

Projects to Learn How to Program the NC Mill at SiLab



The default shapes that the NC Mill can make are very limited - only circles and squares. What about when more complex polygons or other shapes are needed? This guide is a compilation of techniques to draw paths on the NC Mill to make more complex shapes. This will be accomplished using the Arc and Line Tools on the NC mill.

The main idea behind using the Arc and Line tools is that you provide the machine with a set of coordinates, and it follows those coordinates to draw the desired shape. The Line tool simply draws a straight line between the points, while the Arc tool allows the user to set a radius and then draws an arc with that radius between the set points. The main concern that falls on the user is to (1) determine these coordinates for the desired shape and (2) make sure that the mill can execute this path without running into itself. This guide will walk readers through a series of exercises that teach the techniques needed to create custom shapes. The examples are intended to demonstrate these techniques, allowing users to apply them to design any shape they choose rather than simply reproducing the example shapes.

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Project 1: Hexagon Resin Box



Programing Polygons Off Illustrator

We will be making small hexagon tiles out of a 2x4 cross section.

Supplies:

- A 2x4 no longer than 6 inches
- A measuring tool (ruler or calipers or measuring tape)
- NC Mill in SILab
- Flat End Mill Bit ($\frac{3}{8}$ x $\frac{3}{8}$) Note: the first number is the diameter of the mill bit and the second number is the diameter on the shank that will be held by the collet).
- Appropriate Collet and Threaded Sleeves

Step 1: 2x4 Scrap Selection

Make sure that the selected 2x4 scrap is no longer than 6 inches and the cross section is no smaller than 1.25 inches in height and 3.5 inches in width.

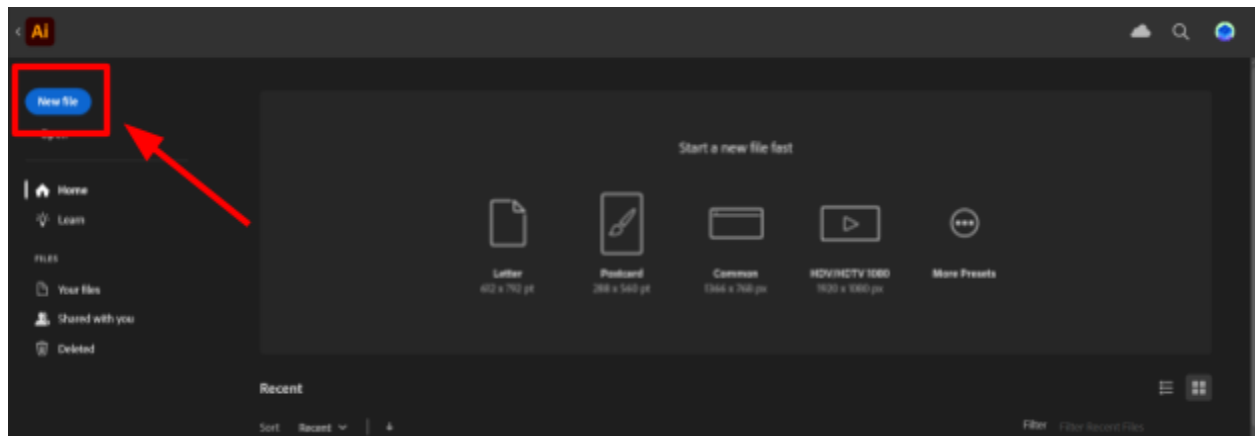
Step 2: Finding Coordinates

In order to find the coordinates, we will need to draw a hexagon in illustrator. As a BU student, you have free access to the entire Adobe workspace and instructions on how to install illustrator can be found here:

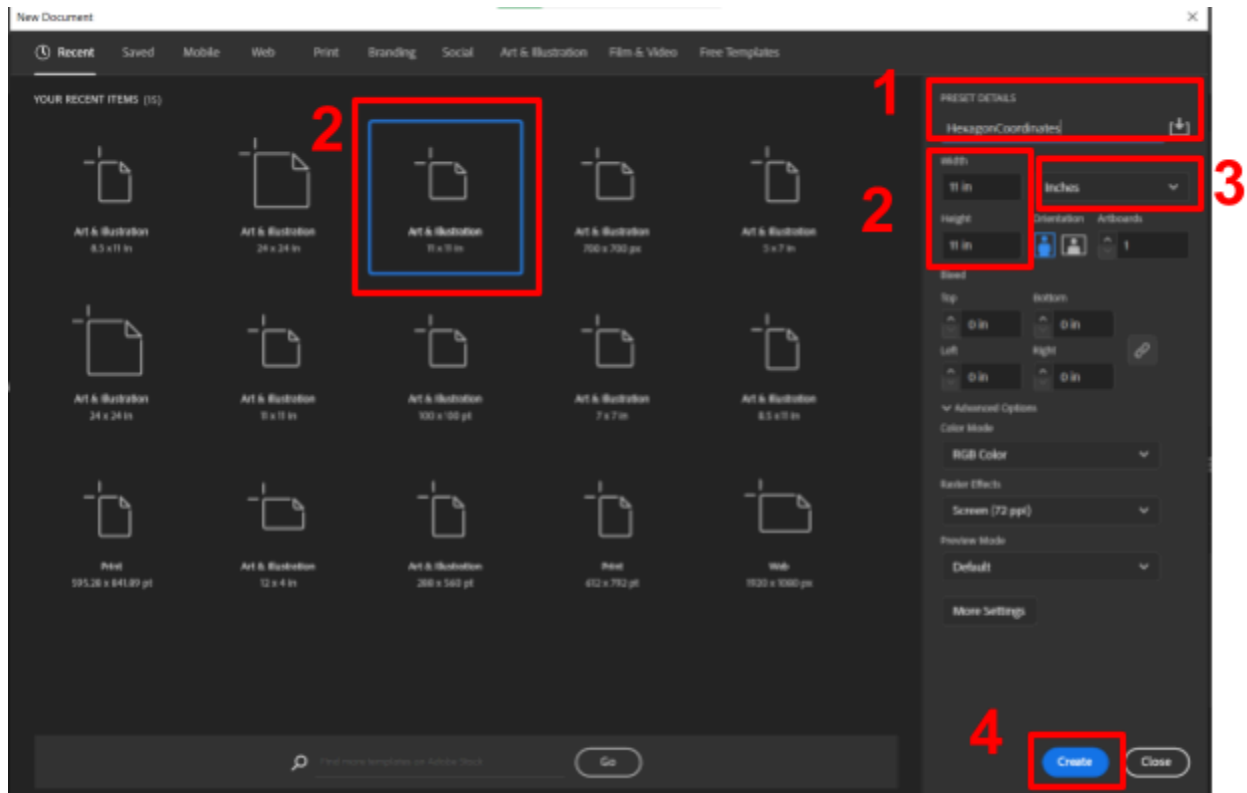
<https://www.bu.edu/tech/services/teaching/digital-multimedia-production/adobe-creative-cloud/installation-instructions/>

You can also use the computer next to the laser cutter for the illustrator part.

With Illustrator installed, open it and click “New File”

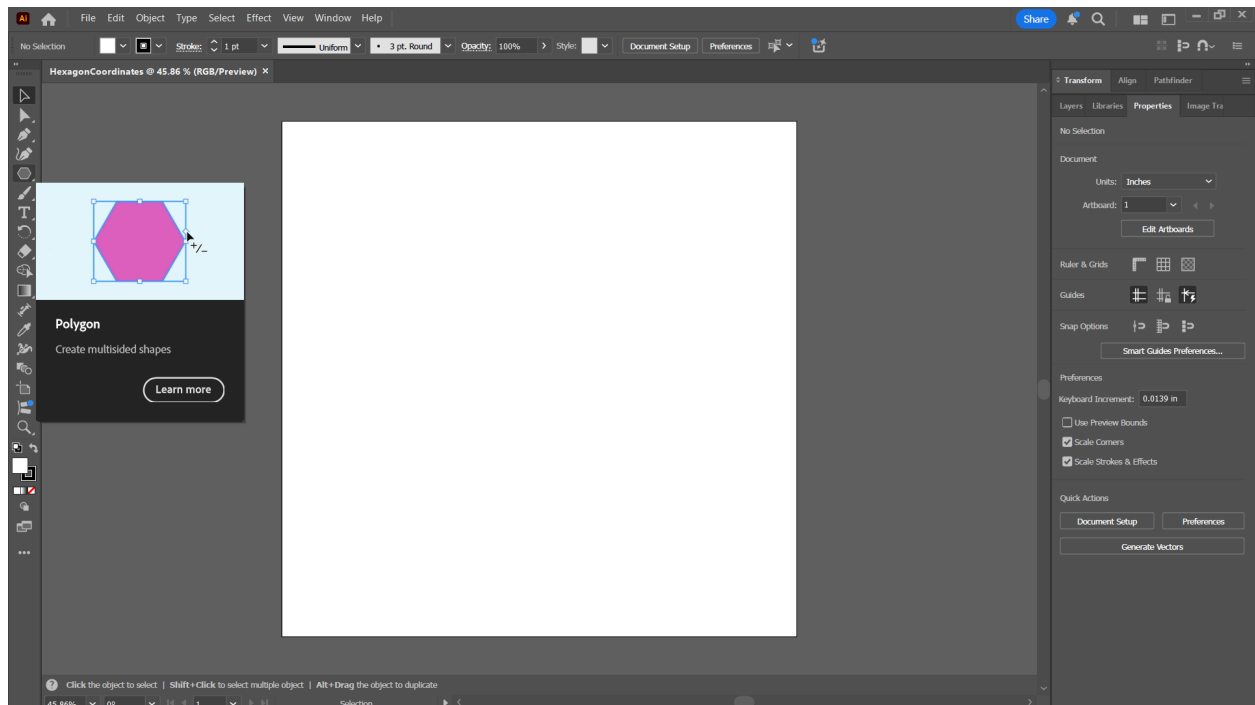


A pop up will appear where you need to set the dimensions of the artboard. In the image below the red numbers correlate to the number instruction details under the image.



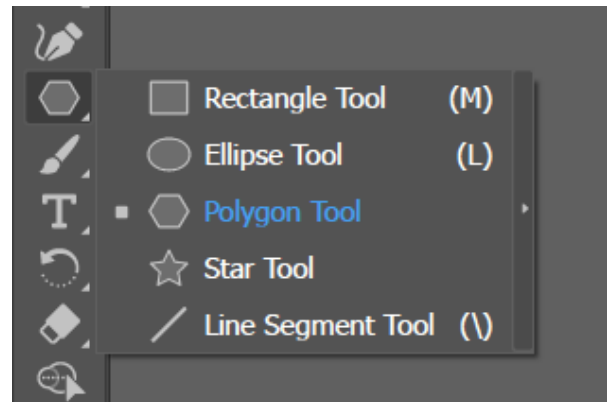
1. This is where you can enter a title for the file. Give a reasonable name.
2. This is where you can set the size of the artboard. On the left are the default sizes or previously used sizes and on the right are the inputs where one can manually type in the artboard size. The artboard dimensions are not really relevant to this project, so make a bigger than 5x5 and smaller than 14x14 square.
3. This is where you set the units of the project. For this project we will work in inches.
4. Click Create.

With the file created and open, we will now use the polygon tool pictured below.

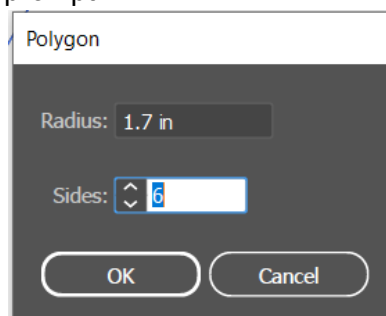


If you cannot see the Polygon tool off the bat in the tool bar, find any of the shape tools pictured on the right and right click on it.

The list of all the shape tools will pop up and you will be able to select the polygon tool.



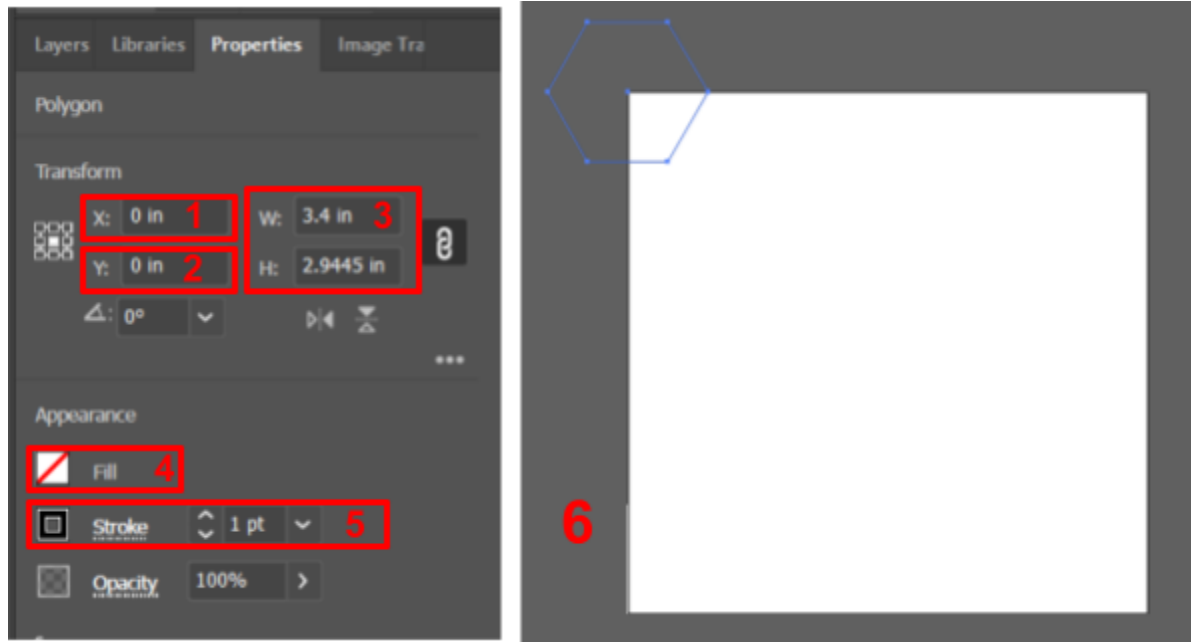
Click once on the polygon tool and then once on the artboard. This will give you the following prompt.



Enter the numbers as pictured and click okay.
(Radius: 1.7 inch and Sides: 6)

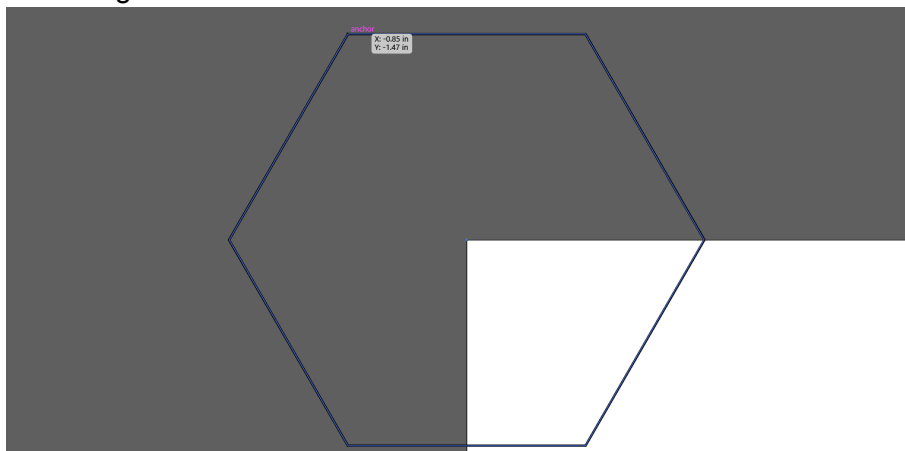
A hexagon outline will appear in a random part of the board. We will now work in the Properties tab that appears when you click on the hexagon.

Edit the following things in the properties tab:



1. This is the location of the X-coordinate. Set it to zero.
2. This is the location of the Y-coordinate. Set it to zero. This way the center of the hexagon will be the center.
3. This is the width and height of the hexagon. You should not need to change anything here because they should already be set by the prompt from initially opening the polygon tool.
4. Make sure the fill is none, so the shape is not filled in.
5. This is the stroke. Make sure it is at least 1pt so you can see it on your screen.
6. If everything is set correctly the artboard should now look like this.

Zoom into the hexagon on the art board, so it fills the screen and so the whole hexagon is visible. When you hover your mouse over the corners, the coordinates of this corner should appear like in the image below:



Now on a piece of paper make an XY table and record all of the coordinates in the table. Make sure that you move in a clock wise direction as you record the coordinates of each corner. Do not skip any coordinates. The order that you record these coordinates is the order that the mill bit will move in to draw the hexagon.

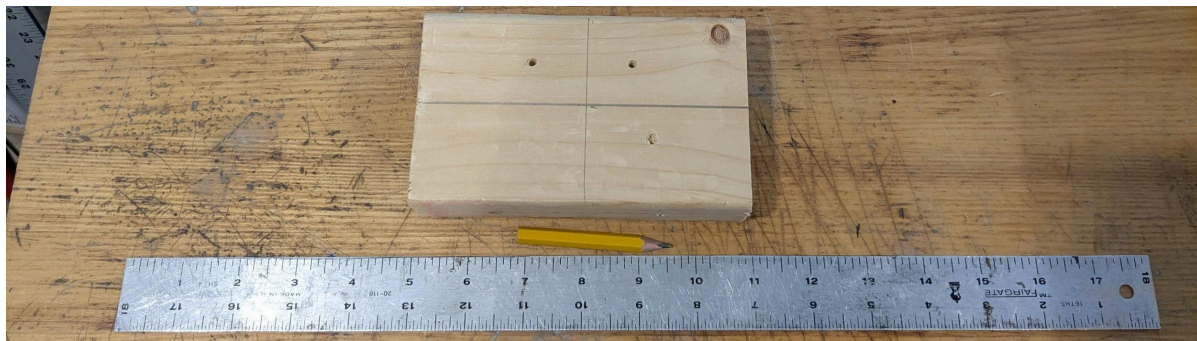
Here is an example of what the table will look like:

X	Y
-0.85	-1.47
0.85	-1.47
1.7	0
0.85	1.47
-0.85	1.47
-1.7	0

The negative signs are important and make sure you write them down where relevant.

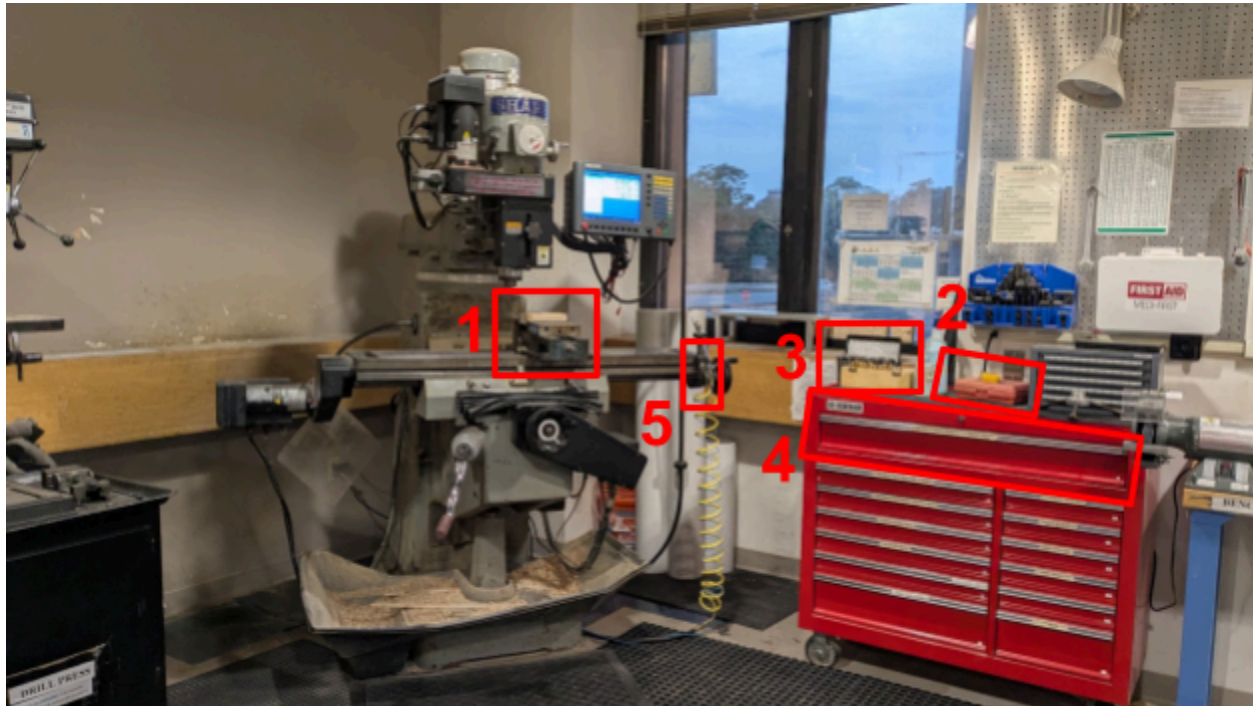
Step 3: Marking the Center on Work Piece

Using a ruler and a pencil find the exact center of your work piece.



Now it is time to move to the NC Mill in SiLab.

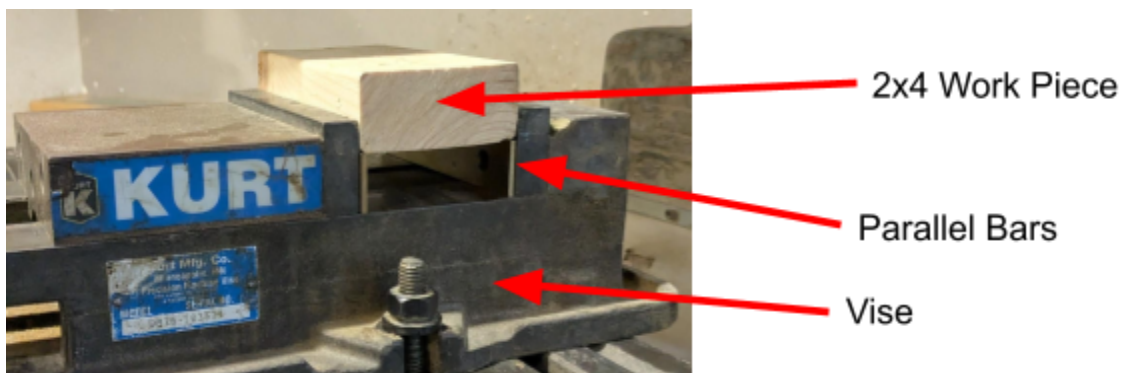
In the image below, the NC Mill supplies relevant for the set up are highlighted and labeled.



1. The vise where all the work pieces are clamped.
2. The location of the parallel bars.
3. The location of the flat end bits and the collets.
4. The top drawer holds the collet collar, collet sleeve and collet key.
5. The square that holds the assembled tool when it is being tightened with the collet key.

Step 4: Stock Material Set Up on NC Mill

Put your 2x4 work piece into the vise and lay it on the 1 and 3/16 inch parallel bars as pictured below.



Make sure the vise is fully clamped down and when you shake the work piece, it does not budge. Take off the vise handle and put it on the red cabinet.

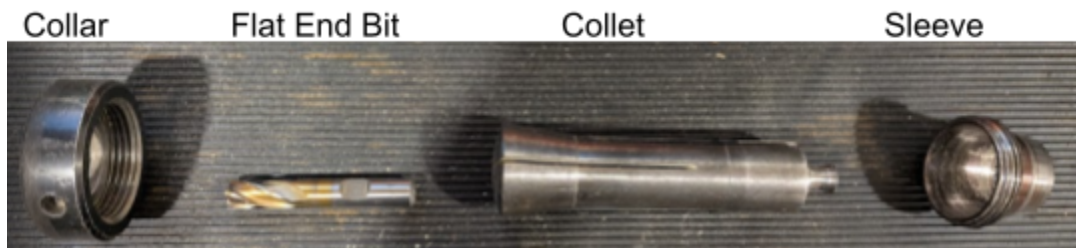
Step 5: Preparing the Tool

On the red cabinet next to the NC Mill find the $\frac{3}{8}$ x $\frac{3}{8}$ flat end bit.

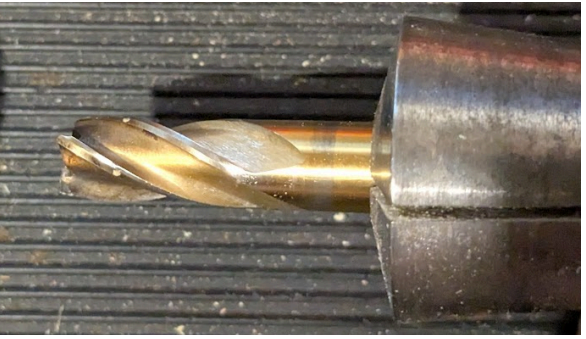
Next to the window behind the red cabinet there is a black box of collets. Find the 3/8th one that will fit with the flat end bit.

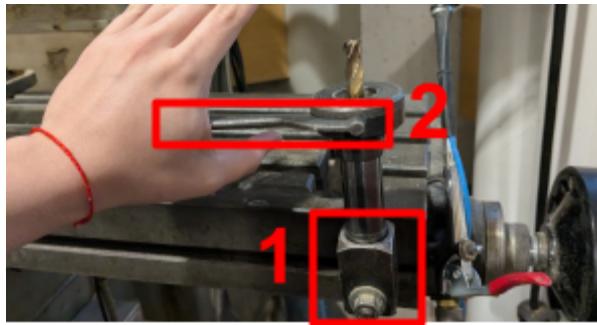
In the top long drawer in the red cabinet you will find the collet threaded collar and sleeve.

With all four items gathered, assemble them like pictured below:



Assembly Note: The line between the gold and the silver metal on the end bit should be right where the teeth of collet start.

Incorrect	Correct
	

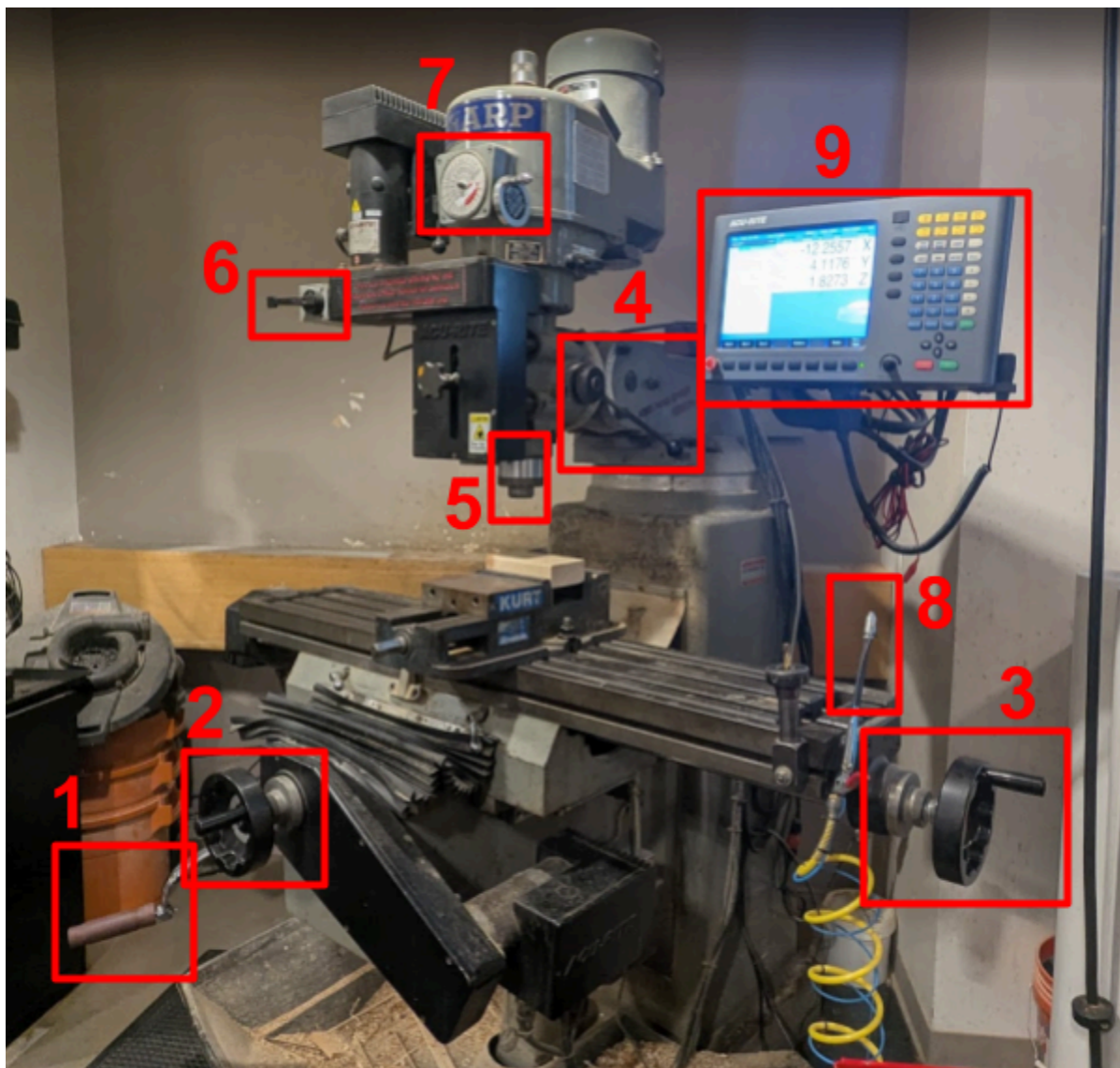


Put the assembled tool into the small square on the side of the mill (labeled 1 on the left) and use the key (labeled 2 on the left) in the top full length drawer of the red cabinet to tighten the collar on the sleeve.

In the picture on the left, the user will need to push to tighten the tool.

Step 6: Starting Using the NC Mill

Below is an image of the NC mill with the main control aspects labeled and explained.



1. The lever to raise and lower the whole table.
2. The handle to control the Y-Axis. The table will move.
3. The handle to control the X-Axis. The table will move.
4. The handle to control the Z-Axis. The mill bit will move.
5. The machine spindle that holds the mill bit.
6. The lever to turn the machine on. Horizontal orientation, machine is off. Angled down orientation, the spindle is rotating to support milling forward. Angled up orientation, the spindle is rotating to support milling backward.
7. Lever to set the spindle speed. Formula to determine spindle speed is taped up on the window next to the NC Mill. Do not change the speed when the machine is not running.
8. Compressed air to blow the woodchips away during the milling process.
9. The programmable attachment.

Step 7: Inserting the Tool

Raise the Z-axis handle (4) all the way up. Insert the tool into the machine spindle (5) and push the Z-axis handle even further up and that should grab on to the tool as you lower the Z-axis handle back. Spin the tool by hand to check that it is seated correctly. Spinning it should require minimal strength and spinning should feel smooth. If the tool does not spin at all or you feel major resistance, try to take the tool out and put it back in. If the problem continues, ask a SIlab advisor for help; the spindle gears might be stuck.



Raised Up



Raised Further



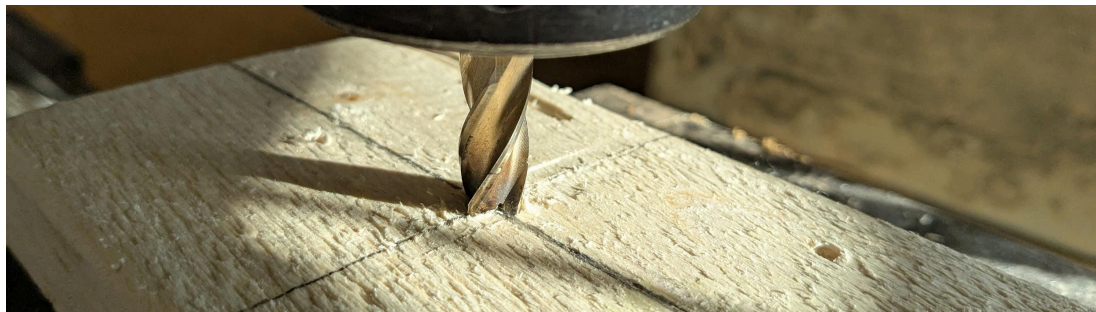
Lowered Back



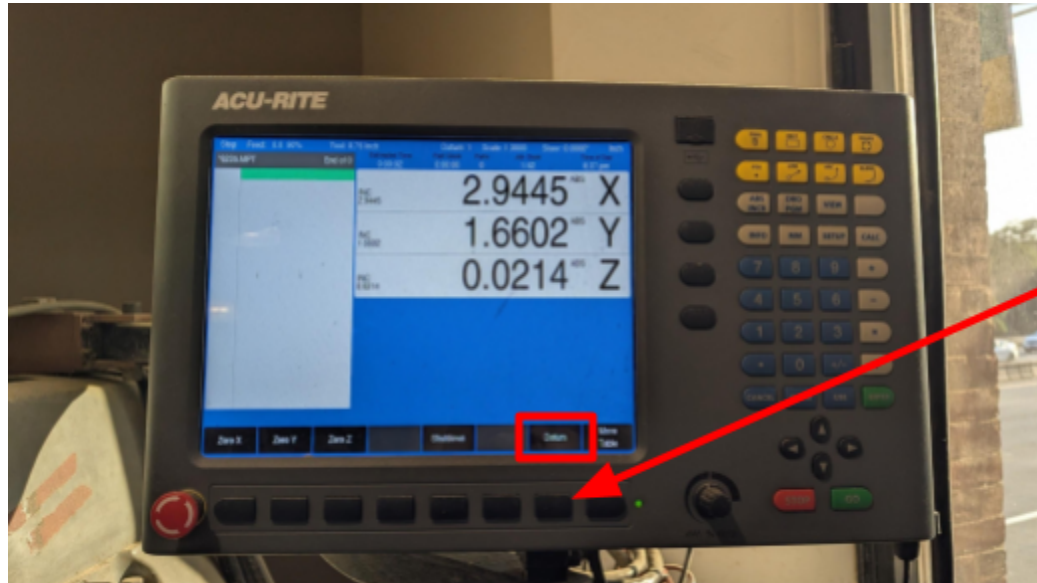
Tool Fully Inserted

Step 8: Setting Datum

Now use the X-axis, Y-axis and Z-axis handles to put the end bit right into the center of your markings.

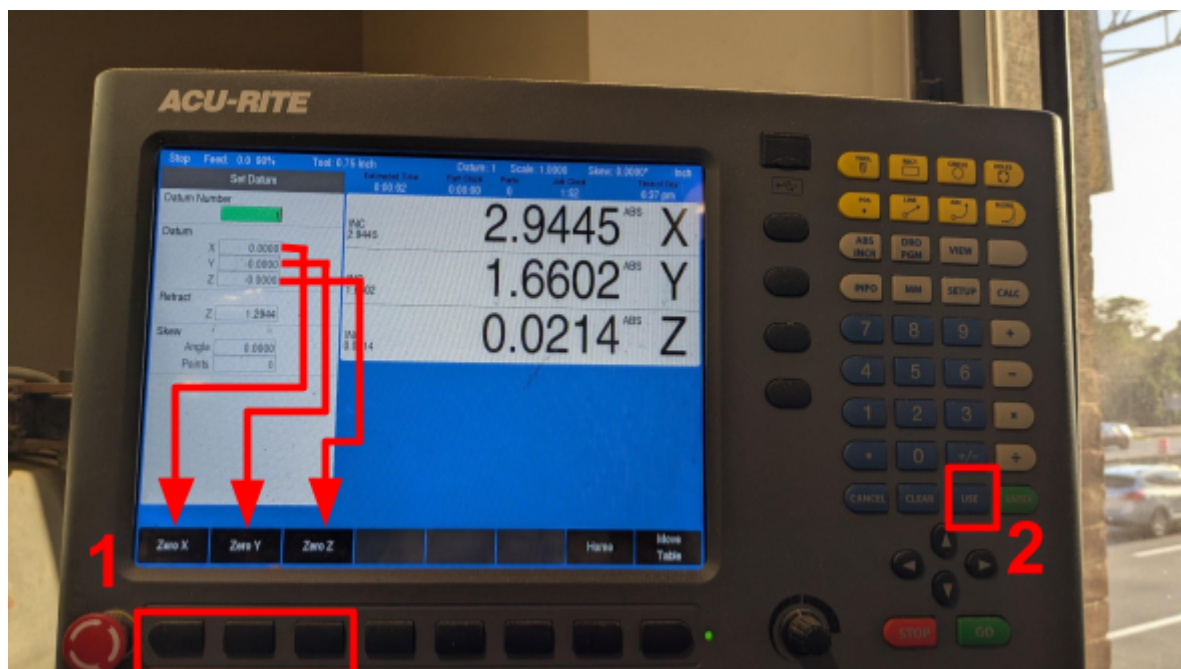


The bottom of the end bit is a cross itself, so you can use each of the four blades to line them up with each of the pencil lines. Avoid moving the end bit in X and Y directions when the end bit is flat on the surface. Always raise the Z-axis a little bit to prevent the end from scratching the surface. Only once all the X and Y directions are set, then you should lower the Z-axis to the surface. Looking up at the digital read out screen, press the datum button.



Need to press this button below the screen display button.

The Datum button will bring up the following screen. Here you will need to press the zero X, zero Y and zero Z buttons (labeled as 1 below). This will tell the machine that this exact alignment of xyz is the origin and we will use it as the starting point for our hexagon tile. Once all the values have been turned to zeros, press the blue USE button (labeled as 2 below) and all the values on the right hand side will also turn into zeros.



The screen should now look like this. To start programming, you will need to press the grey DRO PGM button (labeled as 3 below).



DRO stands for digital readout, which are the xyz numbers that change according to the handle movements. PGM stands for programming, which will allow you to control the xyz handles and draw shapes and paths.

Step 9: Programming

Now it is important to tell the machine what tool you are using. To do this press the yellow tool button as labeled 1 in the picture below.



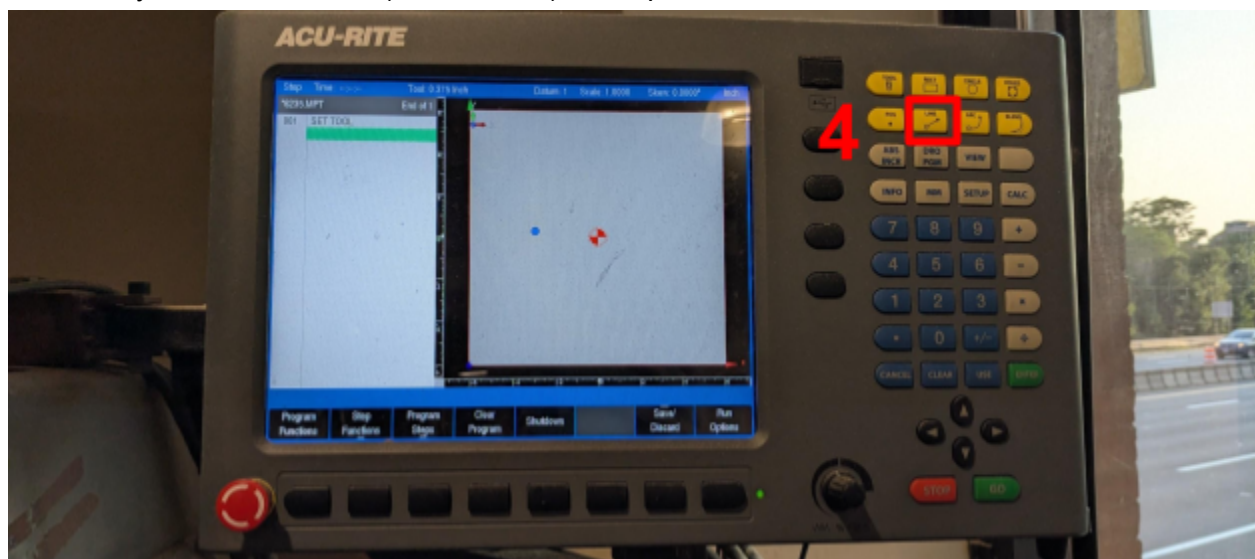
The following screen will pop up. Here, type in the diameter of the tool you're using.



You can use the number keyboard (labeled as 1 above) to enter the fraction value. For example you can press buttons 3, division symbol, 8 and the screen will convert this fraction into a decimal in the Diameter section. You do not need to change any other sections of the tool, but to navigate in between the sections, you can use the up and down arrows (labeled as 2) or the green enter button (labeled as 3).

To save the set diameter, you need to press the USE button. This will take you back to the programming interface.

We will now start telling the machine all of the paths it needs to take to mill out the hexagon. Press the yellow Line Button (labeled as 4) in the photo below.



This will now allow you to input the points that we previously recorded.



Only enter the first two points into the “from” and “to” areas, which are circled in the image above.

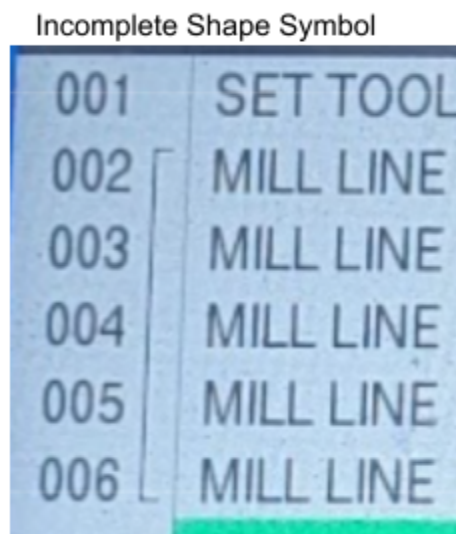
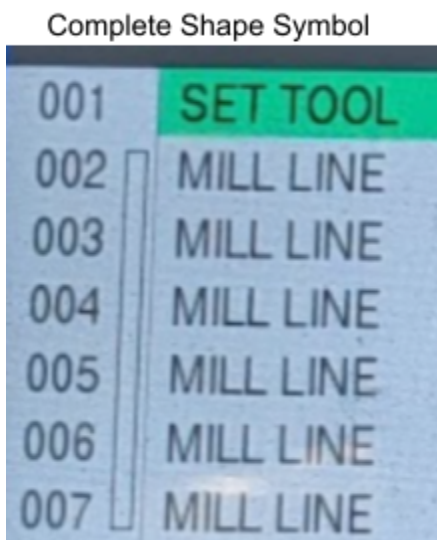
Ignore the “Z” section for now. With the points entered, press the “USE” button and you will see the first line of the hexagon. Continue adding line commands until you have the full hexagon.



After you enter all the line commands correctly, you should see the hexagon shape as below.



One thing to note on the symbol next to the line command, is that you can use it to check if the machine understood your commands. Since the hexagon should be a complete shape (where all ends meet), the symbol should be a closed rectangle (image on the left below). If the points listed do not make a complete shape, the symbol will look like the image on the right.



Step 10: Running the Program - Dry Run

Now we will run the whole operation, just not touching the work piece. This will allow us to see if our programming was correct. After making sure that the tool is above the material, press the green "GO" button.



The yellow bar has some very short text that informs the user what the machine is doing. The first text is the machine verifying what tool you are using. If you set the tool correctly, the value should match the tool you put into the machine. After verifying the tool size, press “GO” again. The next message is warning you that the tool will now move to the starting point. Make sure that the tool is above the work piece and you are not touching the X or Y handles, because they will spin and can hurt you.



Once ready, press “GO” again.

The next displayed message is all about setting the Z axis. Since we are only doing a dry run, no need to have the tool spinning or moving the Z into the material. Simply move it closer to the surface (about a 1 cm above) and press “GO” again.



As the tool starts moving, watch what areas it goes over. Make sure that the tool does not move over top of the vise, will stay inside the workpiece and not crash into anything.



The screen will be showing a live demo as it moves along the path. Make sure you keep an eye on both the screen and the actual tool. If you see that the tool is about to run into the vise or crash into something, press "STOP". This will at first pause the program. If you press "GO" the program will resume. If you press "STOP" twice, the whole program will be canceled and the tool will stay in the same location when you pressed "STOP".

After the program is complete, the next message displayed is the command to raise the tool once again above the work piece.



When you press "GO" the tool should not move and quickly display the message that the program is complete.



If the dry run was successful and you didn't identify any problems, we can begin the Milling Process. The only difference between the dry run and the milling process is that the tool is not spinning and is not inside the material.

Step 11: Running the Program - Milling Process

The first step is to determine the spindle speed for your material (wood) and mill bit size ($\frac{3}{8}$). The formula is taped to the window. $speed = \frac{4 \times 200}{3/8} = 2133.3$ (set as 2000 on the machine)

Do note that the speed can only be set with the machine running. To turn on the machine, you need to angle the horizontal lever down (labeled 6 in the [Step 5](#) image). Then turn the silver knob picture below to set your RPM.

Handle Turned On



Speed Setter and Indicator



With the speed set, you can now do all the steps in [Step 10](#), just when prompted to raise and lower the Z axis, lower it into the material and raise it out of the material.

Make sure that before you start the program, the green highlight is highlighting the “SET TOOL” command and the spindle is turned on.



Since you are milling deep into the material, it is recommended to move in 0.3 inch increments. Make sure you blow the wood chips away as the tool moves and you keep an eye on both the tool and the program screen.



Repeat the milling operation until you run out of tool depth. Milling 1.2 inches down is definitely doable comfortably. You can go deeper than that, just do not bring the collar of the tool too close to the workpiece. This is unsafe.

Step 12: Scaling Operation to Make Frame

Now to make the hexagon into a frame, we will scale the hexagon down. The origin is the point of reference for this scaling, so since we made the origin the very center of the hexagon, we should not have any issues. Both hexagons will be aligned.

To start scaling, press the “SETUP” button and change the 1.000 scale to 0.5 scale. Press “USE” and you will see the ruler adjust.



This is what the screen should now look like.



Repeat [Step 10](#) and [Step 11](#) to mill out a smaller rectangle. Ideally they will be milled to the same depth.

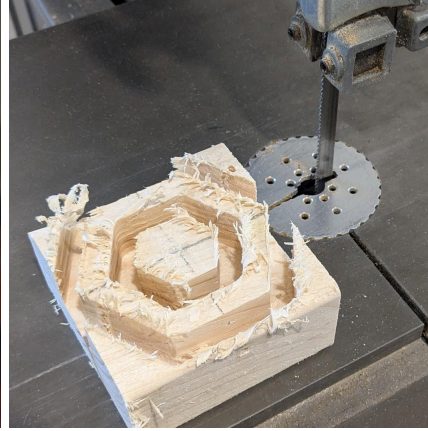
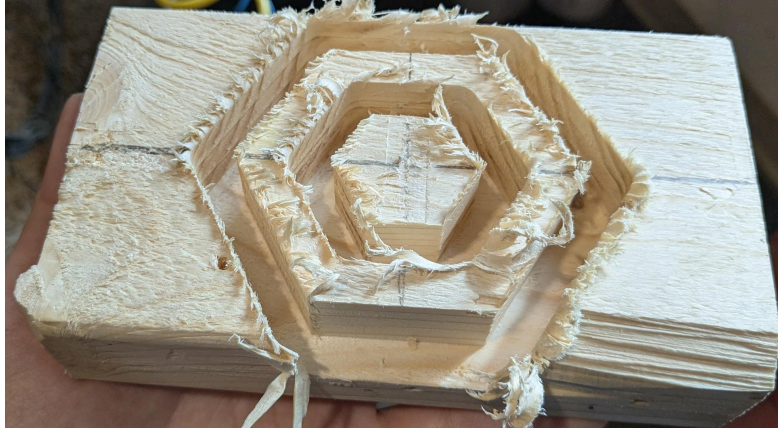
With the scaling, everything changes. So scaling something by 0.5, means that on the digital read out, you will need to mill twice as deep. In reality you might need to mill to negative 1.2 inches, but in the 0.5 scaling mode to reach the negative 1.2 inches in real life, you'll need to mill to negative 2.4 inches on the digital read out.



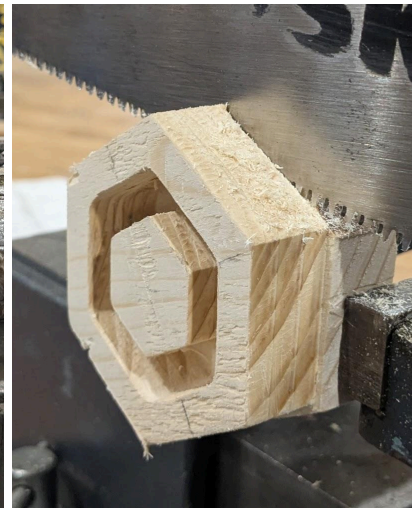
If all goes well, the two hexagons will look like the image above. You can now scale the program back to 1.0, take the work piece off the mill and clean up after yourself.

Step 13: Cutting Off Excess

You can use the miter saw for the big chunks and then the band saw for all the hexagon sides.

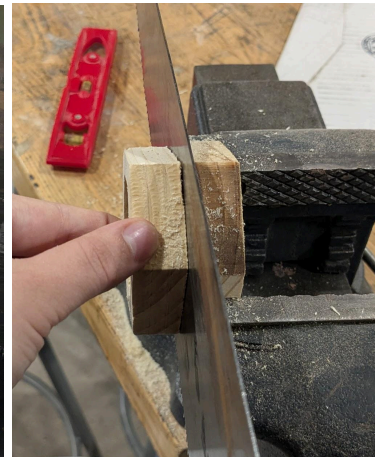
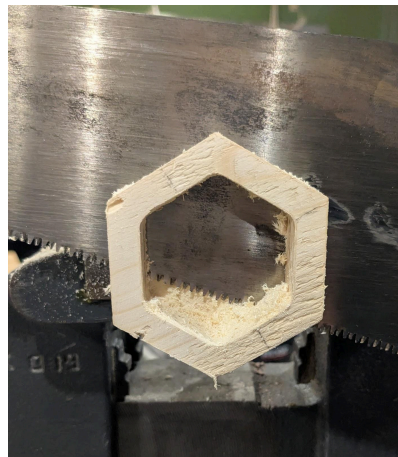
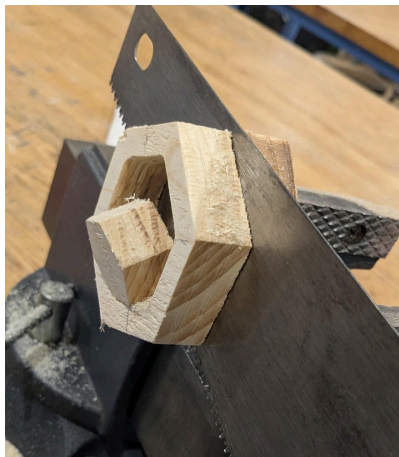


Step 14: Sawing Off Bottom



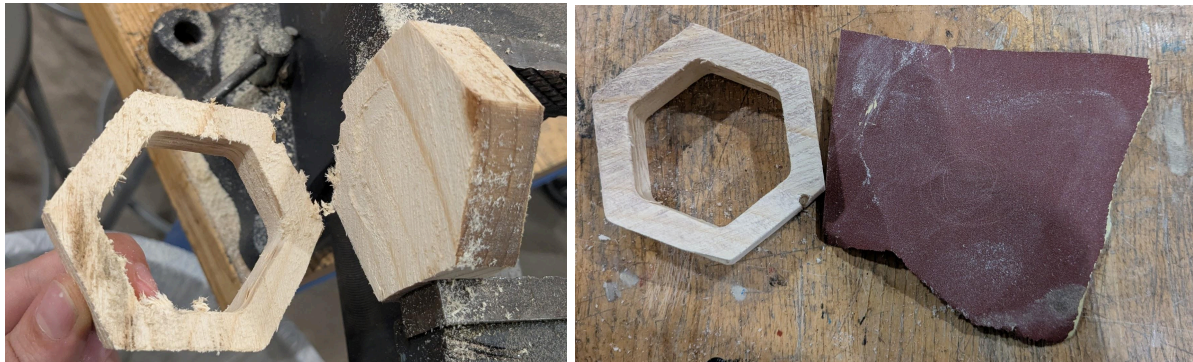
To saw off the bottom, clamp the workpiece into the table vise and put a trashcan underneath to catch all the saw dust.

It is very important that you level the work piece, otherwise the hand saw cut will be angled.



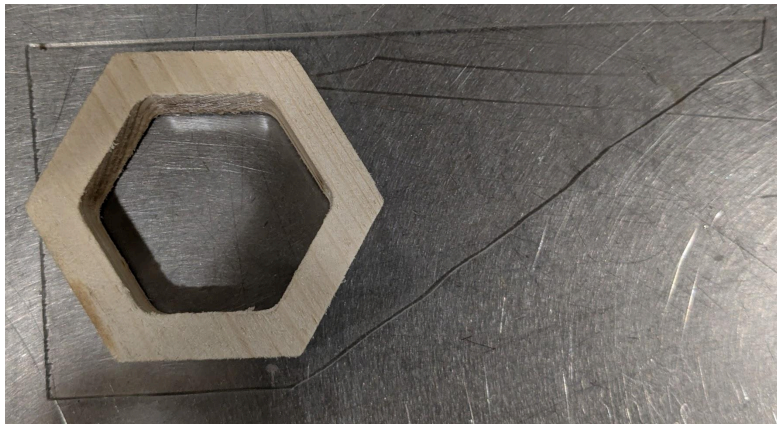
Even though this might seem intimidating, hand sawing is pretty fast and easy.

It is recommended to hold the hexagon frame, so it doesn't fall into the trash can.



At this point you should sand the hexagon frame with some sand paper to get it to be smooth. This will take some time and it is in your best interest to not get lazy with this step.

Step 15: Preparing for Resin



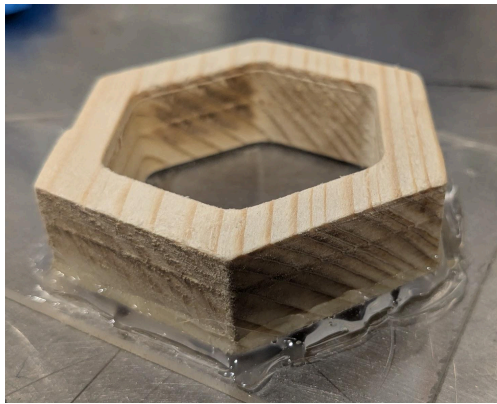
In the plastic drawer find a small piece of plastic to serve as the resin bottom for your box.

Pictured below are all the supplies you will need:



Supplies list:

- Hot glue gun
- Hot glue gun glue sticks
- Two part epoxy resin kit (parts A and B)
- Popsicle stick
- Gloves
- Universal Mold Release
- Small cup
- Glitter of your choice



With all the supplies nearby, hot glue the edges of the hexagon to the small acrylic piece. Make sure to hot glue all around the hexagon. This is the seal for the resin.

Spray the mold release inside the hexagon.

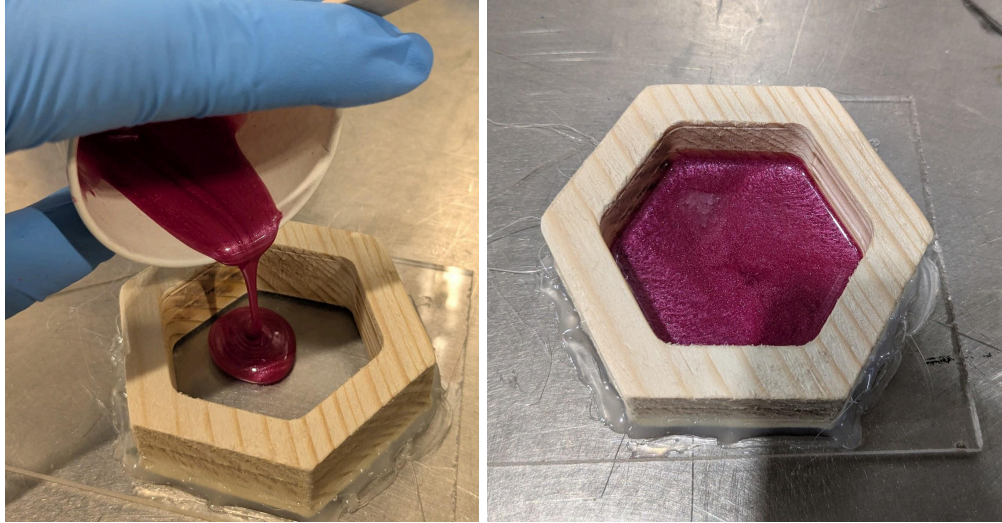
Do so outside, with a blue tarp and in an undercover area.

Silab does not have the ventilation to be safely using aerosol cans inside.

Step 16: Resin

				
Pour step A into the cup. Remember you need very little. Pour just enough to cover the bottom of the cup.	Pour step B into the same cup. Try to match the volume to step A. Too much A? Sticky result. Too much B? Flexible result.	Using the popsicle stick, you can scoop glitter into your cup. You also do not need that much, but make sure to sparkle.	You can then use the same popsicle stick to stir everything together.	Mix for a few minutes, making sure that everything is mixed and the mixture becomes homogenous.

After mixing, you can pour the resin into the hexagon and let it cure overnight.



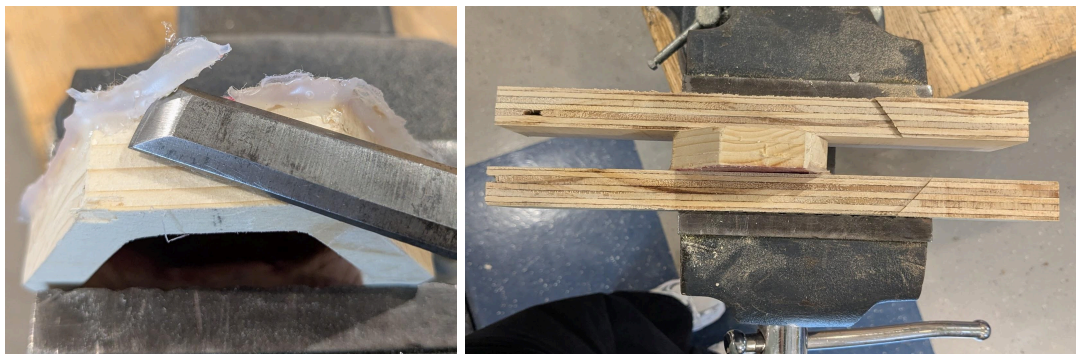
When you are leaving it in Silab, make sure to leave it somewhere on the side and next to a piece of paper with your name, email address, today's date and the date you intend to finish the project.

Step 17: Removal

To remove the acrylic bottom, sometimes you can just tear it off. Usually that is pretty difficult, so I recommend clamping the plastic end in the vise and using a chisel to pry it off, like pictured below. Wear gloves when working with chisels and always point it away from any flesh.



To take off the glue on the sides, also use a chisel to scrape it off, while it is clamped. Since this is a pretty delicate project, I recommend clamping in between two scrap pieces, so no imprints from the vise flaws are left on the resin. The set up of that is pictured below.



Step 18: Result - Optional Post Processing

Sometimes some resin seeps over into the wood on the bottom. If that look bothers you, I recommend using the belt sander to sand the bottom.

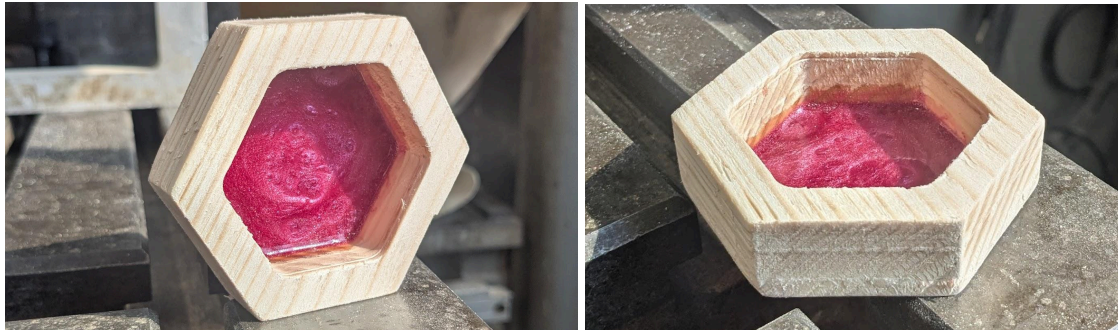


Do note that sanded resin will not be glossy any more and to get some gloss back, you will need the 3-step plastic scratch removal and cleaner products. They are pictured below.



Hexagon Box Result

Feel free to sand the wooden hexagon and coat it in any finish your heart desires.



Now you have a steezy box!

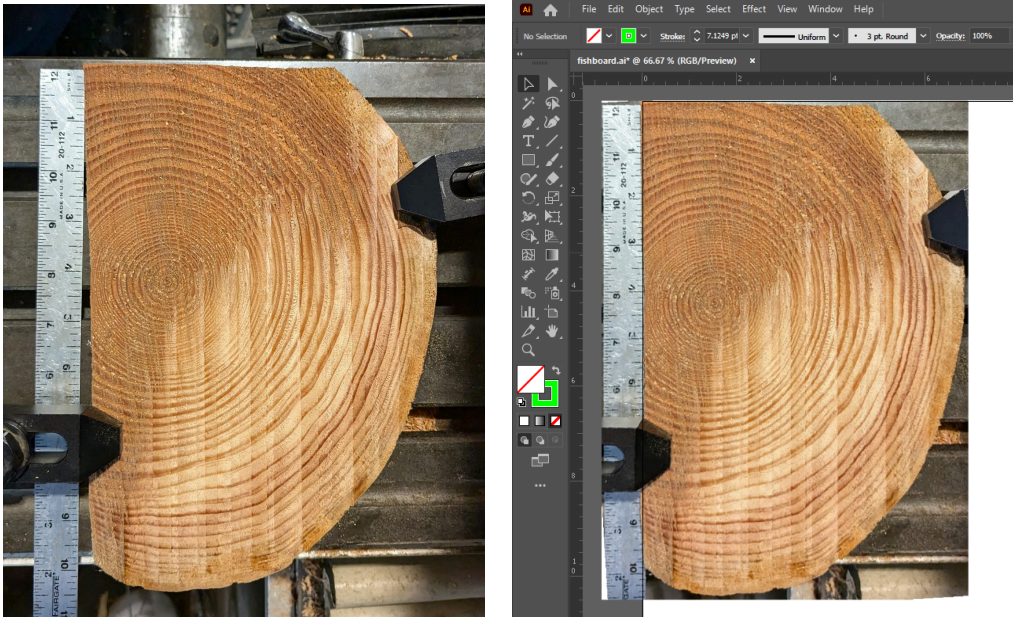
Project 2: Painted Fish



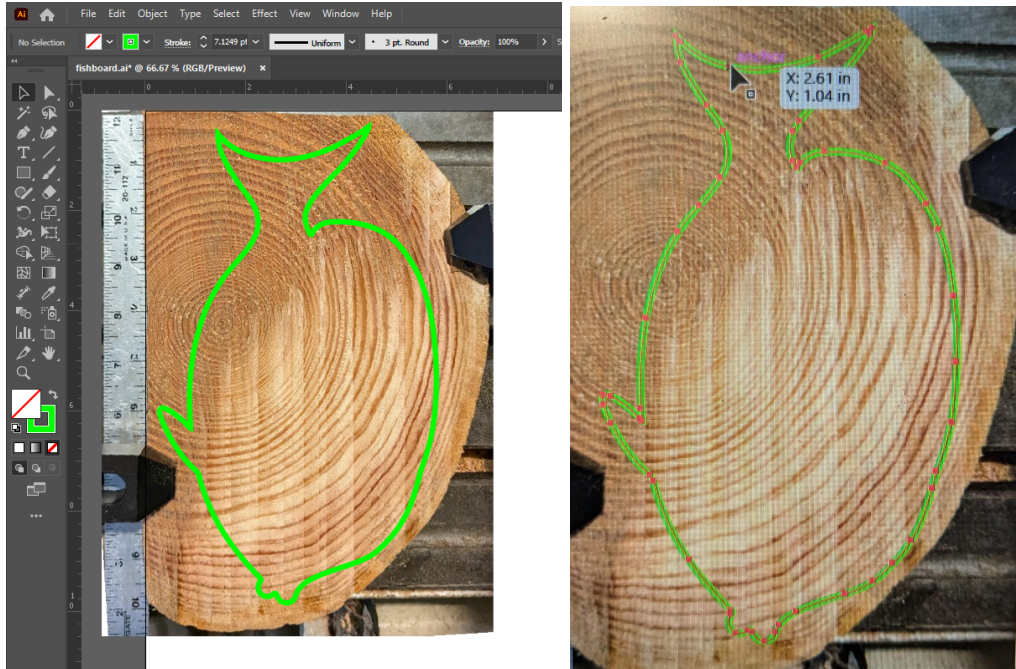
The same principle of inputting points and connecting with lines can be applied to more complex shapes, like this outline of a fish. Exercise 2 will not have you making a file and inputting points, instead you will simply scale an existing NC Mill program.

Backstory: How the File Was Made

A birdseye photo of a piece of wood was taken, clamped to the NC Mill with a ruler in the frame. Then the photo was uploaded to Illustrator and scaled to match the ruler in the photo with the ruler in Illustrator.



Next, an outline of a fish was scaled to fit on the piece of wood. The points on the fish were recorded like in the hexagon box and inputted into the NC mill.



This does take a while, so for this tutorial you will open an existing file. I do, however, encourage you to do this process yourself. Another thing is that instead of LINE commands connecting the points, the ARC commands were used. A circle with an infinitely large radius is a line, so for more flat parts of the design enter a big radius and for more rounded parts enter a smaller radius. You will get a preview on the screen, so you can pick a radius to match your desired drawing best.

Programing Natural Shapes Off Illustrator

Step 1: Opening the Fish File

Click the soft key under the Program Functions square.



Using the arrow keys, find the file called "FISH.MPT"



Highlight the file and press "ENTER".



You will get a yellow message at the bottom of the screen warning that if you proceed to opening the fish file, that everything programmed in the PGM window will disappear. Press the soft key under “YES”.



Step 2: Preparing the Machine

If everything was done correctly, you will see a preview of the fish and all of the commands.



Check that the tool is 3/16th both that is loaded into the machine and set in the “SET TOOL” command. Refer to [Step 6](#) and [Step 9](#) for reference.

The the speed will still be at max RPM, $speed = \frac{4 \times 200}{3/16} = 4266.7$ (set as 2000 on the machine)

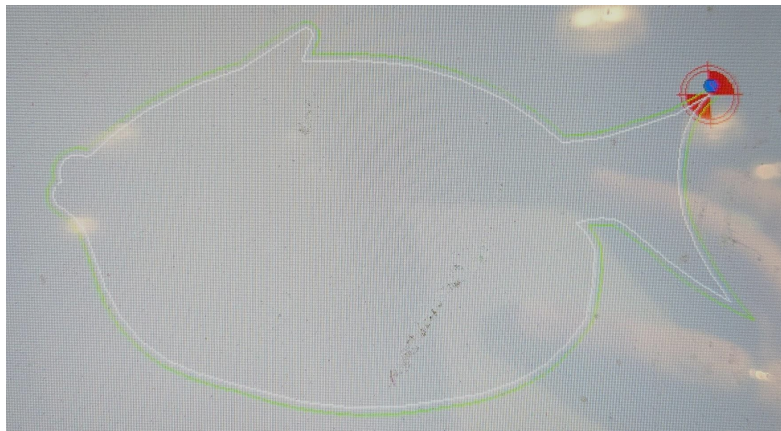
If you don't remember how to do any of the set up, refer to the instructions in the hexagon box tutorial.

Now you can scale the fish down to 0.6 using the “SETUP” button. Refer to [Step 12](#) for guidance on this operation. This scaling down should perfectly make the fish fit on a 2x4 scrap piece that is clamped in the NC Mill vise. The proof of that is pictured below.



Step 3: Milling the Fish

Before you start milling, I recommend you take the time to run a few dry runs ([Step 10](#) in hexagon box) to see that the path will stay within the work piece. I recommend using the example fish as a guide of where the zero of the datum needs to be.



The red marker is the origin in the preview.

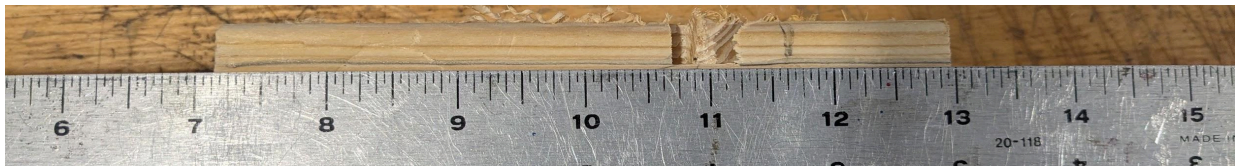
When setting the datum, try to line it up with that red marker.

Only start milling when you are sure that the entire path will fit onto the work piece.

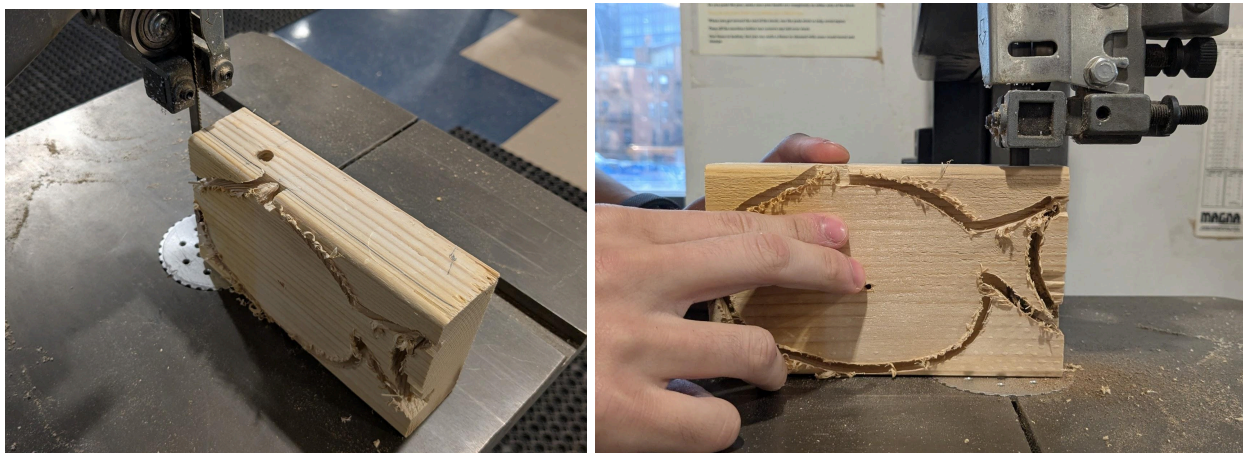


Step 4: Sawing off the Fish - Band Saw

If you do not have a lot of experience with the NC Mill, the next step is to take the fish off the NC Mill and draw a line on the side of the work piece.

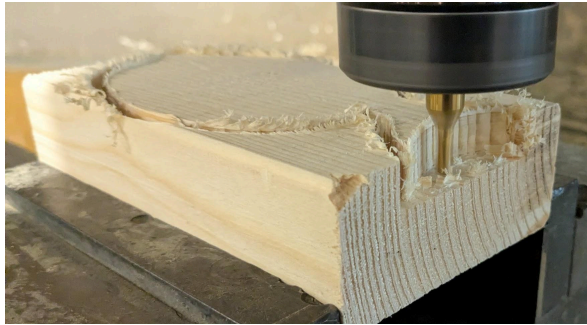


Then you will use this line as a guide as you cut the fish off on the band saw



Step 4: Sawing off the Fish - Challenge

If you do have a lot of experience with the NC Mill and want a challenge, you should manually remove the material around the fish.



The main challenge of this is to not confuse the rotation of knobs and where the mill bit moves.

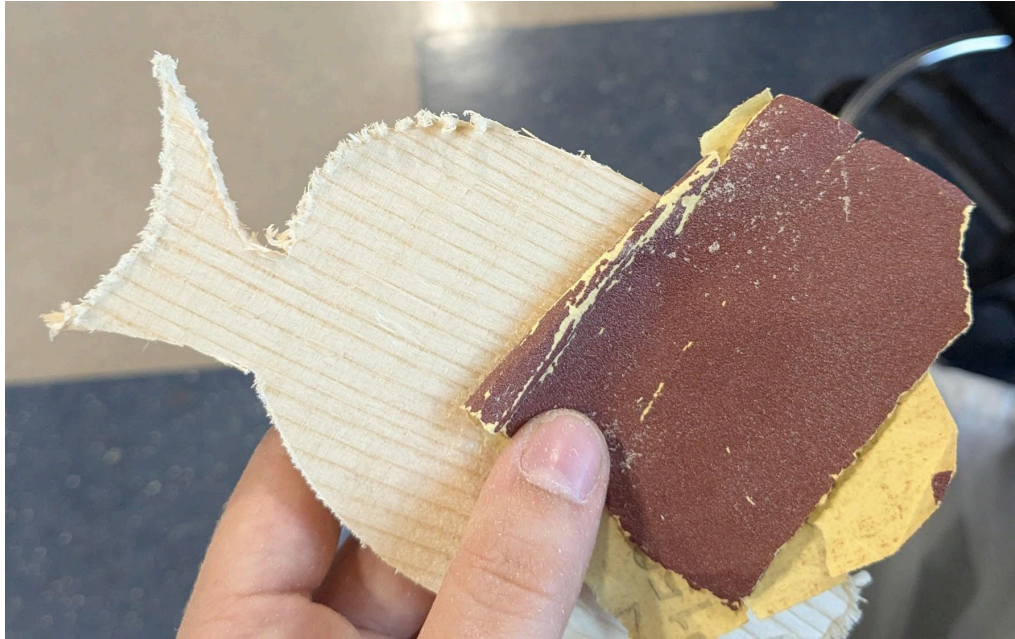
If you are not confident with the knobs, you will face a high risk of running the mill bit into the fish.

Finally, saw-off the fish with a hand saw. Make sure that the work piece is leveled and clamped in the vise, so the cut is straight.



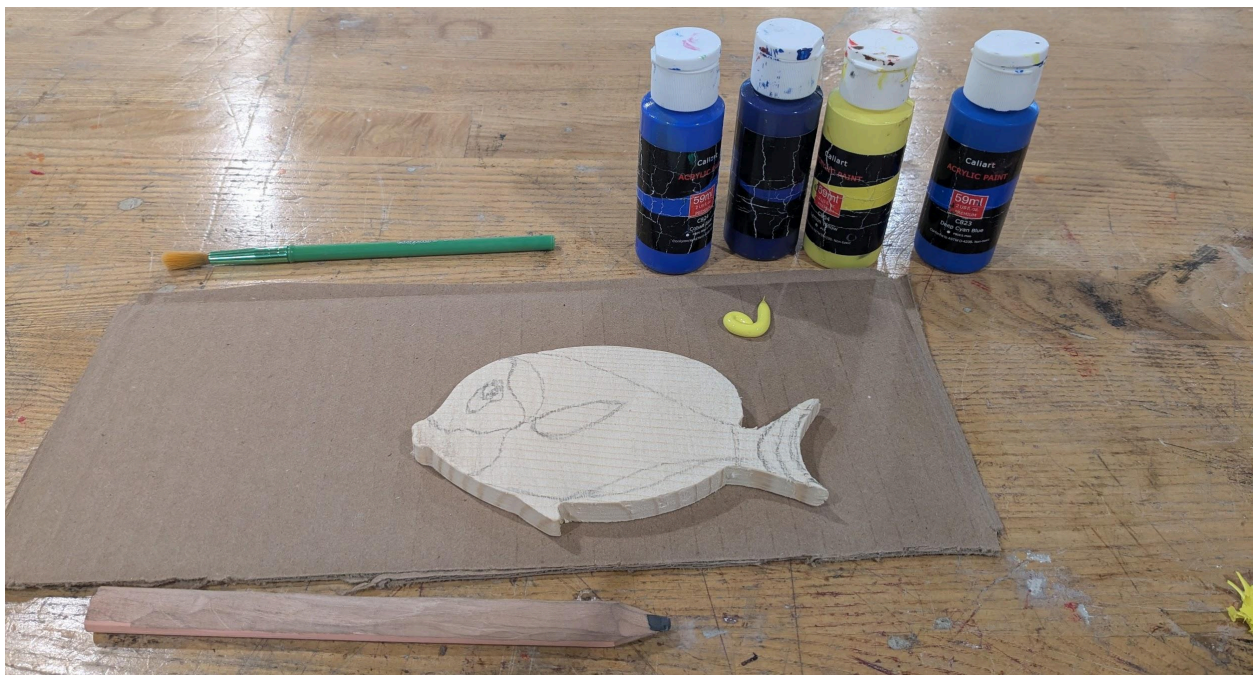
Step 5: Preparing Fish for Painting

Sand the fish with sand paper to take off all of the fuzzy ends. Do note that the smoother the surface, the easier it will be to paint it.



Step 6: Painting Fish

In the flammables cabinet there are many colours of acrylic paint. I do recommend you to plan out your design with a pencil before you start painting.



It is your aquarium and we are just fish living in it, so feel free to paint the fish however you like.

This outline is very similar to a Blue Surgeon Fish: You can use the clipart images of this fish and your creativity to paint the fish.



Acrylic paint dries very fast, so this whole process is pretty speedy.



Step 7: Final Fish Touches

Using the Sharpie marker, you can now add some details to the fish.



Painted Fish Result



Now you have a steezy fish!

You can drill a hole in it and hang it up somewhere like the one hanging above the sink in SIlab.

Back up Table of Points for Fish

X (inch)	Y (inch)	Radius (inch)
0	0	
-0.09	-0.07	LINE Command
-0.48	-0.82	1.5
-0.32	-2.18	2.0
0.14	-2.99	4.5
-0.72	-2.4	5.0
-1.3	-1.89	5
-1.45	-1.80	5
-2.01	-1.84	1
-1.76	-2.26	0.75
-1.93	-3.2	3.0
-2.53	-3.83	3
-3.94	-4.28	3
-5.88	-4.27	5
-6.66	-4.05	5
-6.91	-3.98	1
-7.74	-3.66	4
-8.6	-2.63	2
-8.88	-1.87	8
-9.2	-1.55	1
-9.21	-1.18	0.2
-8.86	-0.84	0.25
-8.07	-0.18	5
-6.73	0.43	5
-5.8708	1.0087	7
BLEND Command here, radius: 0.1		
-5.7287	0.8841	
-5.88	0.54	7
-4.3	0.47	7
-2.98	-0.04	5
-2.16	-0.68	5
-1.07	-0.46	3
0	0	3