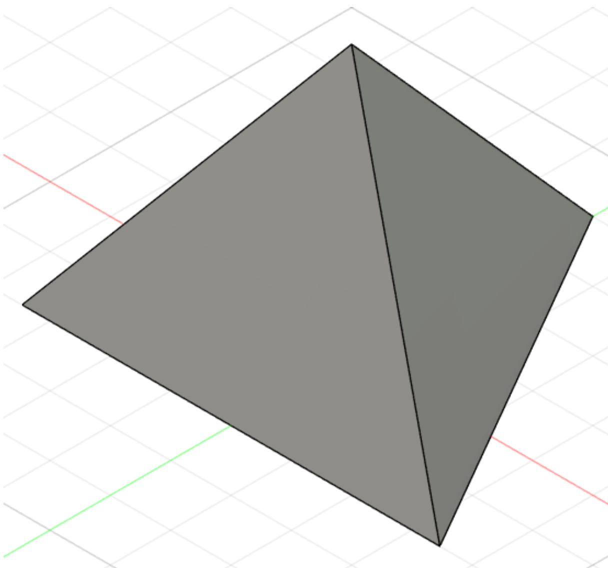
Mr. Barbetta's *"I don't care about 3D Printing. I just want the art credit."* class

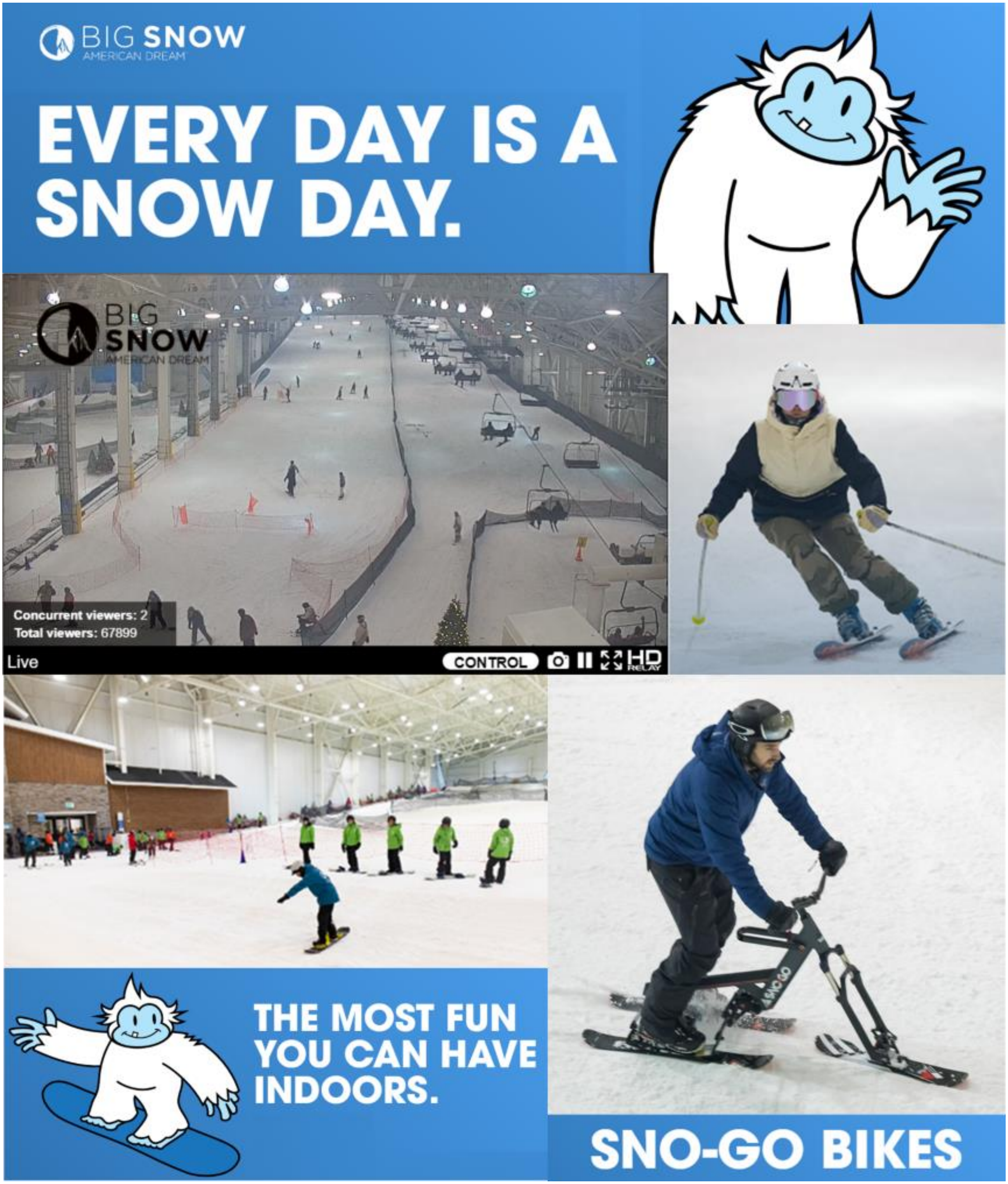
Explore the STL File Format



=

```
solid ASCII
  facet normal 0.000000e+00 0.000000e+00 -1.000000e+00
    outer loop
      vertex   1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   -5.204170e-17 2.000000e+00 0.000000e+00
    endloop
  endfacet
  facet normal -1.170278e-16 -9.128709e-01 4.082483e-01
    outer loop
      vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 2.236068e+00
    endloop
  endfacet
  facet normal 7.905694e-01 4.564355e-01 4.082483e-01
    outer loop
      vertex   1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   -5.204170e-17 2.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 2.236068e+00
    endloop
  endfacet
  facet normal -7.905694e-01 4.564355e-01 4.082483e-01
    outer loop
      vertex   -5.204170e-17 2.000000e+00 0.000000e+00
      vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 2.236068e+00
    endloop
  endfacet
endsolid
```

Today's Lesson is Sponsored by Big Snow at the American Dream Mall



Contents

What is an STL File?

Does **STL** stand for **Stereolithography**, **Standard Triangle Language**, or **Standard Tessellation Language**?

According to Wikipedia STL can stand for any of these.

It is a common file format that *CAD software*, such as Fusion, will generate for a solid object. For 3D printing the STL file is then opened in *slicer software*, such as Ultimaker Cura, to generate g-code data for the 3D printer to use.

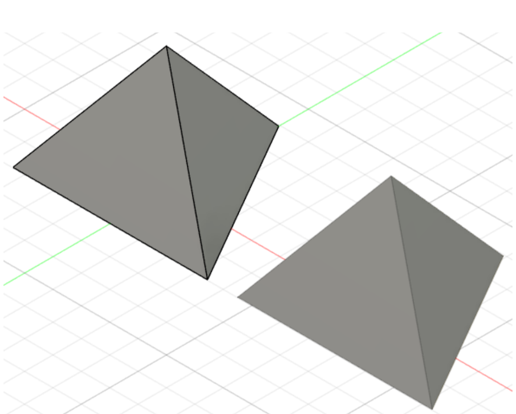
The STL file is essentially **many triangles** defined in 3D space that **defines the surface of an object**. The term **mesh** is often used in CAD terminology.

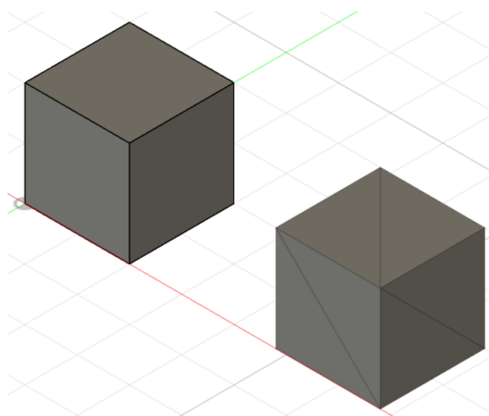
Below are examples of solid shapes and their resultant mesh objects from their imported STL file.

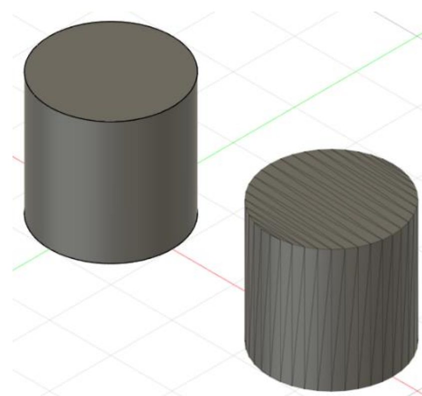
A **tetrahedron** (4 sided pyramid) produces the simplest STL file with **4 triangles** completely defining the object.

A **cube** has 6 sides and because a rectangle is defined with 2 triangles its STL file is comprised of **12 triangles**.

Any shape with curved surfaces, such as the cylinder shown, can only be approximated with triangles. The STL file for this cylinder is comprised of **156 triangles**. Fusion has **Refinement settings** that can be used to allow for more triangles to more accurately define the surfaces, which will also result in a larger file. The 156 triangles is the result of Fusion's default Refinement settings.





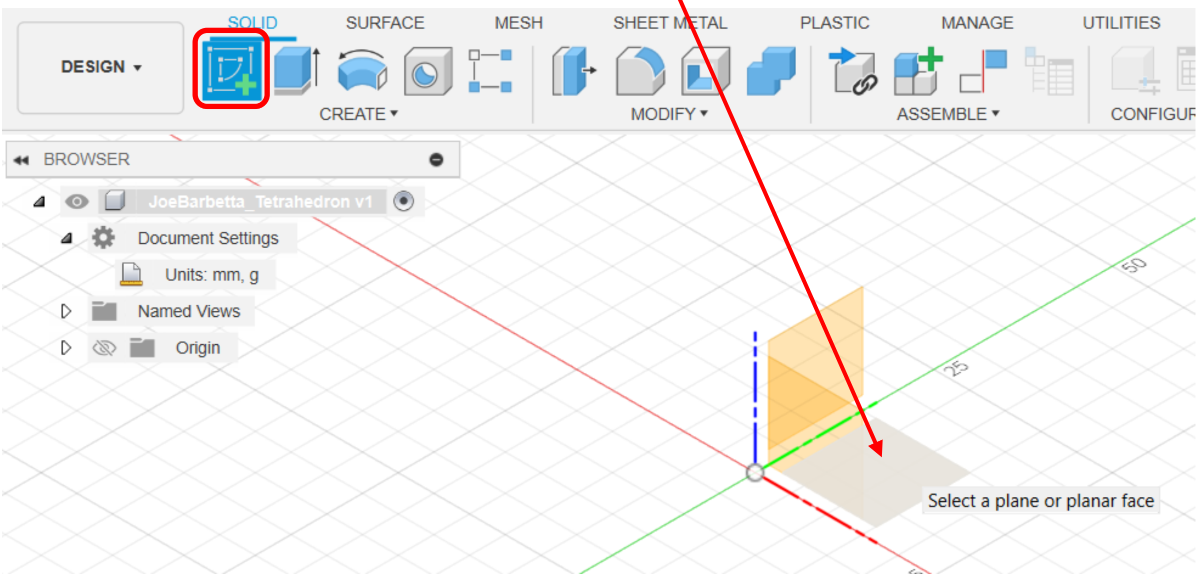


The following instructions will guide one in creating a tetrahedron and analyzing the STL data to learn how the STL data defines an object.

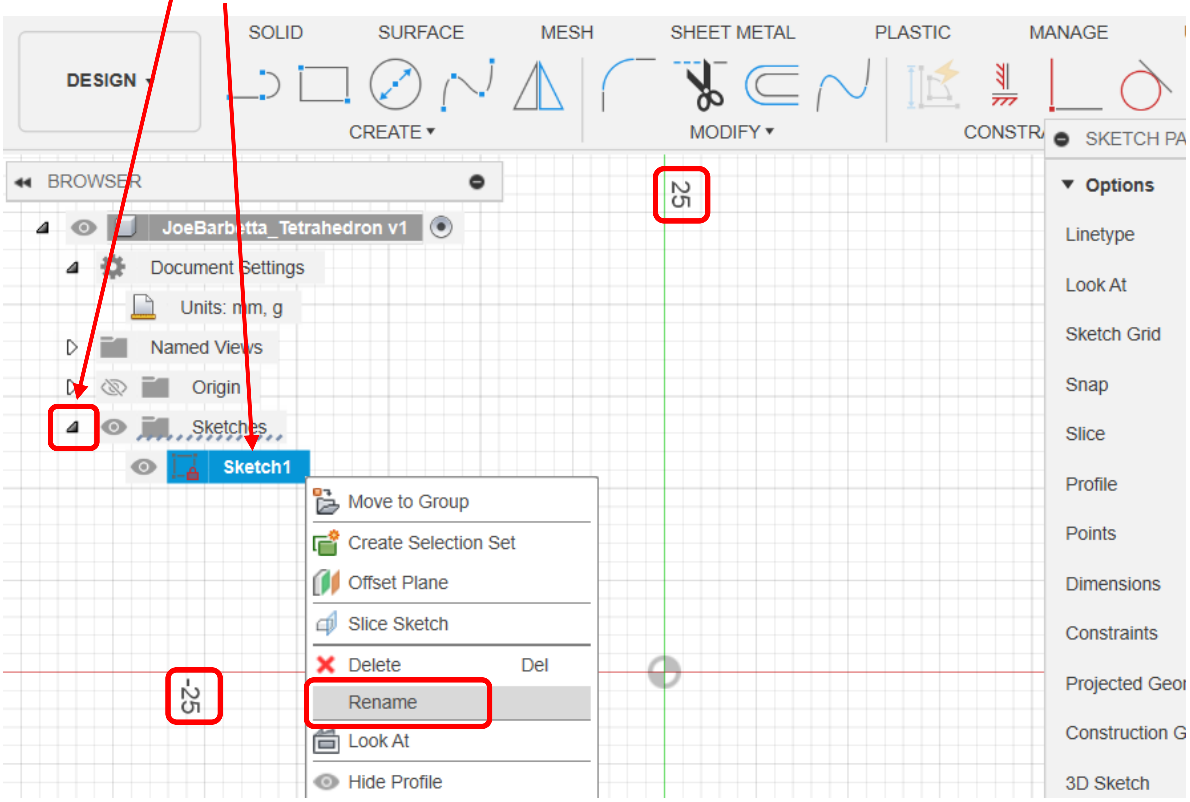
Creating the Tetrahedron

A fusion expert would tell you to create a new Component first, but you can say **"Dude. I'm just creating a little pyramid."**

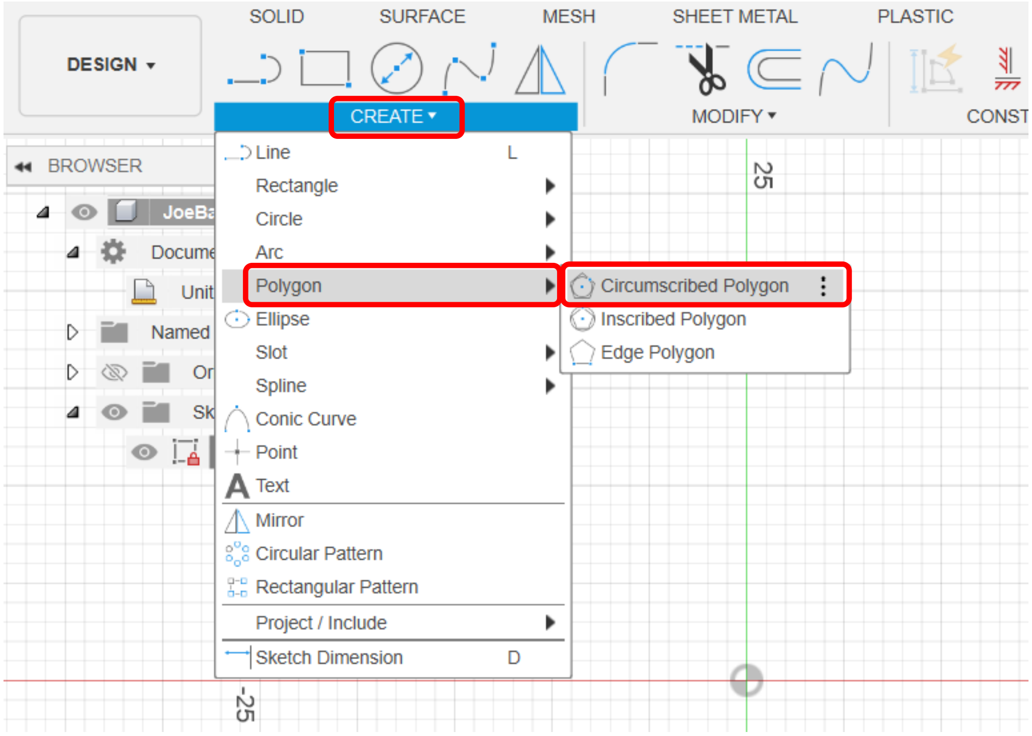
- select the **Create Sketch** tool and click on the **bottom rhombus**. If a tool icon is not visible, one can find it in the pull-down menu for the group.



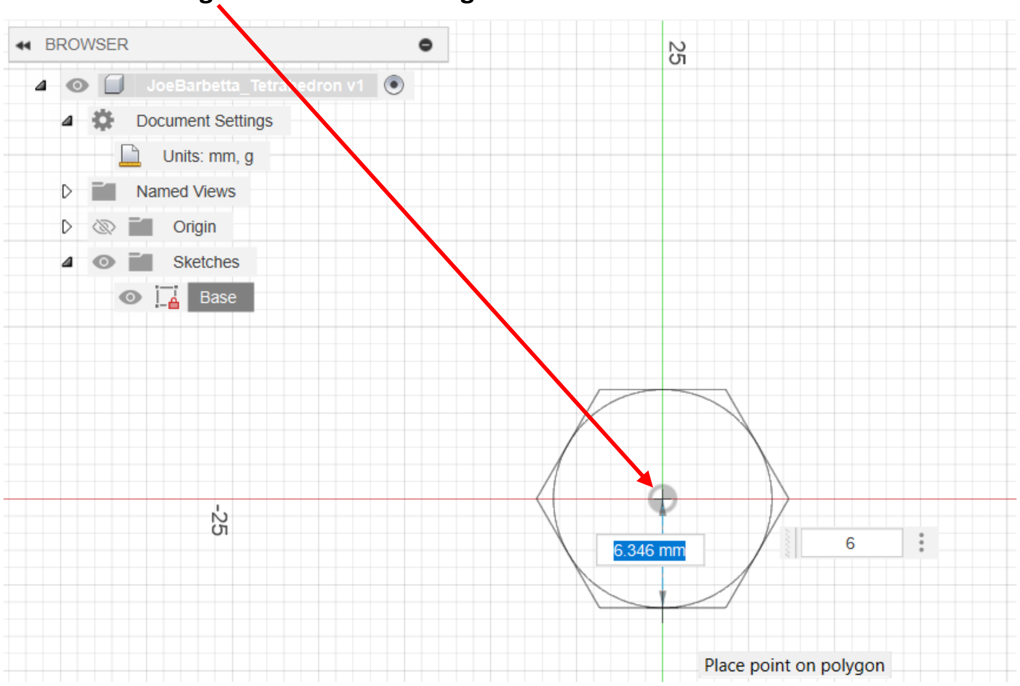
- check that the **View Cube** in the upper right shows **TOP**. If a sketch view ever needs to be rotated, hover over the view cube and click a curved rotation arrow.
- zoom using the mouse wheel so that that the **two 25 mm labels** are shown as below
- click on the **arrow** to open the **Sketches** folder
- right-click on **Sketch1**, select **Rename**, and change the name to **Base**



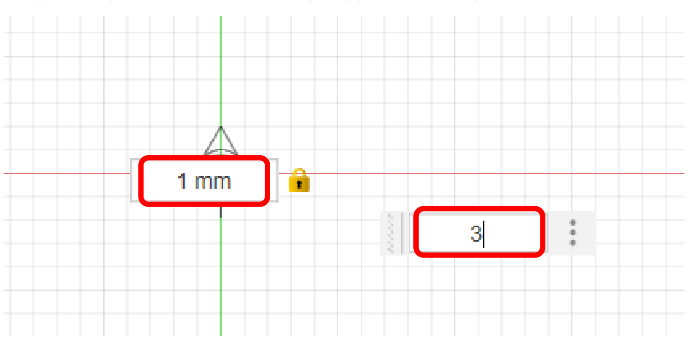
- from the **CREATE** menu select **Polygon** and **Circumscribed Polygon**



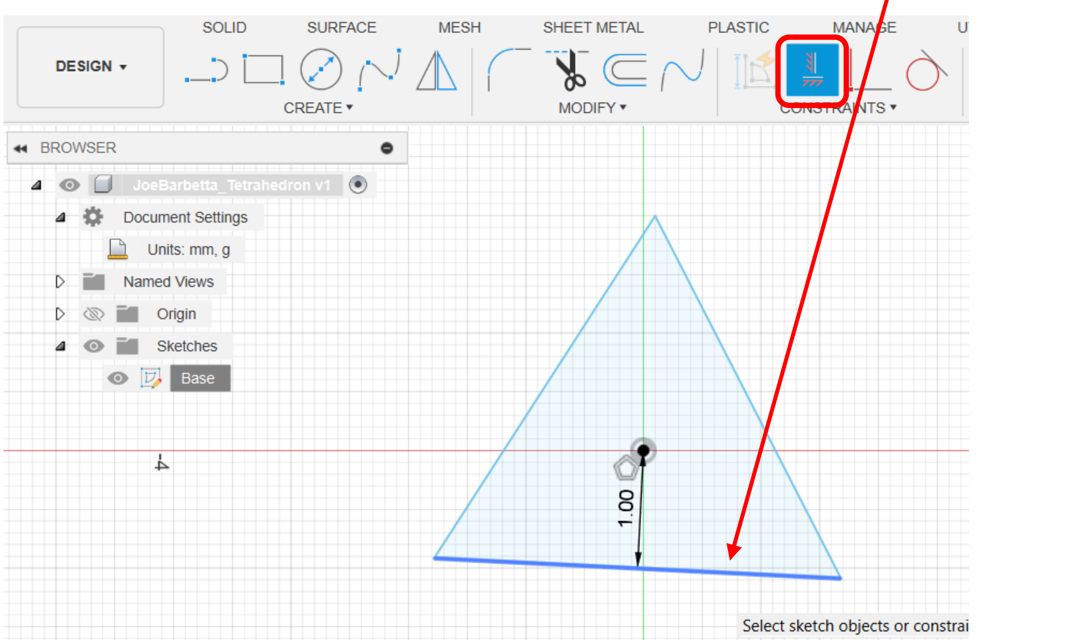
- click on the **Origin** and extend the **edge downward**



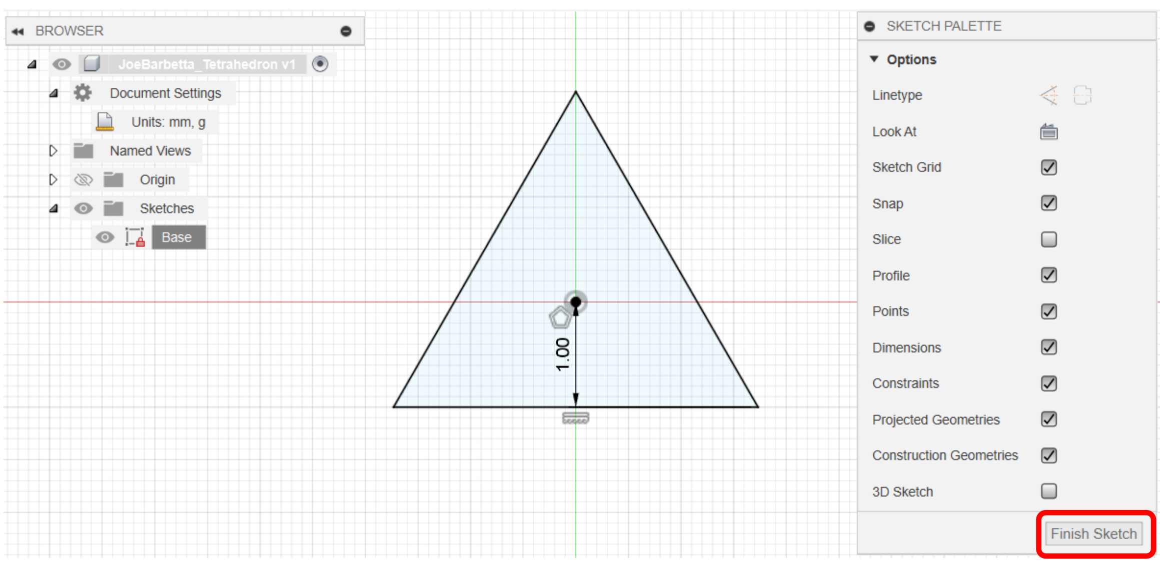
- type **1**, press the **Tab key**, type **3**, and press the **Enter Key**



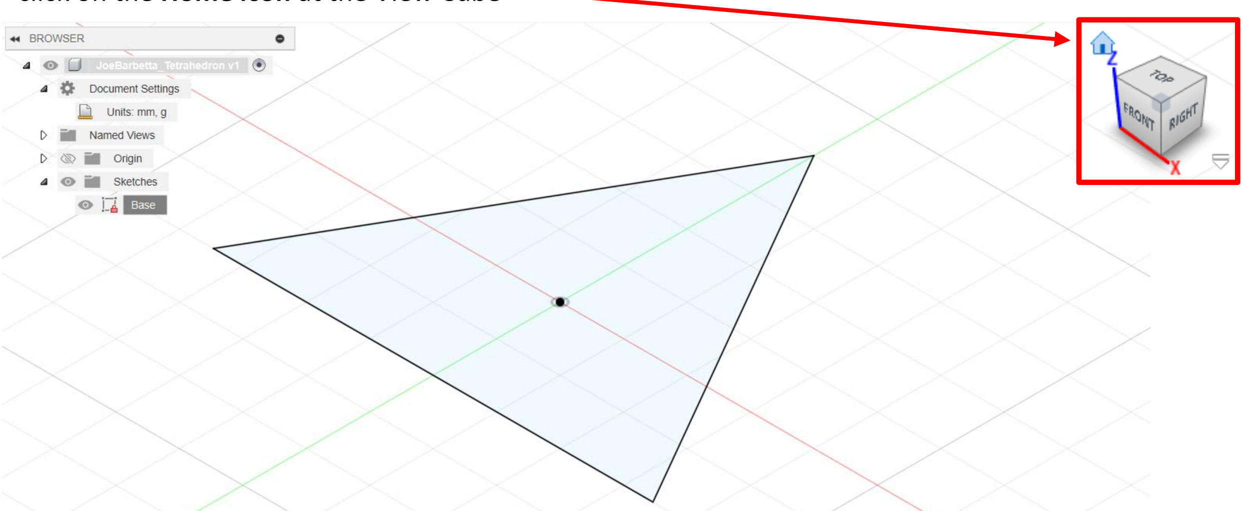
- zoom in to the resultant triangle
- select the **Horizontal/Vertical Constraint** tool and click on the **bottom edge** of the triangle



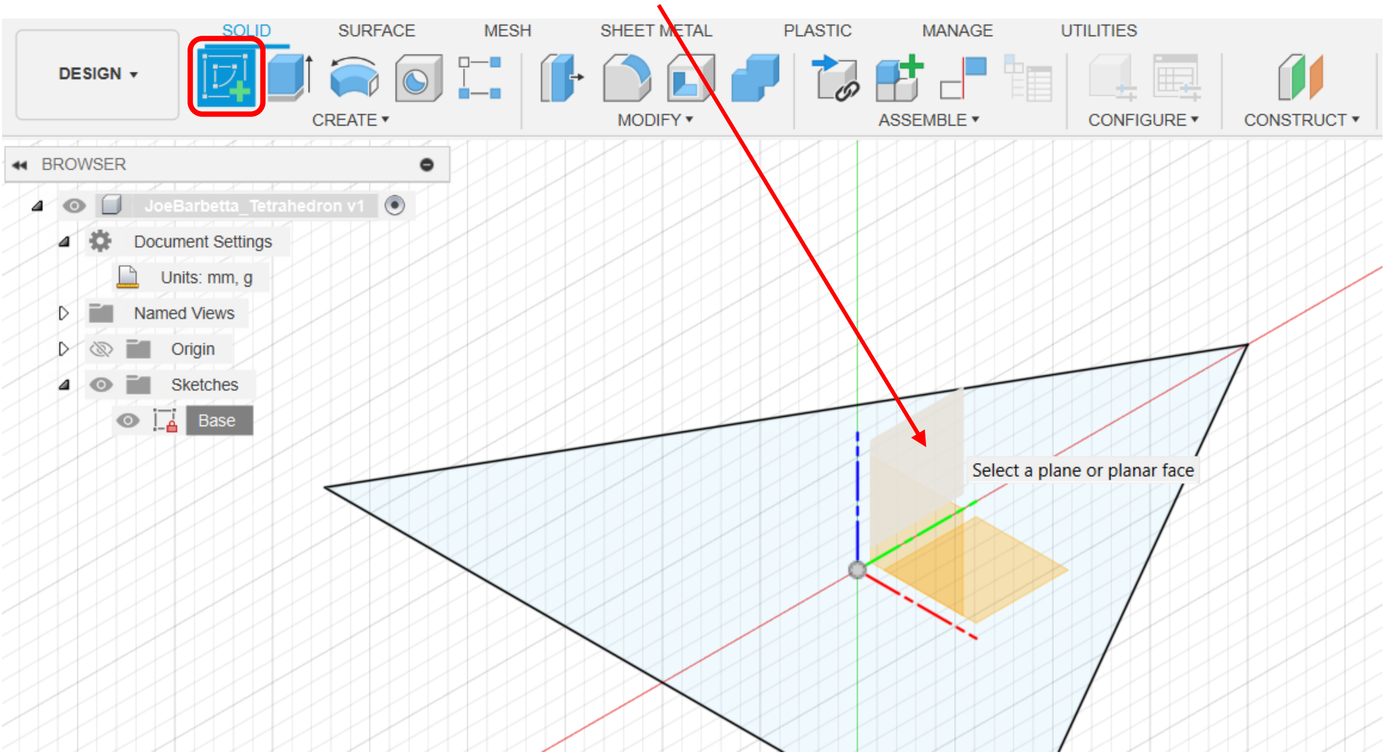
- click **Finish Sketch**



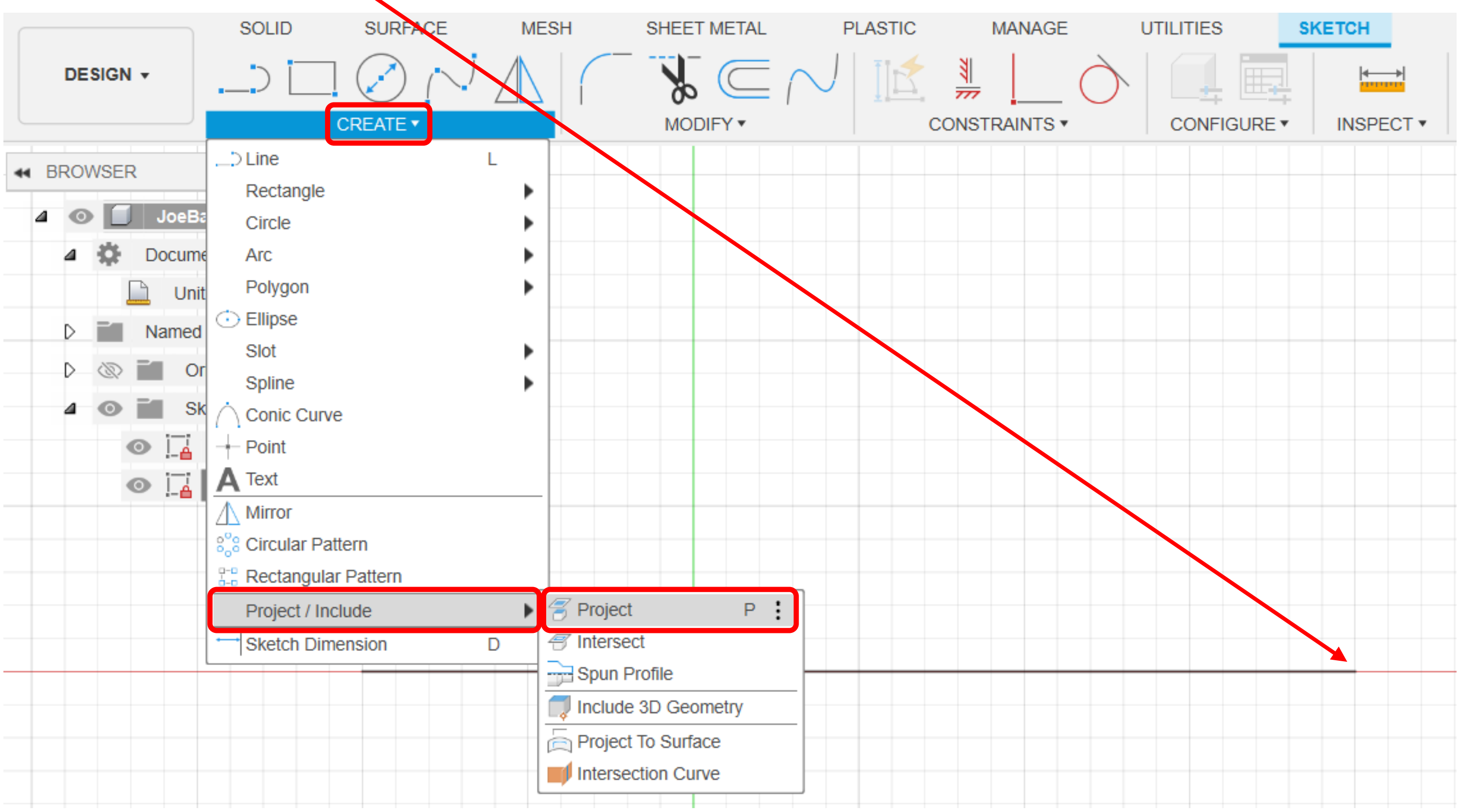
- click on the **Home icon** at the View Cube



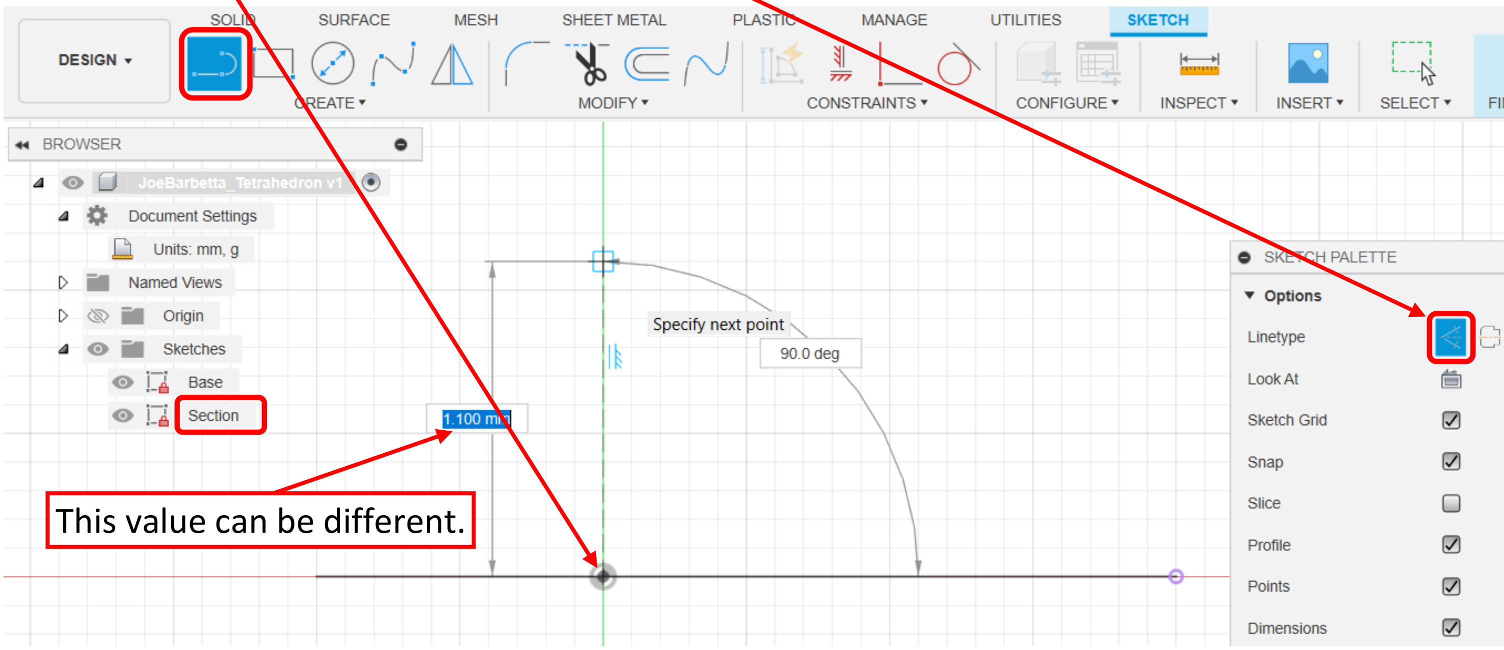
- select the **Create Sketch** tool and click on the **rhombus indicated**



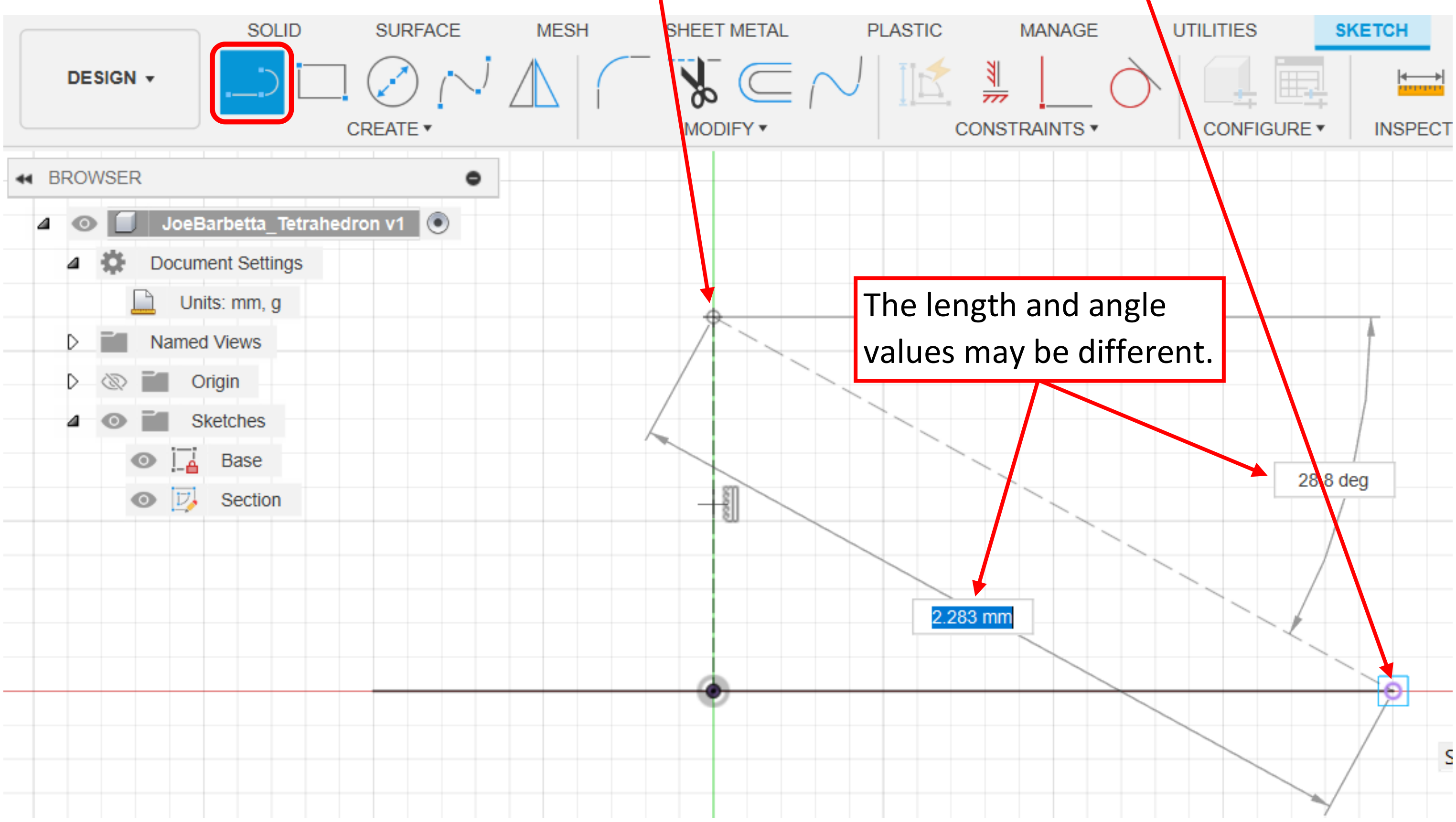
- from the **CREATE** menu select **Project / Include** and **Project**
- click on **the right end of the line**, which should create a small circle at the end



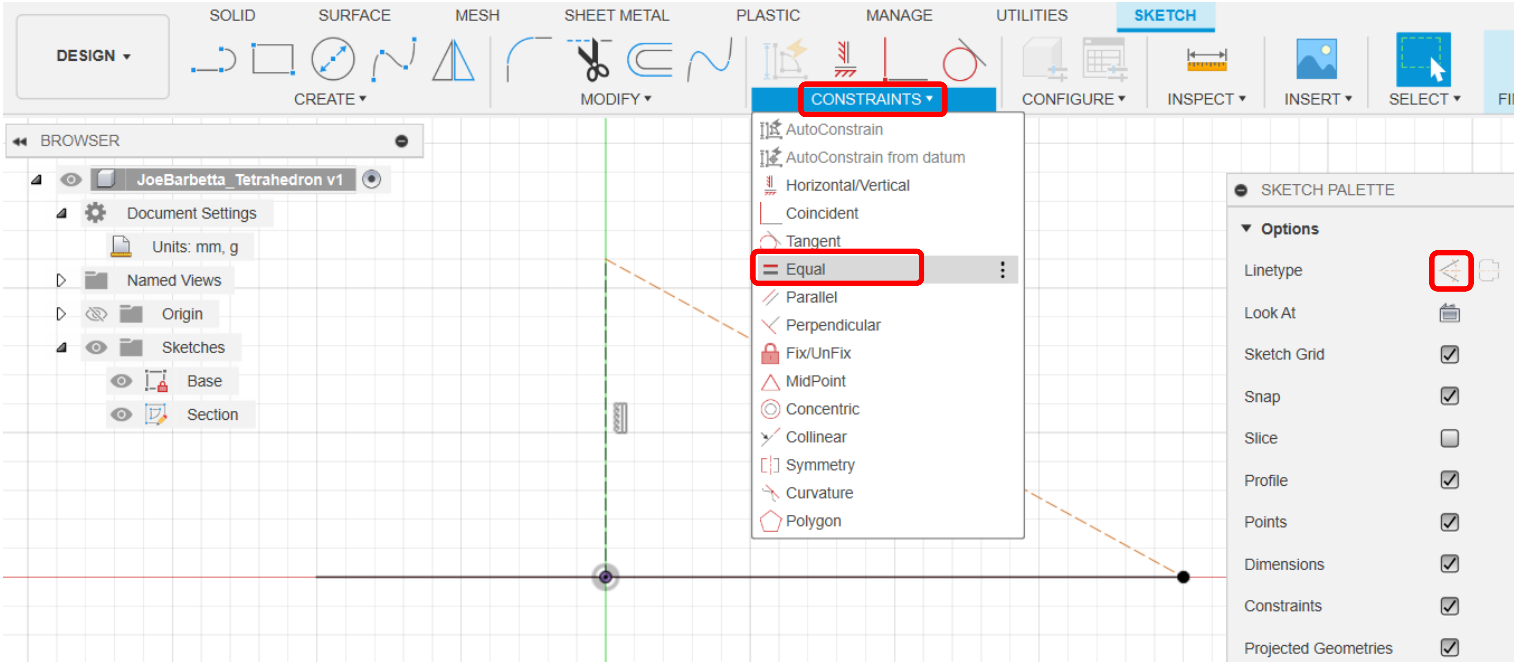
- rename the Sketch to **Section**
- select the **Line** tool and click on the **Construction** icon for **Linetype** to highlight it
- click on the **Origin** and extend the line upward and **click again** when the length shows a value around **1 mm**, and press the **Esc key**. Do Not type a value.



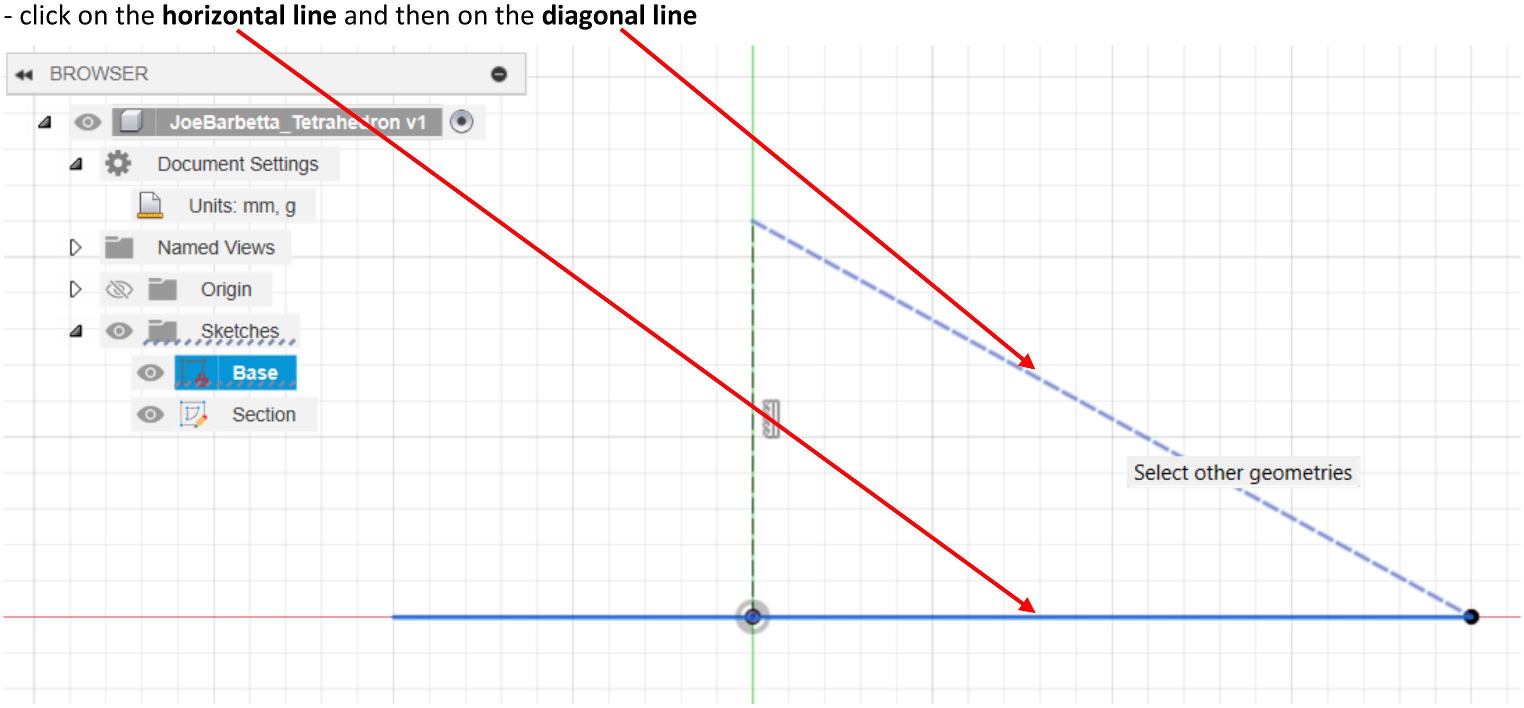
- select the **Line** tool again and click on the **point at the top of the vertical line** and then on the **right end of the line**. Your value in the length rectangle may be different.



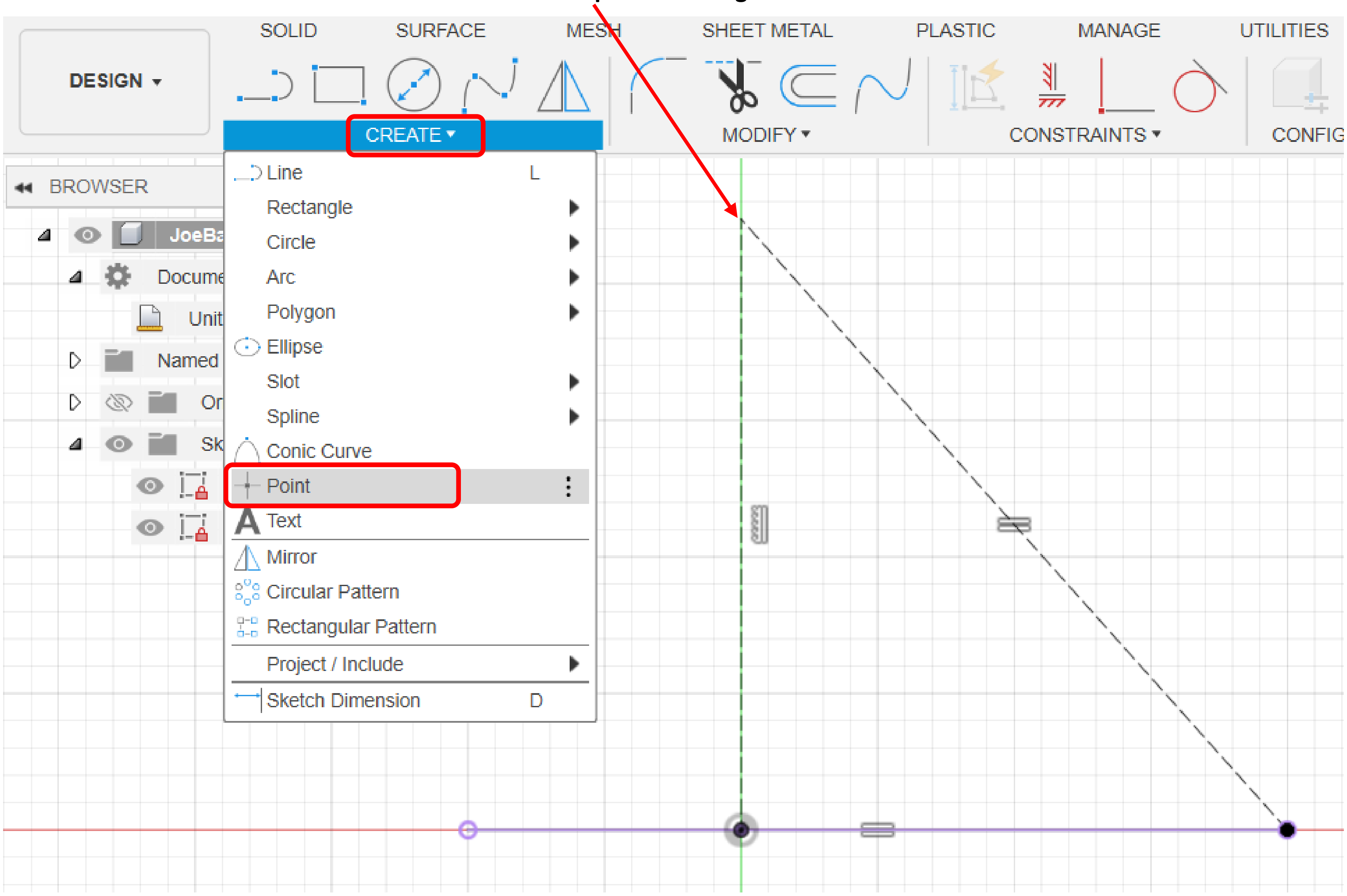
- click on the **Construction** icon for **Linetype** to **remove the highlighting**
- from the **CONSTRAINTS** menu select **Equal**



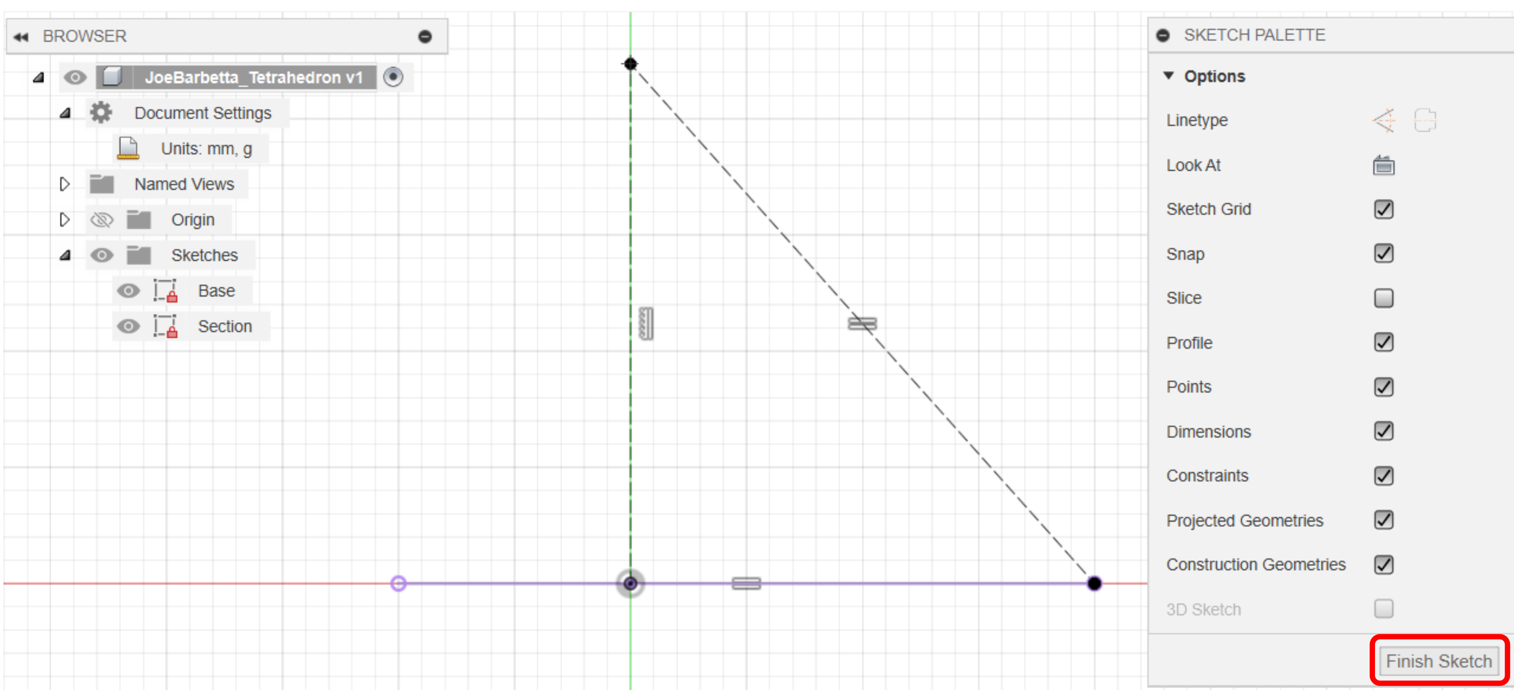
- click on the **horizontal line** and then on the **diagonal line**



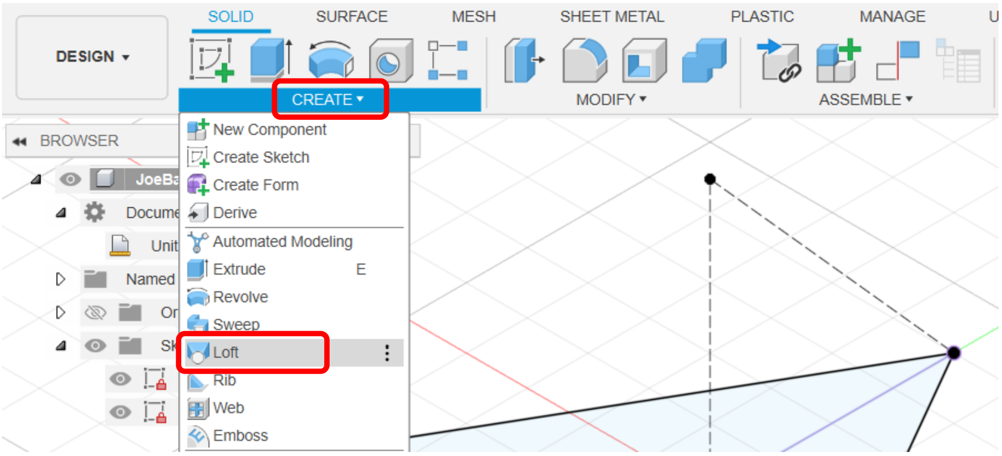
- zoom out to see the entire triangle
- from the **CREATE** menu select **Point** and click on the **top of the triangle**



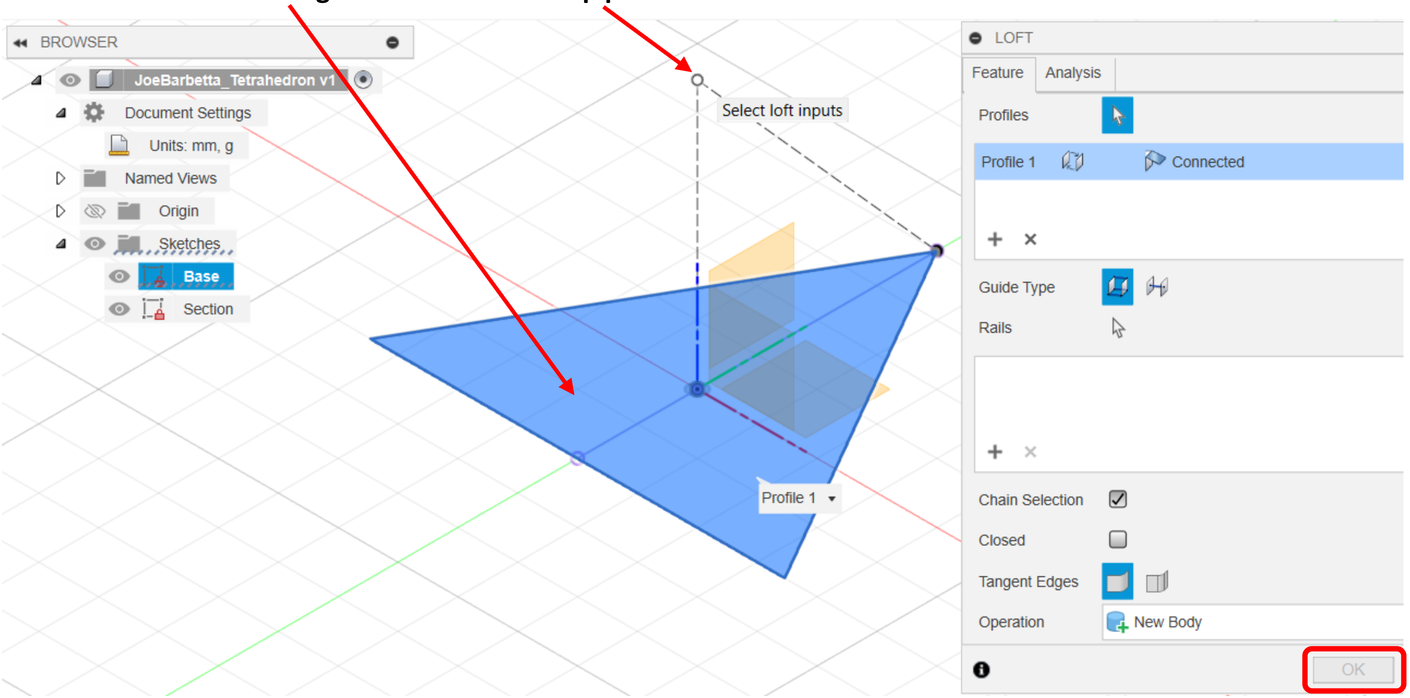
- click **Finish Sketch**



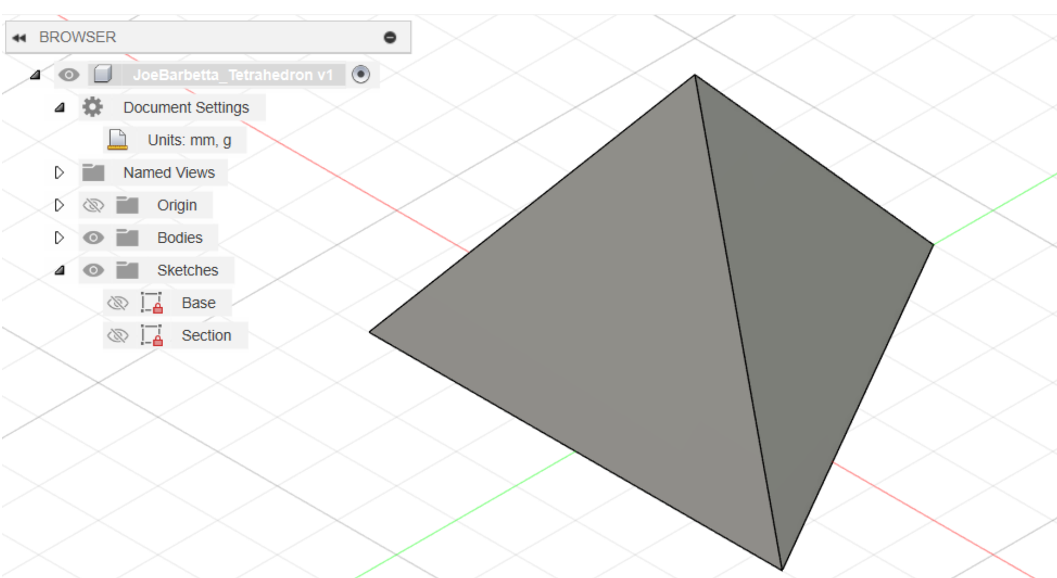
- from the **CREATE** menu select **Loft**



- click on the **bottom triangle** and then on the **top point** and then **OK**

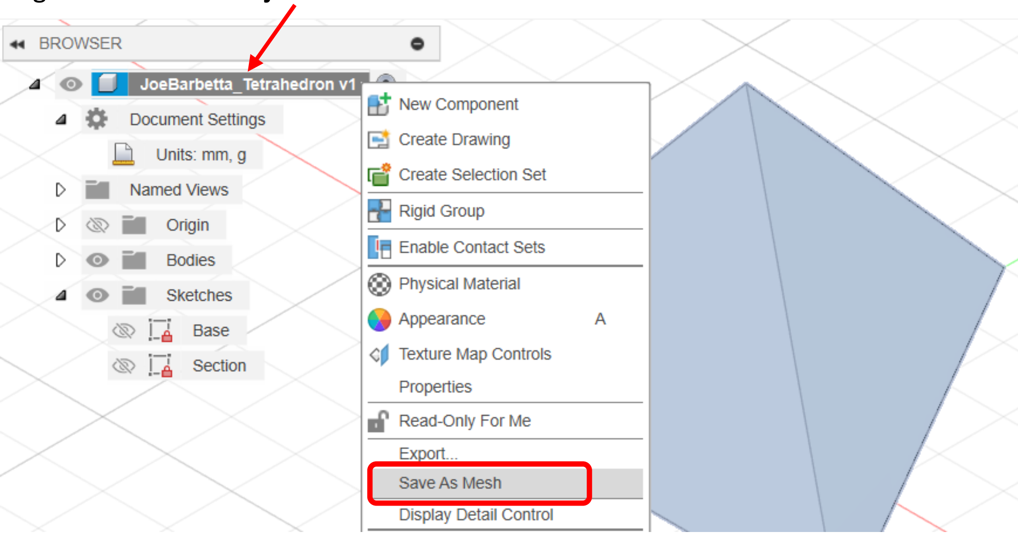


- admire your beautiful Tetrahedron

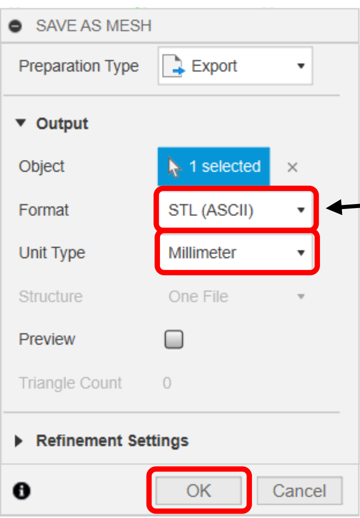


Creating the STL File

- right-click on the **Project Name** and select **Save As Mesh**



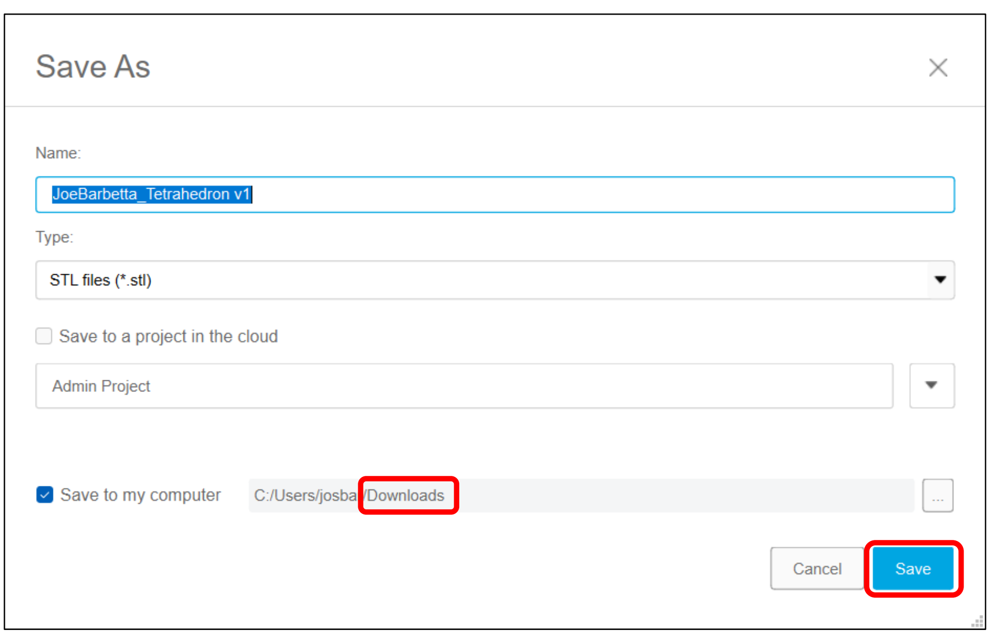
- set **Format** to **STL (ASCII)** and **Unit Type** to **Millimeter**, and click **OK**



Normally STL (Binary) is selected, however, we are selecting STL (ASCII) to allow human readable values to appear in the .STL file.

The Binary option is normally used because it results in a smaller file size.

- the default location should be the **Downloads** folder. Click **Save**.

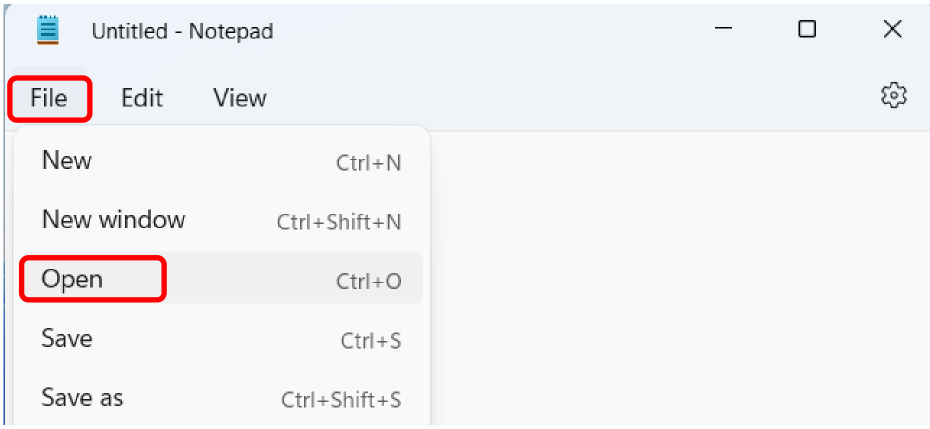


Viewing the .STL file

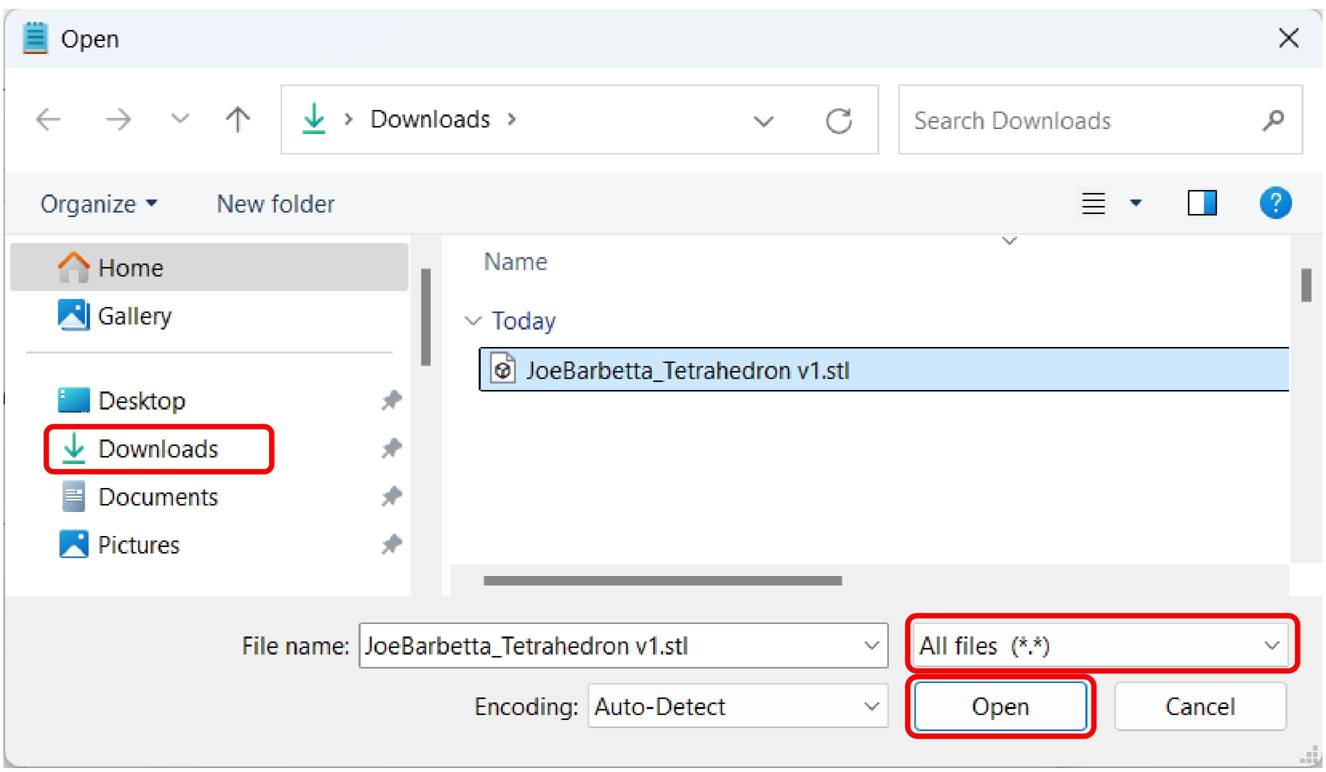
When the .STL file is created as ASCII, it can be viewed in any text editor.

- using the lower **Windows Search** box enter **NotePad**, which should open the NotePad text editor. Note that Macs have an equivalent text editor.

- from the **File** menu select **Open**

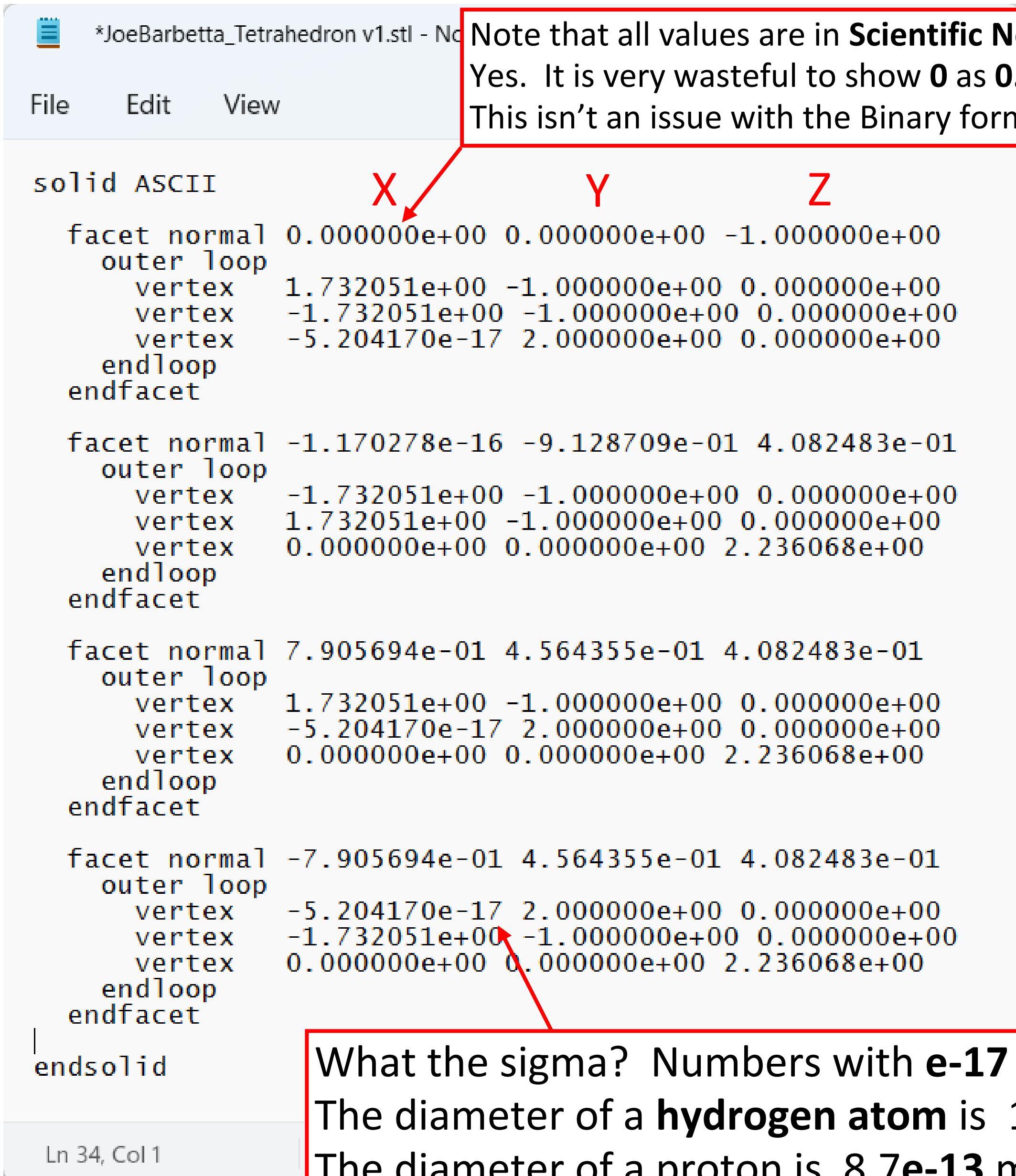


- select the **Downloads** folder
- change the file filter to **All files (*.*)**
- select the .stl file just created and click **Open**



Here is the STL file shown in NotePad. A few empty lines were added between facet sections to help identify them.

This is the simplest possible .STL file. Because a .STL file defines triangular surfaces in 3D space, the object with the least such surfaces is a tetrahedron and that is why we created one.




```
solid ASCII
  facet normal 0.000000e+00 0.000000e+00 -1.000000e+00
    outer loop
      vertex   1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   -5.204170e-17 2.000000e+00 0.000000e+00
    endloop
  endfacet

  facet normal -1.170278e-16 -9.128709e-01 4.082483e-01
    outer loop
      vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 2.236068e+00
    endloop
  endfacet

  facet normal 7.905694e-01 4.564355e-01 4.082483e-01
    outer loop
      vertex   1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   -5.204170e-17 2.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 2.236068e+00
    endloop
  endfacet

  facet normal -7.905694e-01 4.564355e-01 4.082483e-01
    outer loop
      vertex   -5.204170e-17 2.000000e+00 0.000000e+00
      vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 2.236068e+00
    endloop
  endfacet

endsolid
```

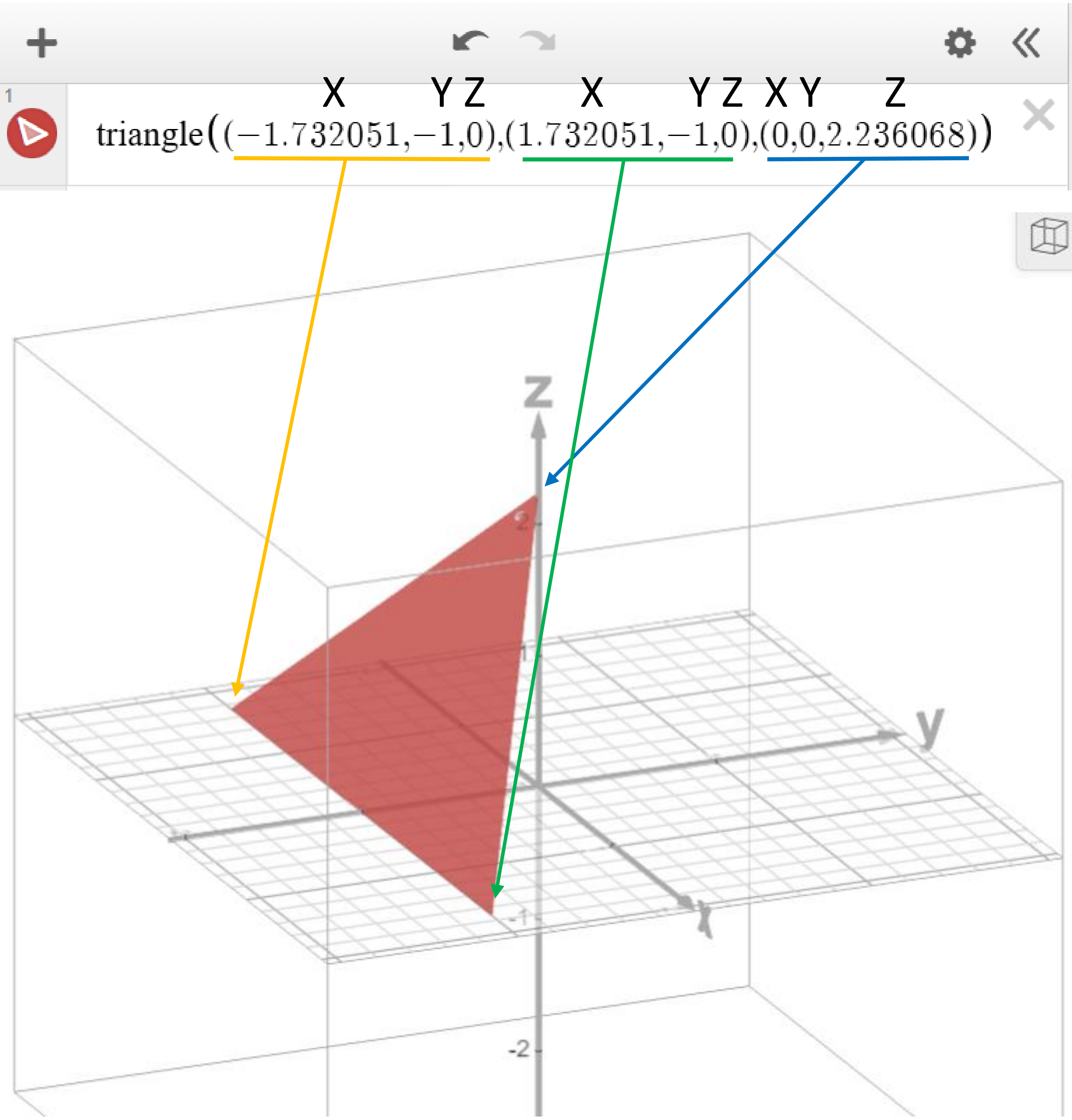
Note that all values are in **Scientific Notation**.
Yes. It is very wasteful to show **0** as **0.000000e+00**
This isn’t an issue with the Binary format.

What the sigma? Numbers with **e-17** ?
The diameter of a **hydrogen atom** is 1.0**e-7** mm
The diameter of a proton is 8.7**e-13** mm
This is ten thousand times smaller than a proton!
This must be an artifact from a rounding error. It would have been nice if Fusion just made it 0, but perhaps Autodesk programmers let it be as a joke.

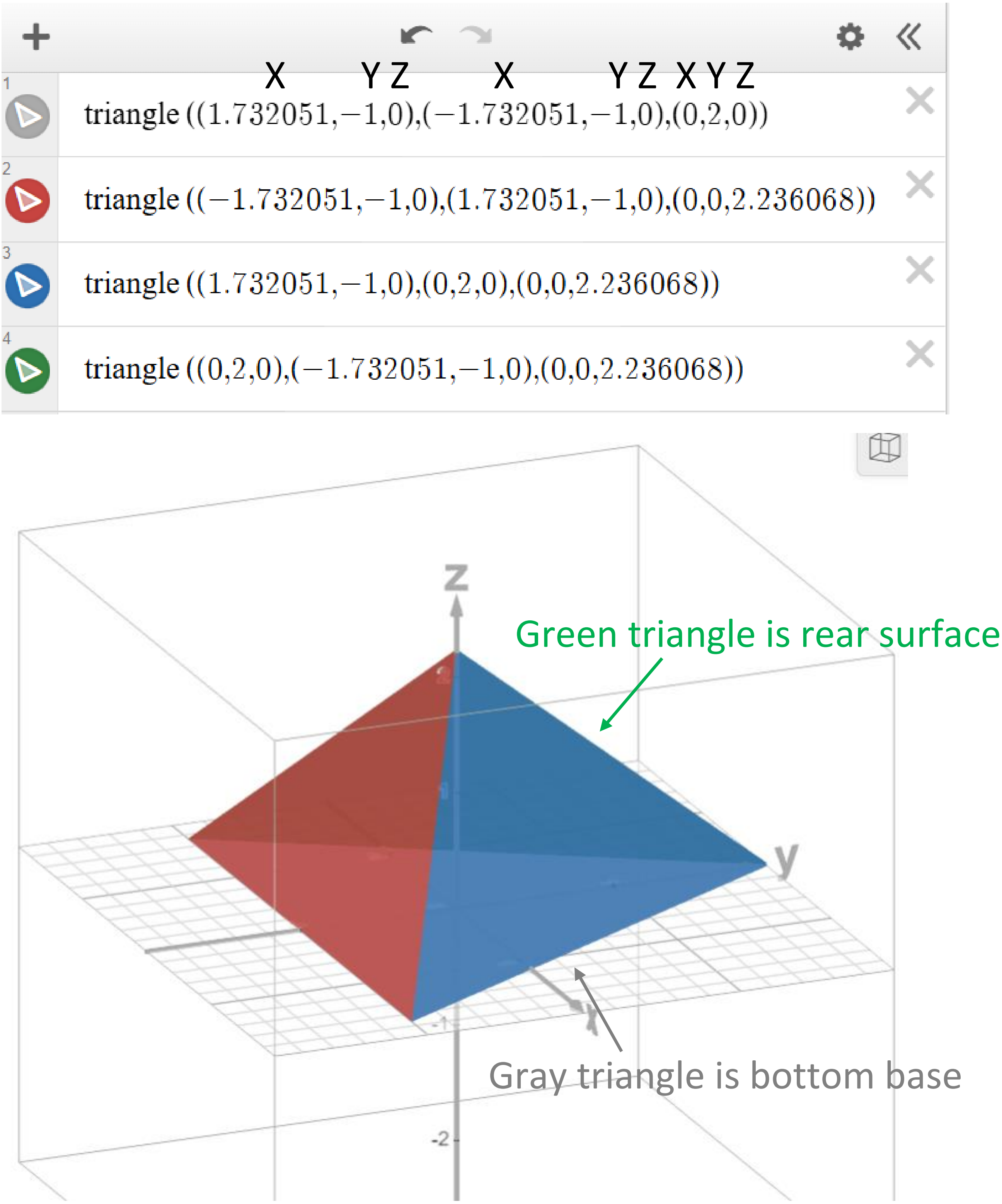
Here are the vertex values of the 2nd triangle followed by the resultant triangle command for Desmos with the scientific notation format removed and the result from desmos.com/3d The 2nd triangle is shown here because the 1st is the bottom and flat on the X, Y axis and thus less informative.

One can see how the triangle is define in 3D space using an **X, Y, Z** value for each **vertex** of the **triangle**.

	X	Y	Z
vertex	-1.732051e+00	-1.000000e+00	0.000000e+00
vertex	1.732051e+00	-1.000000e+00	0.000000e+00
vertex	0.000000e+00	0.000000e+00	2.236068e+00

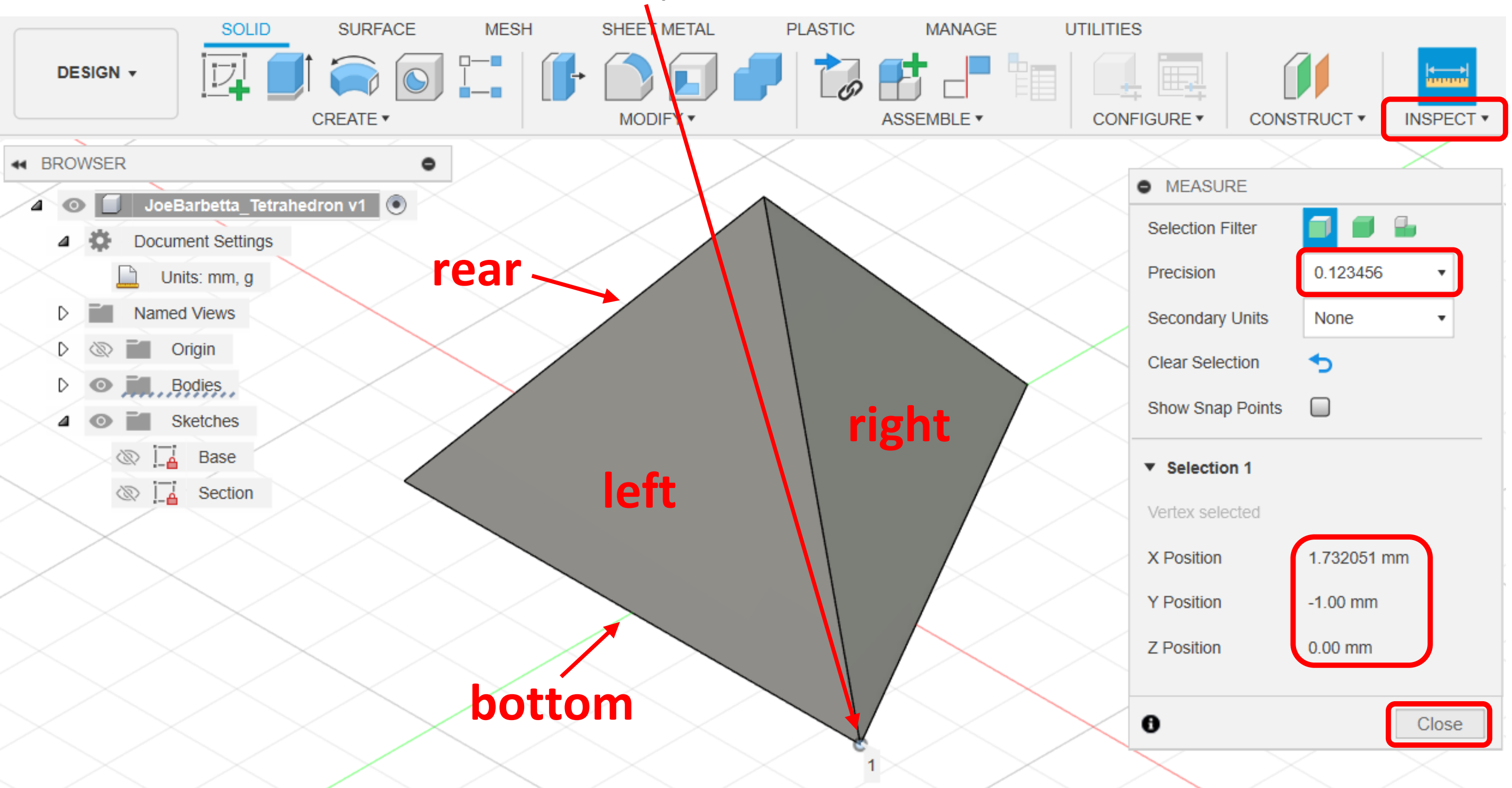


Here are **all 4 surfaces** represented as triangles for desmos and the result from desmos.com/3d. The gray triangle is the bottom face.



Using the Measure Tool

- from the **INSPECT** menu at the top right select **Measure**
- set the **Precision** to **0.123456** and click on the **bottom point** and note the **X**, **Y**, and **Z Positions** and then click **Close**



Note that the position of that point: **X = 1.732051 Y = -1.00 Z = 0.00** matches the X, Y, Z values of 3 lines. This makes sense because there are 3 triangular faces, **bottom, left, and right**, that share that point.

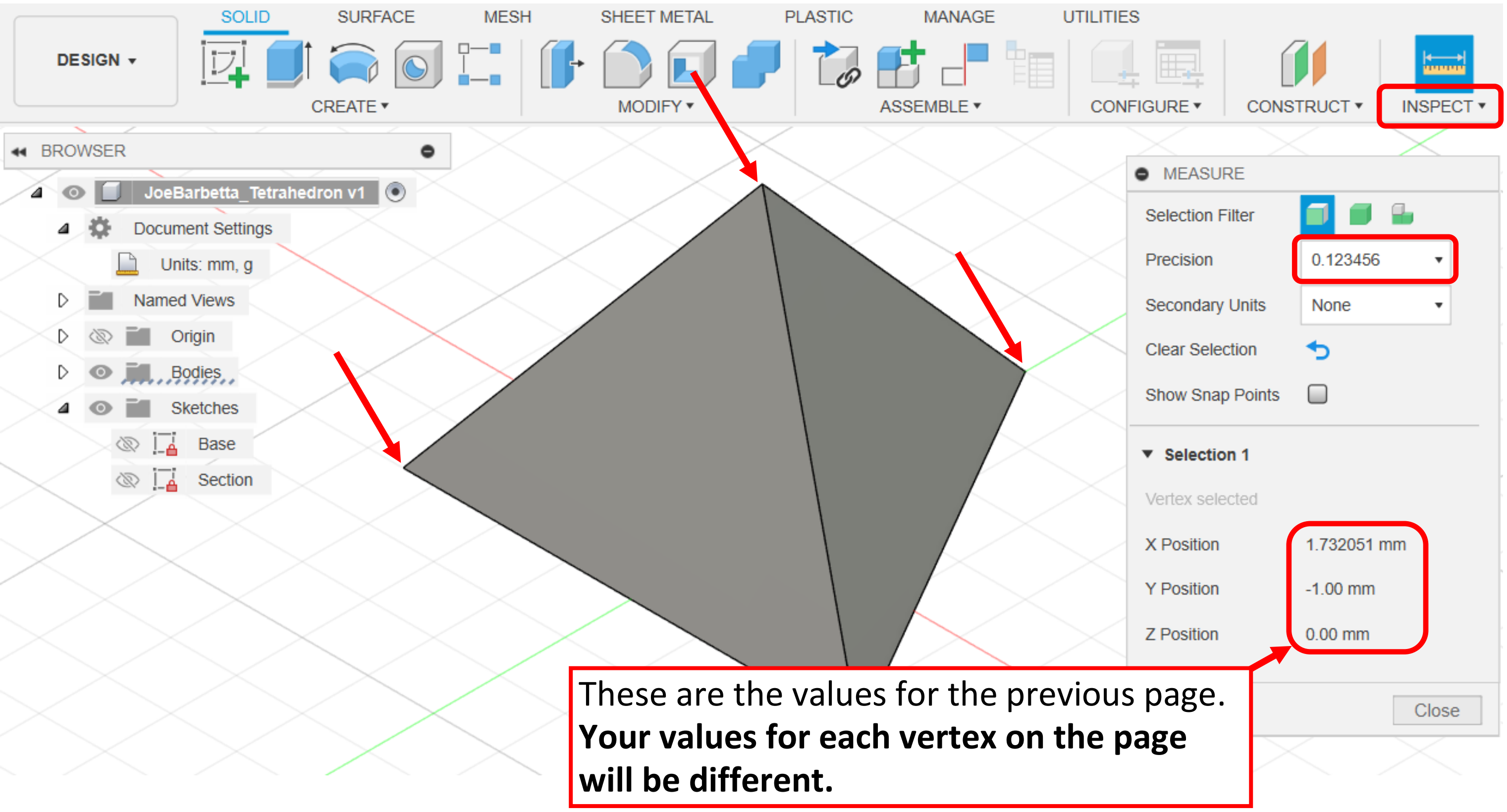
```
solid ASCII         X              Y              Z

  facet normal 0.000000e+00 0.000000e+00 -1.000000e+00
    outer loop
      vertex   1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   -5.204170e-17 2.000000e+00 0.000000e+00
    endloop
  endfacet

  facet normal -1.170278e-16 -9.128709e-01 4.082483e-01
    outer loop
      vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 2.236068e+00
    endloop
  endfacet

  facet normal 7.905694e-01 4.564355e-01 4.082483e-01
    outer loop
      vertex   1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   -5.204170e-17 2.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 2.236068e+00
    endloop
  endfacet

  facet normal -7.905694e-01 4.564355e-01 4.082483e-01
    outer loop
      vertex   -5.204170e-17 2.000000e+00 0.000000e+00
      vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 2.236068e+00
    endloop
  endfacet

endsolid
```

Your turn to use the Measure tool

- as done on the previous page use the **Measure** tool to determine the **X, Y, Z positions of each vertex** indicated with an arrow.

- in a Google doc **paste your screen shot of your Fusion screen**, similar to that below, with the Measure results shown for one of the vertices indicated with an arrow. In this document also **paste your STL file as shown in Notepad** or the Mac equivalent.

- in your Google doc **draw a rectangle around the facet section** that has X, Y, Z values matching that of the 3 Measure tool results. This facet (triangle) represents the rear face.



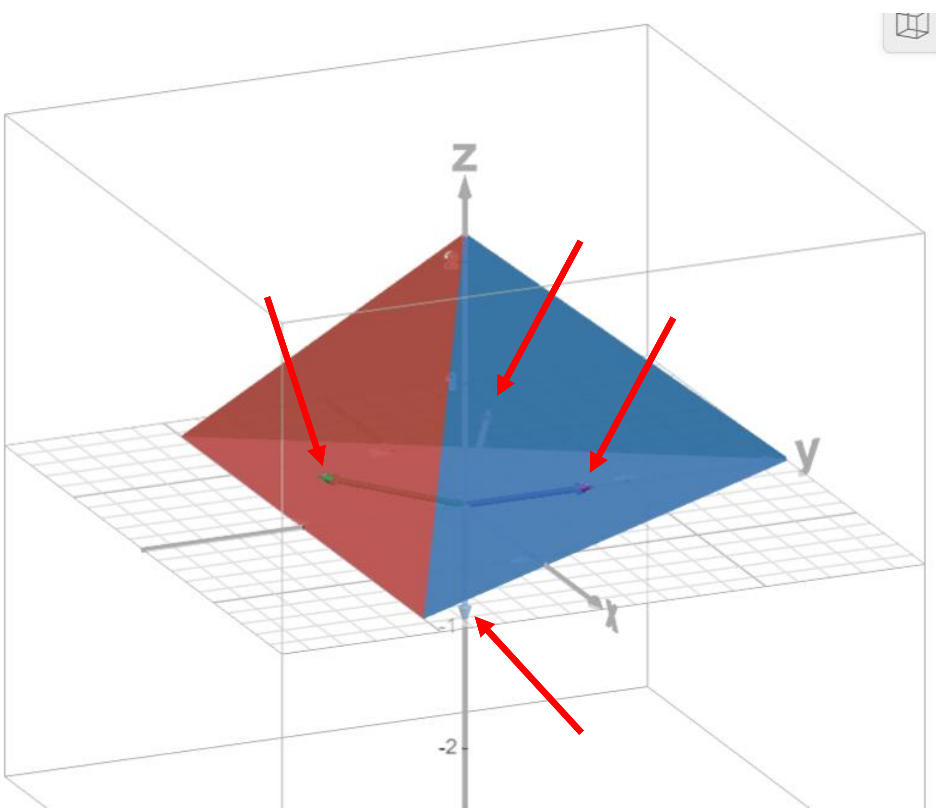

```
solid ASCII          X           Y           Z

  facet normal 0.000000e+00 0.000000e+00 -1.000000e+00
    outer loop
      vertex   1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   -5.204170e-17 2.000000e+00 0.000000e+00
    endloop
  endfacet

  facet normal -1.170278e-16 -9.128709e-01 4.082483e-01
    outer loop
      vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 2.236068e+00
    endloop
  endfacet

  facet normal 7.905694e-01 4.564355e-01 4.082483e-01
    outer loop
      vertex   1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   -5.204170e-17 2.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 2.236068e+00
    endloop
  endfacet

  facet normal -7.905694e-01 4.564355e-01 4.082483e-01
    outer loop
      vertex   -5.204170e-17 2.000000e+00 0.000000e+00
      vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 2.236068e+00
    endloop
  endfacet

endsolid
```

Normal Vectors

One may have noticed that each set of "triangle data" starts with X, Y, Z data labelled as **normal**, which has not yet been addressed. For each triangular surface a vector with an axis normal (perpendicular) to the triangular surface is defined. The lower screen shot is from desmos.com/3d after vectors starting at the origin were added. They can be difficult to see and the red arrows point to them. They are added to specify the which face of the triangle is the outer surface of the object.

The ***Normal*** **vector data is often ignored by a slicer program** because the slicer program can determine the outside surface from the triangle data alone. A test was done with all the normal values set to 0.000000e+00 and Ultimaker Cura produced the same object.

```
facet normal 0.000000e+00 0.000000e+00 -1.000000e+00
  outer loop
    vertex   1.732051e+00 -1.000000e+00 0.000000e+00
    vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
    vertex   -5.204170e-17 2.000000e+00 0.000000e+00
  endloop
endfacet

facet normal -1.170278e-16 -9.128709e-01 4.082483e-01
  outer loop
    vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
    vertex   1.732051e+00 -1.000000e+00 0.000000e+00
    vertex   0.000000e+00 0.000000e+00 2.236068e+00
  endloop
endfacet

facet normal 7.905694e-01 4.564355e-01 4.082483e-01
  outer loop
    vertex   1.732051e+00 -1.000000e+00 0.000000e+00
    vertex   -5.204170e-17 2.000000e+00 0.000000e+00
    vertex   0.000000e+00 0.000000e+00 2.236068e+00
  endloop
endfacet

facet normal -7.905694e-01 4.564355e-01 4.082483e-01
  outer loop
    vertex   -5.204170e-17 2.000000e+00 0.000000e+00
    vertex   -1.732051e+00 -1.000000e+00 0.000000e+00
    vertex   0.000000e+00 0.000000e+00 2.236068e+00
  endloop
endfacet
```



G-code

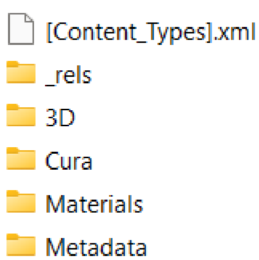
G-code is a file format that has been used long before 3D printing came unto the scene. Its first use was for CNC (Computer Numerical Control) machining and specifies a language to define machine operations and X, Y, Z coordinates. Because the X, Y, Z movement of the 3D printers print head relative to the build plate is similar to that of a cutting tool of a CNC machine, g-code was readily adopted for 3D printing. I was easy to extend the g-code command set to include operating parameters specific to 3D printing. For example, a CNC machine can have additional axes, such as a rotational axis, and for 3D printing an additional axis is used for the movement of filament through the extruder.

Sometimes a slicer program will produce a file that is readily identified as g-code and may also have a .gcode file extension. Sometimes the g-code is hidden. For example, when using Ultimaker Cura to produce g-code for an Ultimaker printed, it will use a default **.ufp** format. It is interesting that this is actually a .zip file in disguise. One can rename the .ufp file to have a .zip extension and unzip it. In Windows, one can right-click on a file name and select **Extract All**. However, it has been found that the Windows built-in unzip feature can produce and error and one may have to use another program, such as 7-Zip or a free on-line unzip website.

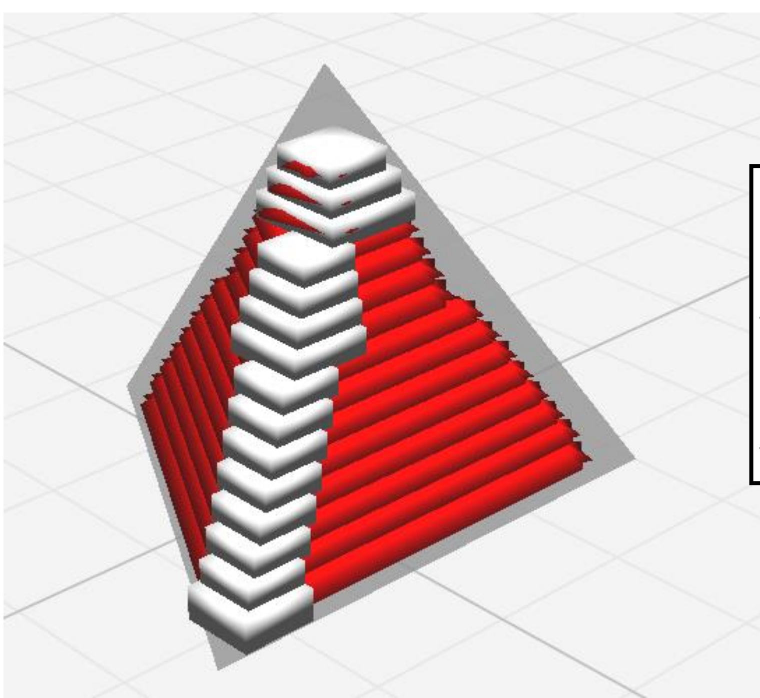
This is the result of the file and folders extracted from a .ufp.

The **Metadata** folder includes an image file **thumbnail.png**. This is the image that an Ultimaker shows on its small LCD screen. It would too computationally intensive for the printer to generate that image from the g-code, but easy for it to quickly show that *pre-generated* .png image.

The **3D** folder includes the g-code file **model.gcode**, which contains the g-code.



This is the **Preview** image of the tetrahedron in Ultimaker Cura with a layer height of 0.15 mm. The tetrahedron is only 2.2 mm high and thus there are only 17 layers.



In the Preview mode Cura uses different colors to identify different print features, such as red for outside walls, and white for the z-seam, which is the starting point of printing for a layer.
In this case it has a very rough look because the object is so small.

Here is the g-code for the tetrahedron with **sections for layers 3 to 15 removed**.

```
;START_OF_HEADER
;HEADER_VERSION:0.1
;FLAVOR:Griffin
;GENERATOR.NAME:Cura_SteamEngine
;GENERATOR.VERSION:5.2.1
;GENERATOR.BUILD_DATE:2022-10-19
;TARGET_MACHINE.NAME:Ultimaker S5
;EXTRUDER_TRAIN.0.INITIAL_TEMPERATURE:200
;EXTRUDER_TRAIN.0.MATERIAL.VOLUME_USED:4
;EXTRUDER_TRAIN.0.MATERIAL.GUID:506c9f0d-e3aa-4bd4-b2d2-23e2425b1aa9
;EXTRUDER_TRAIN.0.NOZZLE.DIAMETER:0.4
;EXTRUDER_TRAIN.0.NOZZLE.NAME:AA 0.4
;BUILD_PLATE.INITIAL_TEMPERATURE:60
;BUILD_VOLUME.TEMPERATURE:28
;PRINT.TIME:25
;PRINT.GROUPS:1
;PRINT.SIZE.MIN.X:163.742
;PRINT.SIZE.MIN.Y:118.773
;PRINT.SIZE.MIN.Z:0.2
;PRINT.SIZE.MAX.X:166.258
;PRINT.SIZE.MAX.Y:120.951
;PRINT.SIZE.MAX.Z:2.6
;SLICE_UUID:654ab64d-22f9-4e0b-862d-346379b112bf
;END_OF_HEADER
;Generated with Cura_SteamEngine 5.2.1
T0
M82 ;absolute extrusion mode

G92 E0
M109 S200
G280 S1
G0 Z20.001
G1 F2700 E-6.5

;LAYER_COUNT:19
```

Note that comment lines start with semicolons. In CNC g-code comment lines are typically ignored by the machine, but with 3D printers they can provide configuration data.

The file starts with a header section and some initial g-code commands.

Following is g-code for the **first 2 layers**, specified as **LAYER:0** and then **LAYER:1**

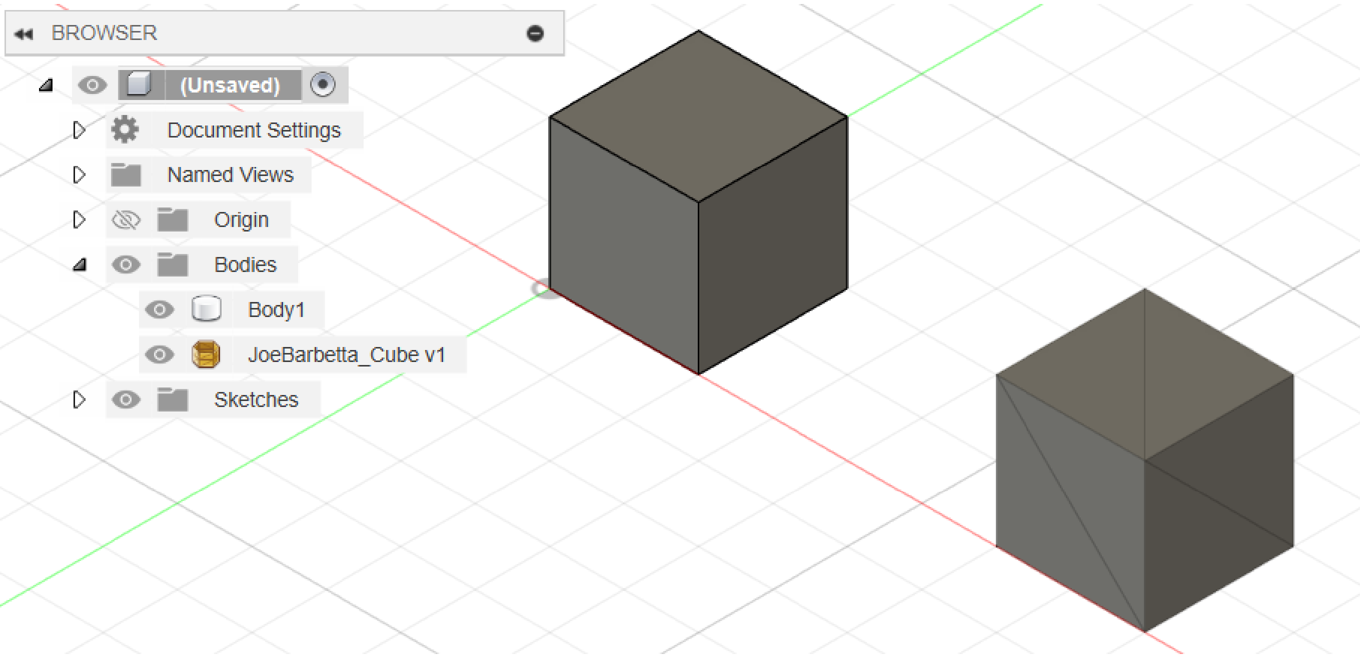
```
;LAYER:0
M107
M204 S1000
M205 X20 Y20
G1 F600 Z2.2
;MESH:Tetrahedron_1mm.stl
G0 F1285.7 X163.742 Y118.773 Z2.2
;TYPE:WALL-OUTER
G1 F600 Z0.2
G1 F2700 E0
G1 F600 X165 Y120.951 E0.03785
G1 X166.258 Y118.773 E0.0757
G1 X165 Y118.773 E0.09463
G1 X163.742 Y118.773 E0.11356
G0 F1285.7 X163.842 Y118.946
G0 X164.579 Y119.256
;TYPE:WALL-INNER
G1 F591.9 X165 Y119.985 E0.12639
G1 X165.421 Y119.256 E0.13921
G1 X165 Y119.256 E0.14563
G1 X164.579 Y119.256 E0.15204
M204 S1250
G0 F1285.7 X164.728 Y119.341
;MESH:NONMESH
G0 F600 X164.728 Y119.341 Z0.35
G0 F1285.7 X164.803 Y119.39
G0 X164.105 Y118.982
G0 X163.78 Y118.796
;TIME_ELAPSED:11.898470

;LAYER:1
M106 S85
;TYPE:WALL-OUTER
;MESH:Tetrahedron_1mm.stl
G1 F300 X165 Y120.908 E0.17498
G1 X165.609 Y119.852 E0.18645
G1 X166.22 Y118.796 E0.19792
G1 X163.78 Y118.796 E0.22087
G0 F5142.9 X163.88 Y118.969
G0 X164.564 Y119.248
;TYPE:WALL-INNER
G1 F386.5 X165 Y120.004 E0.23122
G1 X165.218 Y119.626 E0.23639
G1 X165.436 Y119.248 E0.24156
G1 X164.564 Y119.248 E0.25189
M204 S1500
;MESH:NONMESH
G0 F600 X164.564 Y119.248 Z0.5
G0 F5142.9 X163.872 Y118.848
;TIME_ELAPSED:13.919215
```

Here is the remainder of the g-code, which includes **LAYER:2** and the final layer, **LAYER:16**. Followed by some final g-code and comments that may be used for settings as well. Sections for layers 3 to 15 were removed.

```
;LAYER:2
M106 S170
;TYPE:WALL-OUTER
;MESH:Tetrahedron_1mm.stl
G1 F300 X165 Y120.801 E0.2731
G1 X165.563 Y119.824 E0.28371
G1 X166.127 Y118.848 E0.29431
G1 X163.872 Y118.848 E0.31552
G0 F9000 X163.972 Y119.021
G0 X164.609 Y119.273
;TYPE:WALL-INNER
G1 F513.9 X165 Y119.951 E0.32382
G1 X165.195 Y119.612 E0.32797
G1 X165.391 Y119.273 E0.33212
G1 X164.609 Y119.273 E0.34041
;MESH:NONMESH
G0 F600 X164.609 Y119.273 Z0.65
G0 F9000 X163.964 Y118.901
;TIME_ELAPSED:15.687770


;Layers 3 to 15


;LAYER:16
;TYPE:WALL-OUTER
;MESH:Tetrahedron_1mm.stl
G1 F358.2 X164.952 Y119.503 E0.73869
G1 X165.014 Y119.467 E0.73926
;TIME_ELAPSED:25.088293
G1 F2700 E-5.76074
M204 S3000
M107

M82 ;absolute extrusion mode
M104 S0
M104 T1 S0
;End of Gcode
;SETTING_3 {"global_quality": "[general]\\nversion = 4\\nname = Normal #2\\ndefi
;SETTING_3 nition = ultimaker_s5\\n\\n[metadata]\\ntype = quality_changes\\nqual
;SETTING_3 ity_type = fast\\nsetting_version = 20\\n\\n[values]\\nadhesion_extru
;SETTING_3 der_nr = 0\\nadhesion_type = none\\n\\n", "extruder_quality": ["[gene
;SETTING_3 ral]\\nversion = 4\\nname = Normal #2\\ndefinition = ultimaker_s5\\n\
;SETTING_3 \n[metadata]\\ntype = quality_changes\\nquality_type = fast\\nsetting
;SETTING_3 _version = 20\\nposition = 0\\n\\n[values]\\nbrim_gap = 0.24\\nbrim_l
;SETTING_3 ine_count = 12\\nxy_offset = 0\\n\\n", "[general]\\nversion = 4\\nnam
;SETTING_3 e = Normal #2\\ndefinition = ultimaker_s5\\n\\n[metadata]\\ntype = qu
;SETTING_3 ality_changes\\nquality_type = fast\\nsetting_version = 20\\nposition
;SETTING_3  = 1\\n\\n[values]\\nbrim_gap = 0.25\\ninfill_line_distance = 2.0\\n\
;SETTING_3 \n"]}
```

STL File for a Cube

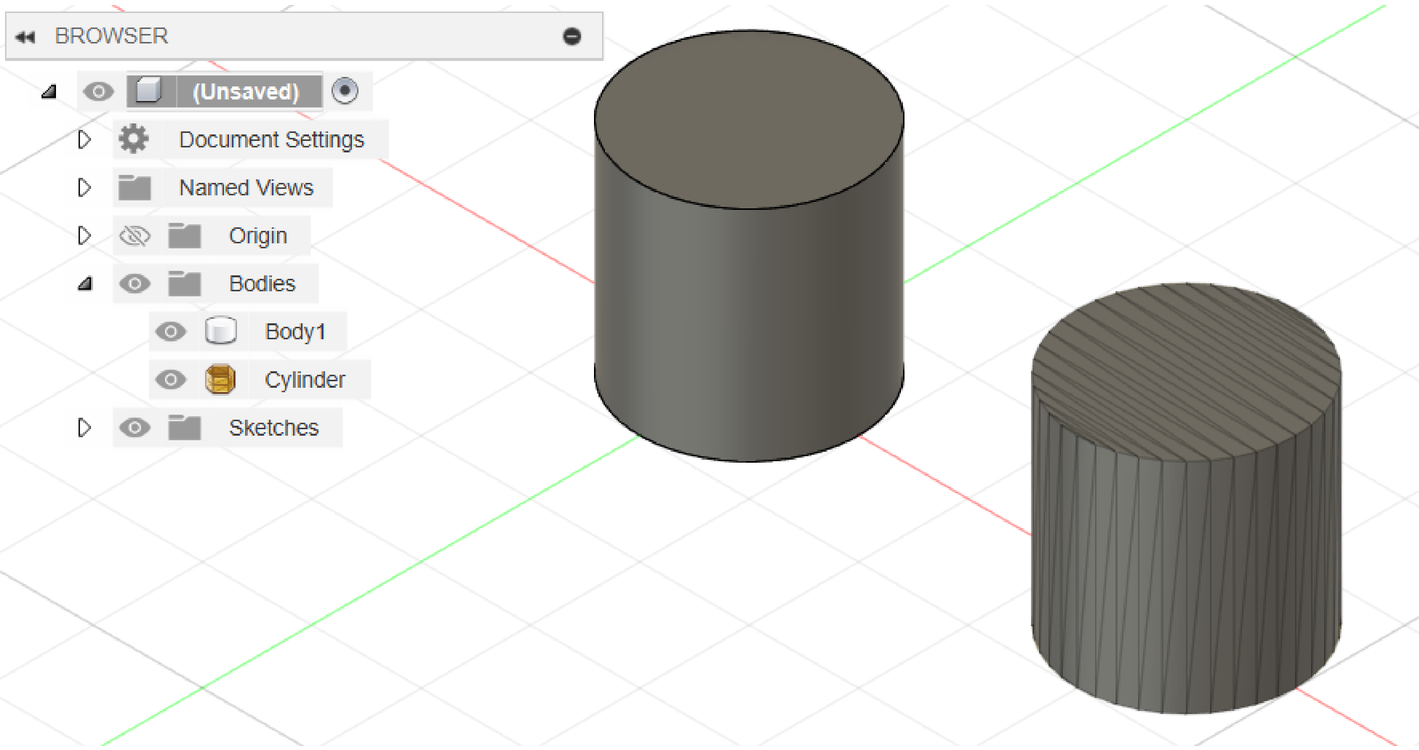
Here is a 1mm cube and the resultant STL file. Note that there are **12 triangles** needed to represent the object.




```
solid ASCII

  facet normal 0.000000e+00 1.000000e+00 -0.000000e+00
    outer loop
      vertex   1.000000e+00 1.000000e+00 0.000000e+00
      vertex   0.000000e+00 1.000000e+00 0.000000e+00
      vertex   1.000000e+00 1.000000e+00 1.000000e+00
    endloop
  endfacet

  facet normal 0.000000e+00 1.000000e+00 0.000000e+00
    outer loop
      vertex   1.000000e+00 1.000000e+00 1.000000e+00
      vertex   0.000000e+00 1.000000e+00 0.000000e+00
      vertex   0.000000e+00 1.000000e+00 1.000000e+00
    endloop
  endfacet

  facet normal 1.000000e+00 0.000000e+00 0.000000e+00
    outer loop
      vertex   1.000000e+00 0.000000e+00 0.000000e+00
      vertex   1.000000e+00 1.000000e+00 0.000000e+00
      vertex   1.000000e+00 0.000000e+00 1.000000e+00
    endloop
  endfacet

  facet normal 1.000000e+00 -0.000000e+00 0.000000e+00
    outer loop
      vertex   1.000000e+00 0.000000e+00 1.000000e+00
      vertex   1.000000e+00 1.000000e+00 0.000000e+00
      vertex   1.000000e+00 1.000000e+00 1.000000e+00
    endloop
  endfacet

  facet normal 0.000000e+00 -1.000000e+00 0.000000e+00
    outer loop
      vertex   0.000000e+00 0.000000e+00 0.000000e+00
      vertex   1.000000e+00 0.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 1.000000e+00
    endloop
  endfacet

  facet normal 0.000000e+00 -1.000000e+00 0.000000e+00
    outer loop
      vertex   0.000000e+00 0.000000e+00 1.000000e+00
      vertex   1.000000e+00 0.000000e+00 0.000000e+00
      vertex   1.000000e+00 0.000000e+00 1.000000e+00
    endloop
  endfacet

  facet normal -1.000000e+00 0.000000e+00 0.000000e+00
    outer loop
      vertex   0.000000e+00 1.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 0.000000e+00
      vertex   0.000000e+00 1.000000e+00 1.000000e+00
    endloop
  endfacet

  facet normal -1.000000e+00 -0.000000e+00 0.000000e+00
    outer loop
      vertex   0.000000e+00 1.000000e+00 1.000000e+00
      vertex   0.000000e+00 0.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 1.000000e+00
    endloop
  endfacet

  facet normal 0.000000e+00 0.000000e+00 1.000000e+00
    outer loop
      vertex   0.000000e+00 0.000000e+00 1.000000e+00
      vertex   1.000000e+00 0.000000e+00 1.000000e+00
      vertex   0.000000e+00 1.000000e+00 1.000000e+00
    endloop
  endfacet

  facet normal -0.000000e+00 0.000000e+00 1.000000e+00
    outer loop
      vertex   0.000000e+00 1.000000e+00 1.000000e+00
      vertex   1.000000e+00 0.000000e+00 1.000000e+00
      vertex   1.000000e+00 1.000000e+00 1.000000e+00
    endloop
  endfacet

  facet normal 0.000000e+00 0.000000e+00 -1.000000e+00
    outer loop
      vertex   0.000000e+00 1.000000e+00 0.000000e+00
      vertex   1.000000e+00 1.000000e+00 0.000000e+00
      vertex   0.000000e+00 0.000000e+00 0.000000e+00
    endloop
  endfacet

  facet normal 0.000000e+00 0.000000e+00 -1.000000e+00
    outer loop
      vertex   0.000000e+00 0.000000e+00 0.000000e+00
      vertex   1.000000e+00 1.000000e+00 0.000000e+00
      vertex   1.000000e+00 0.000000e+00 0.000000e+00
    endloop
  endfacet

endsolid
```

STL File for a Cylinder

Here is a 1mm diameter **cylinder** with a height of 1mm and the resultant STL file. Fusion generated a STL file with 156 triangles to ***approximately*** represent the object. This was the result of using Fusion's default **Refinement settings**, which can be adjusted to more accurately representing the object by using more triangles. Increasing the accuracy results in a larger file, however, as storage, such as a hard drive, solid state drive, USB drives, etc., becomes cheaper, this has become less of an issue.




```
solid ASCII
  facet normal -9.969173e-01 7.845910e-02 0.000000e+00
    outer loop
      vertex   -4.938442e-01 7.821723e-02 1.000000e+00
      vertex   -4.938442e-01 7.821723e-02 0.000000e+00
      vertex   -5.000000e-01 -6.123234e-17 1.000000e+00
    endloop
  endfacet
  facet normal -9.969173e-01 7.845910e-02 0.000000e+00
    outer loop
      vertex   -5.000000e-01 -6.123234e-17 1.000000e+00
      vertex   -4.938442e-01 7.821723e-02 0.000000e+00
      vertex   -5.000000e-01 -6.123234e-17 0.000000e+00
    endloop
  endfacet
  facet normal -9.969173e-01 -7.845910e-02 -0.000000e+00
    outer loop
      vertex   -5.000000e-01 -6.123234e-17 1.000000e+00
      vertex   -5.000000e-01 -6.123234e-17 0.000000e+00
      vertex   -4.938442e-01 -7.821723e-02 1.000000e+00
    endloop
  endfacet
  facet normal -9.969173e-01 -7.845910e-02 -0.000000e+00
    outer loop
      vertex   -4.938442e-01 -7.821723e-02 1.000000e+00
      vertex   -5.000000e-01 -6.123234e-17 0.000000e+00
      vertex   -4.938442e-01 -7.821723e-02 0.000000e+00
    endloop
  endfacet
```

152 more triangles

Deliverables

- After creating your tetrahedron, creating the .STL file, and opening the .STL in Notepad, follow the instructions in the section titled “Your turn to use the Measure tool”. Save the Google doc as a .pdf file and upload this .pdf file to Schoology.