**Design Three**
Adjustable Art Table

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Objective

What the Product Does

Basic Functions

This table will provide a smooth and steady surface for artists to work upon. Foremost, the table shall be safe so that nobody is injured. Once this is assured, the table should be able to adjust in height so that it could fit somebody in a wheelchair comfortably underneath it. This means that its clearance must be higher than the legs of someone in a wheelchair, the width must be wider than the wheels on the wheelchair, and the depth must be longer than the legs of someone sitting in the chair. The table will accommodate individuals in an oversized wheelchair. For this particular design, there will be a shaft that will connect the gears on the two legs of the table, and this should be out of the way of the user’s legs. If the user is comfortably underneath the table, the table will be lowered so that the artist can be comfortable without feeling enclosed. While underneath the table, the user should have confidence that the table will not fall. When the artist feels inclined to leave the table, it would be easy to do so. The height adjustable art table could then be adjusted for the next user. The table shall be reliable enough to withstand many adjustments over many years without much upkeep, other than cleaning the surface. A height adjustment would be useful for the artists at Passion Works to be more comfortable while creating the art they enjoy.

How It Will Be Implemented

The table will be developed by purchasing the basic components, assembling them and then testing the prototype for safety. This will be done in three stages. Firstly, the tabletop will be purchased that has a size and finish that is appropriate for art purposes. The tabletop is an important piece in the table because it must have good durability since it will be used very often throughout the day. The laminate surface would also make for an easy clean up. Knowing the weight of the table will be important in the force required for adjusting the table height. The table should require very little force from the user, and the weight of the table will determine that required force.

Most importantly, the device and its operations must be failsafe. The safety of the user is of utmost importance and will be a top concern. The safety latch is designed so that it only needs to be released in order to lower the table. In other words, if the safety latch is not touched, then the user will only be able to raise the table, by turning the handle. Therefore, the safety latch will be stopping the crank from turning, so this will be an important element in the table and will be given much attention. The texture, corners and edges of the tabletop must be specifically designed so that they are as safe as possible. To reiterate, the height adjustment mechanism must not cause harm to the user while in operation or while the table is being used. In short, the project will improve upon the past and existing tables and also satisfy the needs of those at Passion Works Studio.
**Block Diagrams**

**Helper’s Perspective – Appendix I**

The diagram is a basic schematic that represents how the user will interact with the table. It is composed of a two feedback loops that would allow the user to become most comfortable with the table. Once the user is comfortable, the remainder of the block diagram shows instructions on how to use the table.

**Design Process – Appendix II**

The schematic represents Team 9’s plan of execution to implement the manufacturing of the height adjustable art table. As of now, the team is currently on the Design Process step.

**Major Components**

The following diagrams of the front view and the side view of the tabletop show the dimensions of the table. As previously mentioned, the height, width and depth have to accommodate someone who may be in a wheelchair. Using a top down approach, one should note that there are rounded corners of the tabletop. This will assure that nobody will hurt themselves when walking into the tabletop. The table will be supported by two adjustable legs on the sides of the table which will be mounted to a base. The base will be wide enough to provide support, and will extend all the way to the front and back of the table to prevent the table from tipping.

**Rear View**

The rear view below shows what the table would look like if someone was looking directly at the artist using the table. A rear view was chosen instead of a front view, so that the gear rack and the gear would be included. The front view would just have a smooth, rectangular table leg and would not denote a gear or a gear rack. One can note that the corners are rounded on all parts of the table: the tabletop, the table base, and the handle. The gear rack is shown by the shading on the table leg, as this is a direct view at grooves on it. The handle can be turned in either direction so that the table is raised or lowered as desired. If the table should be raised, one would go about turning the handle clockwise. The handle turns the gear in both table legs which raises the table as the inner leg slides out of the larger outer leg which attaches to the base of the table. Should the table be lowered, the safety latch must be removed, and then the handle should be turned counterclockwise. The gear is held in place by two support panels which will be welded onto the bottom leg. The steel rod that connects the two gears passes through each support panel so that the torsion forces can be transferred appropriately.
Side View

The side view depicts the depth of the table which could not be seen in the front view. The table was designed to have a depth of 30” which will give the artist enough room for a moderately sized art project. The support beams depicted make it seem as if they will be in the users way, however the two support beams will be to the side of the table as depicted in the rear view. The table base was also designed to have a curvature in order to avoid corners that could harm someone. The other side view, Figure 3, shows the side view as if one were underneath the table and looking outward. One view shows what the gear would look like as if the mounting plate were not blocking one’s vision. The other view shows how the gears would look if the mounting plate were not there.
Figure 2: Side View From Outside

Figure 3: Side View From Inside
**Mechanism Close Up**

The following figure shows what the gear would look like from underneath the table, looking outward, also looking through the gear support piece. The number of teeth on the gear, for this diagram, is arbitrary. Additionally, the shape of these teeth is not what will be used either. The figure provides a close up of how the gear and the gear rack would interact and also how the gear would be held together. The handle can be turned in either the clockwise or the counterclockwise direction as denoted by the double headed arrow. This close up does not include the safety latch for the sake of simplicity. It will attach vertically from the shaft and will fit into the teeth of the gear rack to prevent the table from falling. The safety latch should be removed from the teeth so that the user could lower the table.

*Figure 4: Handle Close Up From Inside Looking Out*
Figure 5: Mechanism Close Up From Front View

Handle Dimensions
The schematic for the handle was acquired from a source (see Appendix III – References). This is a basic handle that serves as a way to increase the mechanical advantage of turning the gear. The mechanical advantage comes about by having a handle which provides a bigger turning radius and therefore a better moment about that point. The bottom portion of the handle slides into the gear and the handle would stick out from the side of the table as depicted in Figure 1.
Figure 6: Handle Dimensions

Three Dimensional View

It should be noted that the three dimensional view depicted below is just a rough schematic. This diagram gives a good idea of how all of the pieces will interact and this is why they are included. The frame itself depicts two extension beams that run from the table leg toward the front of the table. In fact, there may be a mounting plate that would screw into the bottom of the table top to connect the top of the gear rack to the table top. The mounting plates have been found, however it seems that these mounting plates will need reinforcement because they are too small. The ideal frame would look like the diagram below.
Figure 7: Three Dimensional View of Table in Lowered Position

Figure 8: Three Dimensional View of Table in Raised Position
Subunits of Design

Tabletop

The tabletop used in this design should be able to meet the specifications of the Passion Works artists as well as for anyone who would like to draw on it. The edges of the tabletop should be smooth to prevent injury to the user. The surface should also be very smooth, as it will be a drawing surface. The tabletop surface should also be easy to clean since some art materials may be spilled onto it. The tabletop used in this design will be from made by Safco. Its dimensions are 30 in. X 42 in. X 0.75 in. Since the width is 42 inches, this provides any user who is sitting in a wheelchair to have a comfortable full range of motion since maximum wheelchair widths are 35 inches. The width of the tabletop should not be out anyone’s drawing range while it is in use, otherwise this would be a waste of material. The depth of the tabletop is 30 inches. This will provide plenty of arm extension for any user since the shoulder to arm length of a person 6 feet 5 inches tall when fully extended is about 30 inches. A picture of the tabletop can be seen in Figures 1 and 2.

Many of the artists who will be using the table at Passion Works will be in wheelchairs, so it is very important that the table accommodates all wheelchair types. The standard wheelchair is 26” wide and has a seat height of 21”. This standard width would accommodate most of the wheelchairs on the market, but there are some exceptions that would require a larger width for the table. There are wheelchairs made for the obese, which have widths of 35”. Therefore, the width of the space between the bases must be at least 36”. This chair also has a depth of 20”, so the shaft extending across the back of the table should be at least 20” from the front of the table. The artist’s torso takes up anywhere from 5” to up to 15” of that depth, so there would be plenty of leg room for the artist if the shaft is locate approximately 25” back as in our design.

The surface of this tabletop will be that of laminated white melamine material. The inside of the tabletop is made from a plastic fiber, which is compressed cross-linked polymer. The melamine surface is made by mixing melamine powder with other substances, including an aqueous formaldehyde solution. This solution forms a resin which is also known as an adhesive which is added to the outside of the chip board. This resin is then processed further to make the laminate surface for the tabletop. This laminate surface has many good qualities and advantages which our clients will find in the tabletop surface. The melamine laminate surface is extremely durable and resistant to heat. This surface is also scratch and moisture resistant. This increases the lifetime of the tabletop over others since it will not get scratched up and soiled if water or other liquids are accidentally spilled on it. With the surface being moisture resistant, this also makes the tabletop very easy to clean. When looking into electrical conduction, the melamine surface is electrically insulating. Electricity could not be conducted from one side of the surface to another. This is just another extra safety feature that the melamine surface provides. With all the properties of the tabletop taken into account, it is apparent that this tabletop will provide the user with the maximal comfort as well as minimal maintenance.
**Height Adjustment Mechanism**

The adjustment mechanism for this design is a gear rack system, which relies on a handle to raise and lower the tabletop. There are two legs made of steel square tubing located on the sides of the table, but pushed towards the back. This is because there needs to be a shaft going across the back of the table to connect the gears of the racks in the two legs. The shaft cannot interfere with the artist’s legs, which is why the legs are located in the rear. The racks will be mounted to the tabletop and fitted to move up and down inside the square tubing. The shaft is mounted to the square tubing by two steel plates on each leg, so the shaft will run through each plate with the gear in the middle. This supports and allows control of the gear while also allowing free movement of the rack into the tubing.

The rack and gear move together by interlocking teeth. The gear is rotated by a handle, which in turn causes linear movement of the rack. The setup is shown in the following figure.

![Figure 9: Gear Close Up](image)

The force, $F$, is applied to the rack, and in order to raise the rack up, the gear must be rotated to apply the forces, A and B. In the design, $F$ is the downward force of the tabletop and applied load. Since two teeth are articulating with the rack, the force on each tooth required to raise the rack would be slightly greater than $0.5F$. The gear used for the table has a diameter of 2.4 inches, so the torque required would be:

$$T = 0.5 \times F \times (2.4 \div 2) = 0.6F$$

The handle used for turning the shaft is 5” long, so the force needed to provide the necessary torque is found by:

$$F = 0.6F \div 5 = 0.12F$$

The tabletop is going to be approximately 50 lbs, since there are two legs and gear racks the necessary force to raise the table would be:

$$F = 0.12(25) = 3lbs$$
So, an aide would only need to apply a little over 3 lbs of force to raise the table, which is easy to do numerous times throughout the day.

The gear has a diameter of 1.2 inches, so the circumference of the gear is:

\[ C = 1.2\pi = 7.54" \]

With each turn of the gear, or handle, the rack moves a distance of 7.54 inches. So, each tooth on the rack corresponds to a length of:

\[ L = \frac{7.54}{48} = 0.157" \]

**Forces on Table/Joint Reactions**

The table will be placed under many loads while in use, which will cause stresses and moments around the different joints and table components. There will be loads of approximately 100 lbs applied to the front of the tabletop during normal use, but the main concern for table stability will be when large forces not associated with the artist are applied to the table. These large forces are caused by people sitting on the table, or by storing heavy equipment on the table when it is not in use. The legs of the table are located towards the rear of the table because the gears require a shaft to connect the two legs and this shaft cannot interfere with the artist’s legs. This setup leaves the table open to the possibility of tipping if large forces are applied to the front edge of the tabletop. To counteract the tipping moment, the base of the table is extended to the edge of the table. Figure 10 depicts the external forces applied to the table when tipping would occur.

*Figure 10: Free Body Diagram of Table*
There is only a reaction $R_y$ applied to the table base because it is assumed that the table is on the verge of tipping around that point A. In order for the table to tip over, the moment about point A must be positive, with the positive moment for all equations to be defined as counterclockwise rotation.

$$\sum M = F(0) - M_{tt}(25) - 2 \times M_{leg}(25)$$

The moment can never be positive because the force of the load at the farthest point on the tabletop passes through the point at the edge of the base. This means that the force cannot cause any rotation around that point. Plus, the masses of the tabletop and legs ($M_{TT}$ and $M_{leg}$ respectively) cause a negative moment about point A, and would therefore cause reaction forces at other points along the base.

Even though the table cannot tip due to the force applied to it, the load will be felt in the joints and connections between the legs and the tabletop and base. The figure below is the free body diagram of the tabletop.

![Figure 11: Free Body Diagram of Tabletop](image_url)

$F_y$ is the force applied from the support beam and $M_p$ is the moment caused by the support beam. $R_y$ and $R_x$ are the reactions at the joint between the tabletop and the rack. $F$ is the known applied force, and $M_{TT}$ is the known mass of the tabletop. $L_t$ is the known distance from the joint to the attachment of the support beam. If the moment is taken about the joint, one can calculate the moment $M_p$ necessary to support the tabletop. From the sum of the forces in the y-direction, the reaction force $R_y$ can be calculated. Also, from the sum of the forces in the x-direction, it is clear that the reaction force $R_x$ and the reaction force at P, $P_x$, are equal.

$$\sum M = 0 = F(25) + M_{tt}(10) - M_p$$

$$M_p = 25F + 10M_{tt}$$
\[ \sum F_y = -F - M_{TT} + R_y \]
\[ \sum F_x = -P_x + R_x = 0 \]

Therefore \( P_x = R_x \) and \( R_y = F + M_{TT} \).

By examining the forces on the support beam, the force \( P_x \) can be determined. The beam is depicted in Figure 12, and since there is a wheel on one end, there can be no vertical forces acting through the segment.

![Figure 12: Free Body Diagram of Support Beam](image)

The forces \( A \) and \( B \) must be equal, and are equal to \( P_x \). The moment \( M_p \) is equal to the moment caused by \( B \) around the other end of the segment.

\[ \sum M = 0 = M_p - B \times L_p \]

\( M_p = B \times L_p \)

So \( B = \frac{(25F + 10M_{TT})}{L_p} \)

For the rack, there are forces from the support beam, the reactions at the joint, and the reactions from the gear. The rack is shown in Figure 13.
For this free body diagram, the forces $R_y$, $R_x$, and $P_x$ are known. By summing the forces in the x-direction the force $G_x$ is found to be equal to zero, and by summing the forces in the y-direction, the force $G_y$ is found to be equal to $R_y$.

\[
\sum F_x = 0 = -R_x + P_x - G_x
\]

\[
0 = -P_x + P_x - G_x
\]

\[
G_x = 0
\]

\[
\sum F_y = 0 = -R_y + G_y
\]

\[
G_y = R_y = F + Mtt
\]

The force $G_y$ is distributed through the gear to the shaft, because there are no other vertical forces applied to the gear. The shaft is put under more forces, and is where the external forces are divided to fall on a couple different supports as seen in Figure 14.
The $G_y$ calculated in the previous examples is the general force occurring through the supports if the force was in the plane of one of the legs. If the force is more centered, the force will be shared through both the legs.

Therefore, the sum of the forces acting on the shaft at $G_{y1}$ and $G_{y2}$ will be equivalent to the force $G_y$.

$$G_y = G_{y1} + G_{y2}$$

The forces $S_1$, $S_2$, $S_3$, and $S_4$ are the reaction forces in the shaft’s mounts. There are two mounts on each leg, one on each side of the gear. So, the force in the mounts around each leg will be equal because the mounts are equidistant from the gear.

$$\sum M = 0 = S1 \times (\text{length \_ away \_ from \_ gear}) - S2 \times (\text{length \_ away \_ from \_ gear})$$

$$S1 = S2 = 0.5 \times G_{y1}$$

When the load is centered on the table, $G_{y1}$ and $G_{y2}$ are equal, so the forces in all of the mounts are equal.

$$S = S1 = S2 = S3 = S4 = 0.25 \times (F + Mtt)$$

If the load is not centered, but instead is entirely over one leg the forces are different.
\[ S1 = S2 = 0.5 \times (F + Mtt) \]

The forces in the other leg are minimal compared to the forces in the loaded leg. The force \( S \) is then transferred to the bolts or welding attaching the mount to the table leg. So, the force in those joints is going to be a maximum of half the force applied based on where the load is positioned.

The final joint is where the base of the table is joined with the leg.

![Free Body Diagram of Tabletop and Table Leg](image)

\[ \sum F_y = 0 = -Mtt - f + Ky \]

\( Ky = F + Mtt \)

\[ \sum M = 0 = 25F + Lt \times Mtt - Mk \]

\( Mk = 25F + Lt \times Mtt \)

\( K_x = 0 \)

Again, these forces are the maximum possible forces, which are found when the loads are in the plane of the legs. If the load was more central, the forces would be lower because the forces will be shared between two legs. Even though there are no forces in the x-direction, the legs are going to be supported equally in all directions on the base. This will ensure that the base will be stable when the table is pushed or pulled, as during moving the table to new locations.
Safety Latch
When the table is stationary, there will be an extra piece to ensure that the gear and shaft do not rotate and allow the table to lower on its own.

In this, the latch is positioned in the groove between teeth and attached to the leg by a spring. When the table is raised the latch is dragged out of position by the next tooth, and then placed in the next groove by the spring. When the table is to be lowered, the latch must be removed. When the table is held steady, the shaft holds the rack in place and keeps the gear from rotating.
The force, $F$, is the force of the rack, which will be equal to $G_y$. Therefore, the bar will need to be strong enough to withstand the maximum forces applied to the table. It has been assumed that the maximum possible force applied to the table will be 500 pounds, so the joint where the latch is connected to the leg and the latch itself must be able to withstand that force. When this is in use there will be less force on the gears. The overall forces on the table base and joints should be the same as when it is not in use, but the height will be kept constant without force being applied to the handle.

In order for the tabletop to be safe and secure when mounted to the gear rack, a safety bar will have to be implemented on each side of the table between the bottom of the tabletop and the gear rack. This bar will be rigidly mounted to the bottom of the tabletop about half way between the front and back. A free moving wheel will be attached at the end of the bar as to move along with the gear rack and table leg as the table is adjusted to different heights. The bar will also be made out of 6061-T6 aluminum due to its light weight, high strength, high rigidity, as well as relatively low cost. The aluminum bar will be of a square bar type with dimensions of 1 inch by 1 inch. This will enable the wheels to be mounted in an easy fashion. This device will take some of the force away from the moment which would be created at the joint of the gear rack and tabletop if someone sits on the front of the table. That extra force would be transferred through the wheel in the X-direction towards the gear rack.

**Table Base**

The base is a very important component to the design of our art table. The base will be the basis for the strength and stability of the table. The base which will be integrated in this table design will be made out of a 6061-T6 aluminum flat bar. This bar will be split into two separate bars so as to have two bases. Each of the bars will be oriented under the tabletop on the left and right sides of it. They will run the full thirty inches as to be viewed as the same length of the tabletop from a side view. This flat rectangular bar will add extra stability to the base. A figure of one of the flat bars which will be used for one of the bases can be seen below.

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**Figure 18: Table Base**

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This aluminum in general is lighter than most other metals such as steel, brass, or gold. Aluminum is also very versatile and has a wide range of machine ability. In the construction of this table, the base may have to be cut and fabricated in order to ensure certain parts of the table function properly. Aluminum is a great metal to do this with since it can be riveted, welded, brazed, or resin bonded. This metal has greater tensile strengths when compared to other metals. Aluminum also needs no protective coatings applied to it. The aluminum flat bar already comes finished. When looking into the costs for this design, aluminum is relatively less expensive when compared to other metals such as stainless steel. The only area where stainless steel would be more adequate to use would be the higher corrosion resistance it has over aluminum. This higher corrosion resistance would only be needed of the table were to be used outside where weather elements would increase the rate of corrosion. Since this table will be used indoors, the degree of resistance to corrosion of aluminum is negligible.

**Accessories**

Accessories for this art table will maximize the luxury for the Passion Works artists using it as well as for anyone who wishes to use it. This will also help in the marketability of the art table. An accessory which will be implemented in this design will be that of a height sensor. This height sensor will allow the user to know the height of the tabletop by the press of a button. This will save a lot time for future height adjustments for a particular artist since it could be noted exactly what height they had the table adjusted to for their previous usage of the table. This height sensor is made by Zircon. It uses ultrasonic waves which are emitted from the device and then bounced back from the object it is measuring the distance from. A photo of the actual product can be seen below:

![Figure 19: DM S40 Zircon Sonic Measure](image)

This height sensor has a range from 2 to 44 ft. It is 99.55% accurate when measuring to the nearest inch. The height of the table will be adjusted in units of inches and the height sensor will cover the whole range of height adjustments the of the art table. This device is very beneficial, as well as safe, for all the Passion Works artists who will be using it. The weight of this device is only 2.5 ounces. This makes the weight of this measuring tool negligible of adding any amounts
of weight which could create extra moments about the height adjusting mechanisms no matter where it is placed under the tabletop. This device does have a switch, but even if another artist in the room came by and hit a few buttons, it would merely change the units or dimensions the height sensor is reading. It could easily be readjusted to measure in the correct units. Touching any button on this device will not at all have any affect on the tabletop’s orientation in space. This height reading device provides little potential hazard for artists using the table, as well as knowledge about comfortable height levels of the tabletop for the artist.

When this device is purchased, it cannot simply be mounted to the bottom of the tabletop. This is because the wave generator sits above the display screen. This device will have to be taken apart and rearranged into a readable upright display just under the tabletop. All of the components in the height sensing device will be secured into a wooden frame. This will ensure that the components stay where they are at all times while the table is in use. The height sensor will be oriented toward the ground as it will be reading constant heights accurately from here when needed to do so. All that is required to power this device is a 9V battery. This will power the device by being placed in the back of the wooden box which encloses the whole height display system. This will reduce any risk of someone coming along and having easy access to take the battery out of its place in the box. By the height device being battery powered, it requires no use of a power cord which would have to extend across the room in order to power it. When the height sensor is taken apart and reconfigured, the ultrasonic wave generator will be oriented toward the ground while the actual height display screen will be oriented just below the tabletop for the artist to easily see. It will also not protrude out from the tabletop as it could impinge upon by an artist sliding into a drawing position along the edge of the tabletop. A schematic of this can be viewed below.

![Figure 20: Height Display Attachment](image)

As the client desires, certain accessories can be added to the table afterwards. This includes holders for pens, pencils, paintbrushes, chalk or beverages in possibly separate compartments. If the user wishes, there could be a lip on all edges of the table so that materials do not roll or liquids do not drip off the table.
### Budget

#### Table 2: Budget

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Appendix I: Block Diagram for User

1. Is the table comfortable for the user?
   - Yes
      - User Positions Themselves Under the Table
      - Start Art Project
   - No
      - Hold Safety Latch in the Released Position

2. Does the Table Need To Be Raised?
   - Yes
      - Turn Handle in the Appropriate Direction
   - No
      - Hold Safety Latch in the Released Position

3. Is Height of Table High Enough for User to Fit Underneath Comfortably?
   - Yes
      - User Positions Themselves Under the Table
      - Start Art Project
   - No
      - Hold Safety Latch in the Released Position
Appendix II: Block Diagram for Design Process

Design Process

Table Top Manufacturing

Table Base Manufacturing

Redo Base Width to Accommodate Wheelchair

Can a Wheelchair Fit Underneath?

Yes

Attach Gear Rack To Base and Table

Does the Table Adjust Between 27" and at least 40"?

Yes

Attach Gears and Handle

Is Table Stable?

NO

Find Where Instability is Caused and Adjust

Table is Complete, Work on Instructions and Finishing Touches

NO

YES

Adjust the Height Off the Floor
Appendix III: References

1. The height display technical information was taken from:
   http://www.zircon.com/SellPages/Measuring/DMS40/DMS40.html

Appendix IV: Acknowledgements

1. Christopher Liebler
2. Jeff Malash