4.98
	Total:	**$758.87**

5.3.3 Maintenance Costs

There is no additional maintenance cost for the movable instrument storage compartment. Now that the unit is assembled and completed, the storage compartment is standalone aside from a safety check for loose and/or sharp components.

5.4 Instructions for Implementation

Team Strange utilized a U-Line storage unit as the main structure of the compartment. Assembling the U-Line requires attaching horizontal members, which make up the shelving, to a vertical frame; the members snap into place on the frame. The shelving has cross members that allow a particleboard shelf to rest on them. Each shelf can be adjusted by 1.5 in. increments. This feature will no longer be available once the particleboard shelving is attached to the cross members of the frame as requested by Mr. McCay. See Figure 5-8 for assembly.

Figure 5-9*: Assembling the U-Line frame at Zane. Image taken by Haley Isaacson on 4/14/17.*

A single coat of a triple-ply water-based polyurethane was used to finish both sides of the particleboard shelving in order to reduce wear and tear. See Figure 5-9.

Figure 5-10*: Finishing particleboard shelving with polyurethane. Image taken by Haley Isaacson on 4/17/17.*

Magic Sliders were added to the base corners of the unit in order to make the storage compartment easily movable. Heavy duty Magic Sliders can support up to 2500 lbs. and are self-adhesive.

The sides of the U-Line unit were retrofit with sanded 0.5 in. CDX plywood. This allowed Team Strange to decorate the sides with a violin created from upcycled materials including: old records, bottle caps, and other various metal bits. Used bottle caps were spray painted silver and all upcycled components were attached to the side panels with small sheet metal screws. The tips of the screws were hammered off the other side to prevent a safety hazard. See Figures 5-11, 5-12 and 5-13.

Figure 5-11*: Laying out violin design for side panels (left). Sanding CDX plywood used for side panels (right). Images taken by Haley Isaacson on 4/17/17 and 4/21/17 respectively.*

Figure 5-12*: Spray painting bottle caps for side panels (left). Attaching upcycled material to side panel (right). Left image taken by Alexis Clemente on 4/21/17. Right image taken by Haley Isaacson on 4/21/17.*

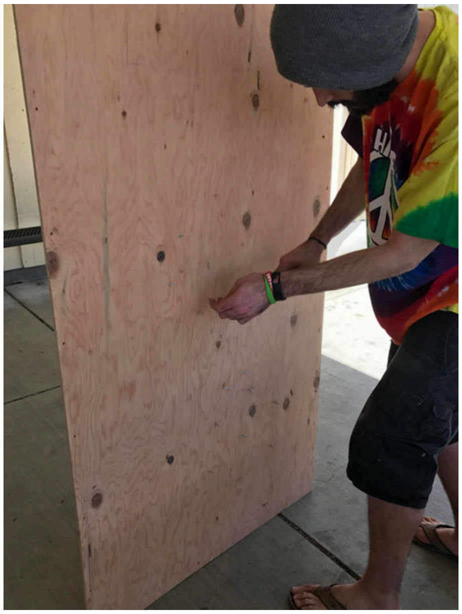


***Figure 5-13**: Hammering off tips of screws used to attach upcycled material to side panels. Image taken by Haley Isaacson on 4/21/17.*

It was imperative to eliminate any screws and/or wood fragments that may hinder the safety of middle school children using this storage compartment for their instruments daily. Checking for safety hazards and testing the movability of the unit are two safety check necessities. Staff at Zane Middle School will have to accommodate throughout the use of this instrument storage compartment in order for it to remain successful.

5.5 Results

The final product completely solved the problem of poor instrument storage at Zane Middle School. The movable instrument storage compartment provides enough space to hold all violins and violas necessary as well as additional cellos. The instrument storage compartment is movable and its shelves are deep enough to prevent instrument cases from hanging over the edge. The movable instrument storage compartment has been modified to be prevent instruments from falling off the sides.

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