Design One
Adjustable Art Table

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Funding: National Science Foundation
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 haphazardly. 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. If the user is comfortably underneath the table, the table will be lowered that the artist can become comfortable without feeling enclosed. While underneath the table, the user should rest assured that the table will not fall. Additionally, it shall not be so unstable that the quality of the artwork is compromised. 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 much adjustment over many years without maintenance other than cleaning the surface. A height adjustment would be useful for the artists at Passion Works to be more comfortable and create the art they enjoy.

Optional Features

Various accessories could be added to the table once it performs the basic functions. To prevent materials from rolling off the table, a lip on the edge of the tabletop could be added. It may be desired that the user know the height of the table when it is in a comfortable position. A height display could help the user adjust the table to the desired height on the first try. These amenities, although attractive and may increase user productivity, are unessential to the basic functions.

How It Will Be Implemented

The table will be developed by purchasing the basic components, assembling them and then testing them for safety. Foremost, the table will use a screw jack so that it can adjust in height. There are manufacturers for the table top who provide smooth art surfaces with optional rubber edging. As always, the safety of the user and any bystander is important and therefore the rubber edging will be purchased for the table top edging. To provide for a strong and sturdy frame, metal table legs will be designed in accordance to the table’s functionality. The side table legs that provide for a safety mechanism should the main screw fail or be turned haphazardly. Therefore these legs will need to be height adjustable and also be customizable so that a safety latch can be added on to it. On each table leg, a smaller cylinder would be fit inside of a slightly larger cylinder. These cylinders should move freely, but be held in place by a pin when the table is in use. To handle the high volume of users, the materials will be chosen which have good longevity and high wear resistance. Therefore the table legs will be made out of aluminum, and the table top will be made out of a wood with a laminate surface finish. The screw jack is made out of industrial material and will be purchased to assure that this most important feature does not break. Most importantly, the device and its operations must be failsafe. The safety of the user is of utmost importance and will be forefront of concerns. The texture, corners and edges of the table top must be specifically designed with this in mind. To reiterate, the height adjustment
mechanism must not cause harm to the user while in operation or while the table is being used. Ideally 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 feedback loop 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 table top show the dimensions of the table. As previously mentioned, the height, width and depth have to accommodate someone who may be in a wheelchair. Therefore, since the average wheelchair has a height of about 40” and a width of 26” then the table is designed so that there are an extra couple of inches for precautionary concerns. Using a top down approach, one should note that there are rounded corners of the table top. This will assure that nobody will hurt themselves when walking into the table top. Next, there are two side table legs that support the main leg in case of a malfunction. Therefore these legs have safety pins (as denoted in the diagram) that will need to be reinserted after the table is adjusted so that the legs support the weight. The main jack has cross hatches that represent threads on the inner cylinder, which travels inside of the outer cylinder below it. From the front view, one cannot see the handle for the screw jack which is why it is in a dotted format, but looking from the side view, one can now see this handle. The table legs will attach to a base that sits flat on the floor. The base will be wide enough to provide support, and will wrap around all sides except the front to provide more stability.
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 moderately sized art project. At the rear of the table the handle can be used to raise and lower the table top. It is at the rear specifically so that somebody else (not the artist) could manipulate the table and so that it is out of the way of the artist’s legs.

**Three Dimensional View**

This is a basic three-dimensional design. The two front legs will actually be cylindrical in shape as will the rear leg.

**Subunits of Design**

**Safety Mechanism**

The safety of the users and bystanders is of utmost importance when dealing with a device such as this. The table could potentially fall, so there could perhaps be a safety mechanism to thwart this. Raising or lowering the table should not require excessive physical exertion to the user, and should allow a user of any stature to do so. The table shall also be stable enough so that it does not move out of the desired position. If the table moves away from the user it could harm somebody as well as create a disturbance to the artist at work. A moving table...
could potentially injure someone if it has sharp corners, so beveled edges and soft corners should cushion anyone who bumps into the table.

**Height Adjustment Mechanism**

It should be easy for the user to raise and lower the table. The adjustment mechanism is a simple screw jack positioned in the rear of the table. It is pushed to the back of the table to accommodate an artist in a wheelchair. Screw jacks are simple mechanical devices used for raising an object by employing two screws. The load is placed on top of the vertical screw, and the rotation of a horizontal screw, or worm, moves the vertical screw up and down. The setup between the two screws is depicted in the figure below.

![Figure 4: Screw Jack](image)

The horizontal screw is turned by the use of a crank or handle, and its rotation is translated into the vertical motion by a grooved worm gear surrounding the vertical screw. The horizontal screw causes the worm gear to rotate around the vertical screw, which moves along the threads pushing the screw up or down. In this design, the screw jack used is an upright inch ball screw jack from Nook Industries.

<table>
<thead>
<tr>
<th>Gear Ratio</th>
<th>Capacity (Lbs)</th>
<th>Screw Diameter (In)</th>
<th>Turns of Worm for 1” Travel</th>
<th>Torque to Raise 1 LB (in-Lbs)</th>
<th>Weight per inch traveled (Lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5:1</td>
<td>1000</td>
<td>0.625</td>
<td>10</td>
<td>0.0242</td>
<td>0.3</td>
</tr>
</tbody>
</table>
The handle to turn the worm screw is a hand wheel with a diameter of four inches. This is also manufactured by Nook Industries.

**Screw Jack Dimensions**

The following diagram is a likeness of a blueprint that was provided by the manufacturer of the screw jack.

![Figure 5: Screw Jack Dimensions](image)

The handle of the hand wheel is two inches from the center of the wheel, where it attaches to the worm. The table is considered to have to raise a maximum of five hundred pounds a distance of 13 inches. The necessary force applied to the handle is calculated using the amount of torque needed to raise 1 lb, .0242 lb-in. The equation for torque is given by:

\[
\text{Torque} = \text{Force} \times \text{Distance}, \quad \text{and when substituting yields,}
\]

\[
0.0242 \text{ lb-in} = F \times 2 \text{ in}.
\]

Solving for F,

\[
F = .0121 \text{ lbs to raise 1 lb load and,}
\]

\[
F = 6.05 \text{ lbs for a 500 lb load.}
\]

The bottom of the screw jack would be mounted to the base of the table 6.5 inches off the floor. The length of the base of the screw jack is 21.5 inches, so with the screw completely retracted the height of the table would be 27 inches. With a screw allowing for 13 inches of travel, the
Table could reach a maximum height of 40 inches. The screw jack is made out of a steel alloy, with a high tensile bronze for the worm gear. These materials allow the jack to support loads up to 1000 pounds. The hand wheel is made out of cast aluminum, which is strong enough to easily endure the light force of 6.05 applied to the handle to turn the worm.

The screw jack would attach from the base to the rear of the table. This allows for the most possible legroom for the user. Also, because of this setup the handle is in the back of the table. This keeps the artist from accidentally adjusting the mechanism, and puts it in a convenient spot for someone to adjust the table down to the artist’s level.

**Tabletop**

In addition to the safety of the tabletop already mentioned, the tabletop itself should have dimensions that are optimal to those using it so that material is not wasted. The tabletop should be sturdy enough so that it can handle the required weight limitations. It could possibly be surface treated to prevent art markings, increase its aesthetic longevity and provide an easy way to clean it. An efficient way would be to add a thin strip of laminate surface which will prevent markings and add to the longevity of the table. The table should be smooth enough so that the texture of it does not appear when the artist is penciling on paper directly on top of the table, and also it should be large enough so that the user could do artwork on it.

![Cross Section of Table Top](image)

*Figure 6: Cross Section of Tabletop*

**Safety Considerations**

With the screw jack height adjusting device located at the back center of the table, there is a crucial need for extra support of the tabletop. Even though the screw jack will be fastened tightly to the tabletop’s bottom, there are still many factors which must be considered when dealing with the safety of this adjustable art table. When the table is in use by an artist, he will put a certain amount of force on the table top opposite of where the screw jack is located. This will create a great moment at the point of connection of the tabletop and screw jack mechanism. With the design of the base, this moment would not cause the entire table to collapse, but rather the tabletop itself could possibly detach from the screw jack mechanism possibly resulting in an injury to the artist using the table. Another possible factor which must be taken into account is
the possibility of the screw jack device itself failing when too great of a moment is put upon it. This could arise from a random person in the art room deciding to just sit on a part of the table whether or not the table is in use by an artist. This greater moment could cause the screw jack itself to possibly bend or even become detached from the table’s base. Through analyzing all these possibilities, a user friendly yet very reliable safety mechanism had to be implemented in order to maximize the safety factor of the table for anyone wanting to use it.

In order to successfully implement a user friendly and reliable safety device for the adjustable table, many things had to be taken into consideration. The safety device will consist of two aluminum cylinders which will be situated towards the front side of the table, one under the right and one under the left side of the table which will move along with the screw jack in adjusting the table’s height. This will happen because the cylinders for each safety leg will have slightly different diameters. One cylinder with a larger diameter will be attached to the bottom of the tabletop while another cylinder with a slightly smaller diameter will be attached to the base. The safety legs will adjust and be stabilized through a pin system.

In order to see if the safety mechanism will hold, all of the possible maximum forces put on the tabletop had to be calculated through force and moment equations. When viewing the tabletop from above in figure below, it is easy to see all the forces acting on it and where they are located. Before this could be done, some basic equations for calculating forces on objects should be known. The density of the tabletop can be defined as:

\[ \text{Density} = \text{mass} \times \text{volume}. \]

Since we are planning to use an oak tabletop, the density of oak as well as the volume of oak being used for the tabletop will be needed in order to calculate the weight of the tabletop. The density is given by:

\[ \text{Density of oak} = 680 \frac{\text{kg}}{\text{m}^3} = 0.02457 \frac{\text{lb}}{\text{m}^3}. \]

The volume is found by:

\[ \text{Vol of oak} = L \times W \times H = 48 \times 30 \times 1.25 = 1800 \text{in}^3, \]

yielding the weight,

\[ \text{Weight of oak} = \text{density} \times \text{volume} = (1800)(0.02457) = 44.23 \text{ lbs} \]
Before implementing these equations, the variables and forces acting on the table had to be defined as follows:

\[
\begin{align*}
\text{Leg 1} &= L_1, \\
\text{Leg 2} &= L_2, \\
\text{Weight of Artist} &= WA = 150 \text{ lbs}, \\
\text{Center of Mass} &= \text{COM} = 44.23 \text{ lbs}, \\
\text{Screw Jack} &= J.
\end{align*}
\]

Now it is necessary to calculate how the forces will be distributed on the screw jack and the safety legs. In doing this we will assume that the greatest amount of force that an artist could put on the table while using it is 150 pounds. The forces can be summed in the y-direction by:

\[ \sum F_y = 0. \]

Which follows that,

\[ L_1 + L_2 + J - \text{COM} - WA = 0. \]

Rearranging the last equation yields:

\[ J = \text{COM} + WA - L_1 - L_2. \]

Then moments were summed up along the rear axis of the table at point J. The weight of the artist will be taken assuming he or she is at the furthest point away from the screw jack device. The moments can be expressed as a sum:
\[ \Sigma M_x = 0. \]

Which follows that,

\[ (22 \times L_1) + (22 \times L_2) - (15 \times COM) - (30 \times WA) = 0. \]

Rearranging this equation yields:

\[ L_1 = \frac{15 \times COM + 30 \times WA}{44}. \]

When substituting in the values for COM and WA, \( L_1 = 117.35 \) lbs. Due to symmetry in the setup of the safety legs, the force on one leg will equal the force on another leg. This will cause the force on \( L_2 \) to also be 117.35lbs. Substituting these values back into equation 1 yields:

\[ J = 44.23 + 150 - 117.35 - 117.35, \text{ or, } J = -40.47 \text{lbs.} \]

This value shows that the screw jack will actually be trying to pull the table down due to the moment that is created by the artist putting force at the front of the table. As explained earlier, this will not affect the stability of the table due to the way the base will be constructed. So now have a force put on one safety leg factored in with an artist trying to push as hard as he or she can on the front of the table. Now, one more factor must be considered. What if a person decides to come by and sit on the table while it is in use by an artist? It will be assumed that a person who weighs 300 pounds could sit on the table while it is in use at a given moment. The maximum possible force that the safety legs would undergo would be if the person decided to sit on the area of the table directly on one of the safety legs while the table was in use. This maximum force would be calculated in the following way:

\[ \text{Max force possible} = \text{weight of person on leg} + \text{force from table} + \text{weight of artwork}. \]

And then substituting some values, the above equation yields:

\[ \text{Max force possible} = 300 + 117.35 = 417.35 \text{lbs.} \]

This value represents the amount of maximum force one of the safety legs may have to undergo at any given moment. The material being used for the cylinders of the safety legs will consist of 6061-T6 aluminum tubing. The safety pin is going to be made of 302 stainless steel. Just by knowing the material being used does not necessarily mean that it will be stable. Many things must be factored in first before the dimensions of the materials can be obtained.

**Safety pin**

In order for the pin to be safe, a shearing force must be taken into account in order to figure out how large the diameter of the pin has to be in order for the pin to support the maximum weight that can be pushing on the pin from the leg of the table. This will require the implementation of an equation for shearing stress:
\[ \tau = \frac{F}{A}, \]  

where \( F \) = the force being applied at a point and \( A \) = area over which the force is applied.

For 302 stainless steel, shear stress, \( \tau = 22 \) Ksi which equals \( 22000 \text{lb/in}^2 \). The variables for the shear stress equation are given by:

\[ A = \pi \left( \frac{d^2}{4} \right), \]

\[ F = 417.53 \text{lbs}, \]  

and,

\[ d = \frac{4 \times F}{\pi \times \tau}. \]

Solving for the diameter of the pin yields an answer of 0.155 inches. This means that the smallest diameter the safety pin can be before it shears with 417.53 lbs of force being applied is 0.155 inches. We are planning for our pin diameter to be \( \frac{1}{2} \) inch. This diameter will more than hold the maximum weight which can be placed on it at any given time. This also yields a safety factor of three since a \( \frac{1}{2} \) inch diameter is about three times the minimum diameter needed to hold up against the maximum force.

**Aluminum cylinder**

The safety legs are going to consist of two aluminum cylinders. The aluminum used will be that of 6061-T6 grade. The two aluminum cylinders will be very close in diameter as to have one just inside the other while the height is being adjusted. Now the factor of stress comes into play. How large does the thickness of the wall of the aluminum cylinder have to be in order to withstand a maximum force applied to it? This can be obtained through manipulation of stress and basic area equations. First, one can start by the definition for axial stress given by:

\[ \text{Axial Stress} = \frac{P}{A}, \]  

where \( P \) = the force being applied over a certain area, and \( A \) = the area over which the force is applied to.

For 6016-T6 grade aluminum, maximum yield strength = 40Ksi, which is \( 40000 \text{lb/in}^2 \).

Since there will be a pin in between the cylinders, a stress concentration factor (K) must be factored in as well.

![Figure 8: Pin Hole](image-url)
In the above diagram, the variables are defined as:
b = $\frac{1}{2}$ circumference,  
d = diameter of pin, and  
K is a function of the ratio of $\frac{d}{b}$.
When read from a stress concentration graph, K = 2.55. This will be implemented in the stress equation in the following way:

$$\text{Stress} = \left(\frac{F}{A}\right) \times K.$$  

Solving for an area yields:

$$A = \left(\frac{F \times K}{\text{stress}}\right) = \frac{\left(417.53 \times 2.55\right)}{40000} = .0266in^2.$$  

This value is the total minimum area of the cross section of the wall which can hold the maximum force applied to it.

![Diagram of cross section of aluminum table leg](image)

**Figure 9: Cross Section of Aluminum Table Leg**

Now the minimum thickness of the wall can be determined with the minimum area given. We are planning to use a 2 inch diameter outer cylinder for the safety legs. The inner cylinder will have a diameter of 1 7/8 of an inch. With this information, a second yet smaller diameter can now be solved for which will give the minimum thickness needed for each cylindrical wall. Either diameter can be used to obtain a wall thickness. We will use a diameter of 2 inches to start. The equation for the cross sectional area of both cylinders is given by:

$$Area = \left(\frac{\pi}{4}\right)\left(D_2^2 - D_1^2\right),$$  

and substituting,

$$Area = 0.0266in^2,$$

$$D_2 = 2in,$$  

and  

$$D_1 = unknown.$$  

When solving this equation, D1 = 1.99 inches. This means that the thickness of the cylindrical wall has to be at least 0.01 inches thick. We are planning to have a wall thickness of 1/16 of an inch. This is equal to 0.0625 inches which is greater than 0.01 by a safety factor of 6. This shows that these safety legs are going to have much more stability than is actually required from the maximum force that can be applied to each of them.
Even when dealing with the shear and axial stresses of the aluminum cylinders, the stability of them is still not all completely secure. In every material there are imperfections somewhere within it. These imperfections can cause internal moments inside the internal structure of the material. This is where the factor of buckling comes in. For every material, there is a critical force at which that material will buckle. This buckling is related to the modulus of elasticity, the moment of inertia, as well as the height of the material. The critical force is given by,

\[ P_{cr} = \left(\frac{\pi^2 \times E \times I}{L^2}\right) . \]

For the particular material made out of aluminum, then

\[ E = \text{modulus of elasticity} = 72000 \times 10^6 \text{ Pascal} , \text{ which when substituting,} \]
\[ = 10,442 \text{ Ksi} \quad = 1.0442 \times 10^7 \text{ lb/in}^2 . \]

The moment of inertia for aluminum is,
\[ I = \text{moment of inertia of cylinder}, \]
\[ = \left(\frac{\pi}{64}\right) \times \left( D_o^4 - D_i^4 \right) . \]
Do = outer diameter = 2 in, and
Di = inner diameter = 1.937 inches.

The length is defined as:
L = height of cylinder = 40 inches at max height. Therefore the critical force is defined as:

\[ P_{cr} = \left(\frac{\pi^2 \times 1.0442 \times 10^7 \times \left(\frac{\pi}{64}\right) \times \left(2^4 - 1.937^4\right)}{40^2}\right) . \]

When solving this equation, the critical load for bucking to occur is at 6,079 pounds. The maximum force that can be put on the aluminum cylinder at one time is 417.53 pounds. This is about 14 times less than the amount of force it would take for the aluminum cylinder to buckle at a wall thickness of .0625 inches. A schematic of the pin safety mechanism can be seen in the figure below.
When all the factors for safety considered, the art table as a whole seems to be very a very safe structure. No amount of force produced by a human being could make this table fail. Even if the screw jack mechanism failed, the artist using the table would be safe from the tabletop collapsing on him or her due to the safety legs implemented. The tabletop would still be connected to the safety legs. Even if the tabletop did fall off of the safety legs, it would fall away from the artist due to the way the safety legs are positioned under the tabletop. This will give any user of this table complete confidence in the safety and reliability of it.

**Accessories**

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**

<table>
<thead>
<tr>
<th>Part</th>
<th>Manufacturer</th>
<th>Quantity</th>
<th>Price</th>
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<tbody>
<tr>
<td>Upright Non-Keyed Screw Jack</td>
<td>Nook Industries Model: .5HL-BSJ-U</td>
<td>1</td>
<td>$110</td>
</tr>
<tr>
<td>Handwheel</td>
<td>Nook Industries Model: H043</td>
<td>1</td>
<td>$27</td>
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<tr>
<td>4’ x 4’ Oak Panel</td>
<td>Home Depot</td>
<td>1</td>
<td>$32.50</td>
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<tr>
<td>2’ x 4’ Gray Glace Laminate Surface</td>
<td>Home Depot</td>
<td>2</td>
<td>$23.62</td>
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<tr>
<td>2” Diameter Aluminum Tubing</td>
<td>Windevor Aluminum Grade: 6061-T6</td>
<td>5’</td>
<td>$10.25</td>
</tr>
<tr>
<td>1.875” Diameter Aluminum Tubing</td>
<td>Windevor Aluminum Grade: 6061-T6</td>
<td>5’</td>
<td>$11.95</td>
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<tr>
<td>T-Handle Positive Lock Pin</td>
<td>G. L. Huyett</td>
<td>2</td>
<td>$24.00</td>
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<tr>
<td>.5” x 4” Aluminum Flat Bar</td>
<td>North Coast Metal Mart Grade: 6061</td>
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<td>$92.25</td>
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<td>Miscellaneous Nuts, Bolts, and Screws</td>
<td>Home Depot</td>
<td>To Be Determined</td>
<td>$35</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>$366.57</strong></td>
</tr>
</tbody>
</table>
Appendix I: Block Diagram for User

1. Helper’s Perspective
2. Is Height of Table High Enough for User to Fit Underneath Comfortably?
   - NO
     1. Remove Safety Pins from Front Legs
     2. Rotate Handle Clockwise to Adjust Table to Higher Setting
     3. Replace Safety Pins
   - YES
     1. User Positions Themselves Under the Table
     2. Remove Safety Pins from Front Legs
     3. Rotate Handle Counter-Clockwise to Adjust Table Down to Comfortable Height for User
     4. Replace Safety Pins
     5. Start Art Project
Appendix II – Block Diagram for Design Process

1. Design Process
2. Table Top Manufacturing
3. Table Base and Safety Leg Manufacturing
4. Can a Wheelchair Fit Underneath?
   - NO
   - YES: Attach Screw Jack to Base and Table Top
5. Does the Table Adjust Between 27° and at least 40°?
   - YES
   - NO: Attach Safety Legs
6. Is Table Stable?
   - NO
   - YES: Table is Complete. Work on Instructions and Finishing Touches
7. Find Where Instability is Caused and Adjust

Adjust the Height Off the Floor the Base is Attached