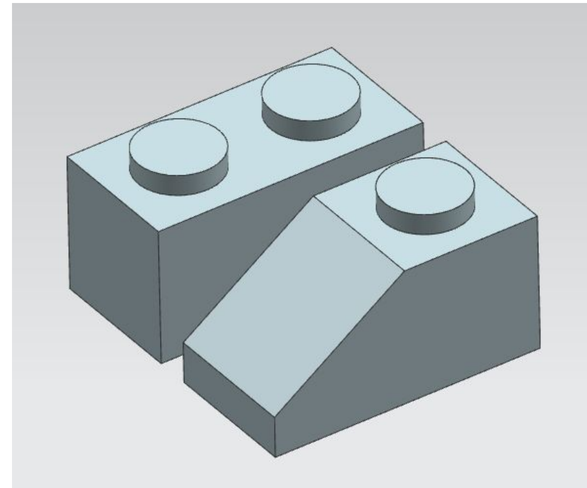
Cindy Zhang
DSGN 345
Final Project

# DSGN 345 Final Project: CAM w/ NX to make Legos

## Introduction

My intent for this project was to manufacture 2 lego blocks that would fit together. I chose to make a lego block because I wanted the base (that would be in the vice) to look like it was part of the product, rather than a static model on a square metal base. I chose to make 2 blocks so that the product would have some kind of functionality, and also to have a feel for the tolerances of a CAM process. I modeled a 1x2 "slope" lego block in NX to meet the surface milling requirements of the project, as well as a 1x2 brick, as pictured to the right.

I'll refer to the bosses on top as "studs" and the holes on the bottom as "tubes" (which seems to be the most commonly used Lego feature terminology I can find). For simplicity, the tubes of each brick were modeled as simple rectangular cavities with a depth matching the height of the studs, and fillets of radius 5/32" (to match my preference of wanting to use the lesser used 5/16ths inch diameter tool).



*models of "brick" and "slope" lego blocks to be manufactured*

## Manufacturing Program

Each block was to be milled on both top and bottom faces, totalling up to 4 programs. The entire process used only 3 tools - a ⅝ths inch diameter ball mill (BM0.625), a ½ inch diameter end mill (EM0.5), and a 5/16ths inch diameter end mill (EM0.3125).

The slope piece required special attention when designing the setup of the program -- the sloped surface itself was too close to the bottom of the part to allow for safe mounting of the part to the machine. Therefore, my initial approach was to put in a stock that was about 0.5 in taller than the final workpiece, mill the top geometry, then cut off the excess bottom material before milling out the bottom tubes. The brick piece did not require the extra manual work, and therefore was programmed simply with a stock close to the size of the final part. Later in the process, I realized it was easier to program the extra height of the stock for the slope part into my manufacturing program, rather than attempt to saw it off, and the proper adjustments were made to the program.

The following details each program and explains the choices made for each operation. Each program was created on a different mill MCS to reflect the new orientations.

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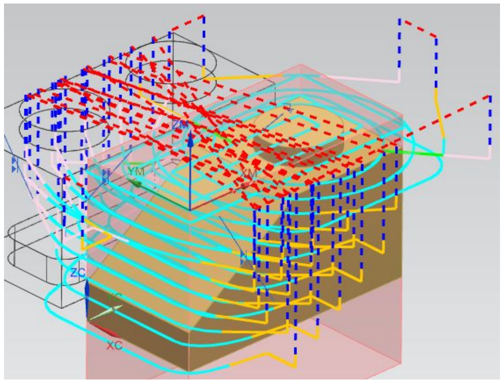
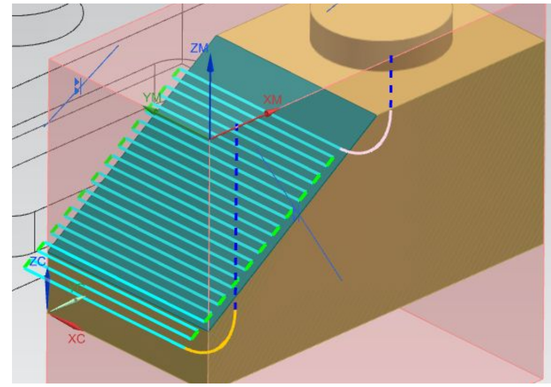
*Slope Top*

1 - <u>Cavity Mill</u> - removes bulk material (with depth) from top of stock



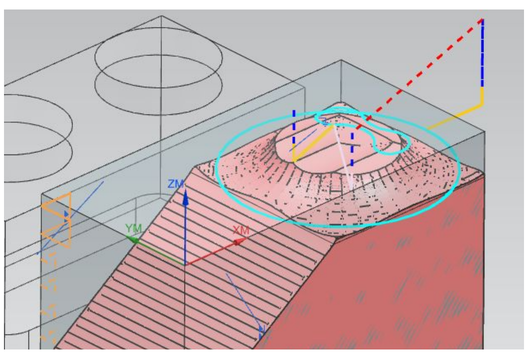

<u>*tool*</u>: ***BM0.625***, large tool for removing bulk material
<u>*method*</u>: ***semi-finish***, to prepare for surface milling during next step. (The tool is large enough such that I decided to go without a roughing pass with it because it felt redundant, since I'd want a semi-finish before my surface milling operation).
<u>*feeds & speeds*</u>: 15ipm, 2500rpm

2 - <u>Surface Mill (Contour Area)</u> - creates a nice non-perpendicular surface



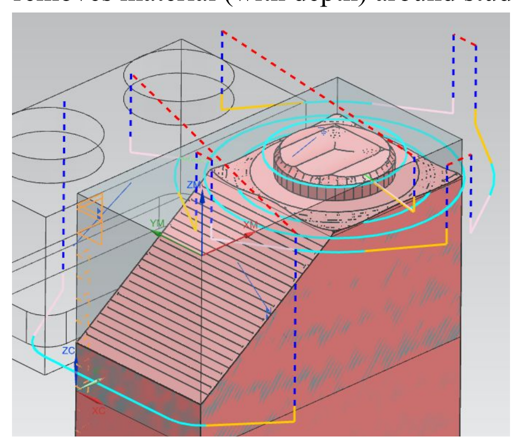

<u>*tool*</u>: ***BM0.625***, large tool for quicker surface milling
<u>*method*</u>: ***finish***, to achieve the necessary dimensions of the desired surface (the final pass for this slanted surface)
<u>*feeds & speeds*</u>: 15ipm, 2500rpm
<u>*misc:*</u> cut area selected (in turquoise), stepover by max scallop height of 0.001in applied on part, to increase the quality of the surface milling

3 - <u>Cavity Mill</u> - removes material (with depth) around stud before the final pass




<u>*tool*</u>: ***EM0.5***, large end mill for quick removal of material before final pass
<u>*method*</u>: ***rough***, to remove material quickly -- part is not ready for a final pass yet, also new tool and remaining stock has lots scallops left over from previous ball mill
<u>*feeds & speeds*</u>: 13 ipm, 3000 rpm
<u>*misc:*</u> follow part, to save time

4 - <u>Cavity Mill</u> - removes material (with depth) around stud as a final pass



<u>*tool*</u>: ***EM0.5***, end mill to achieve desired flat surface, large enough diameter to do the job for efficiency
<u>*method*</u>: ***finish***, final pass of the program
<u>*feeds & speeds*</u>: 13 ipm, 3000 rpm

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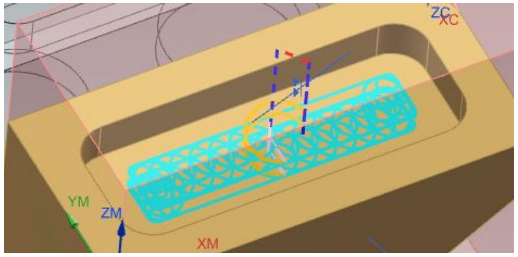
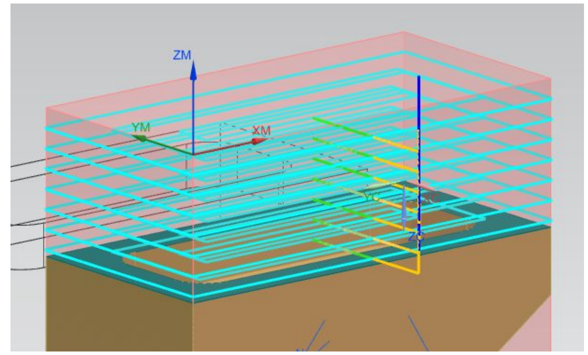
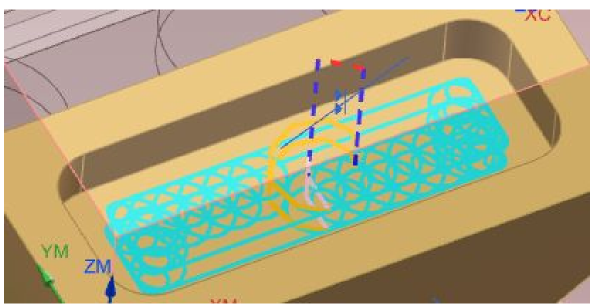
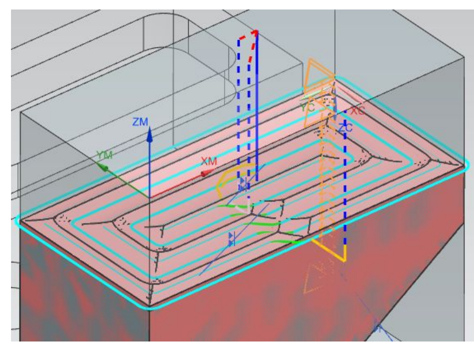
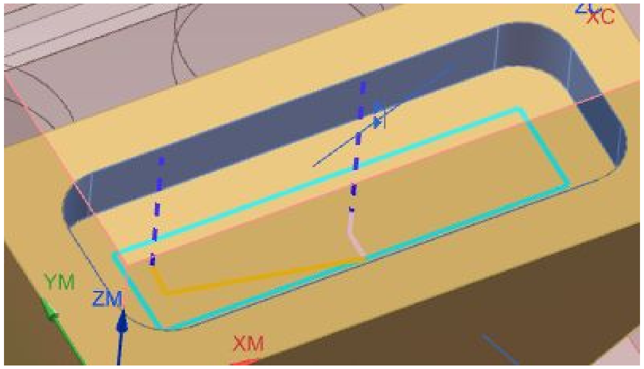
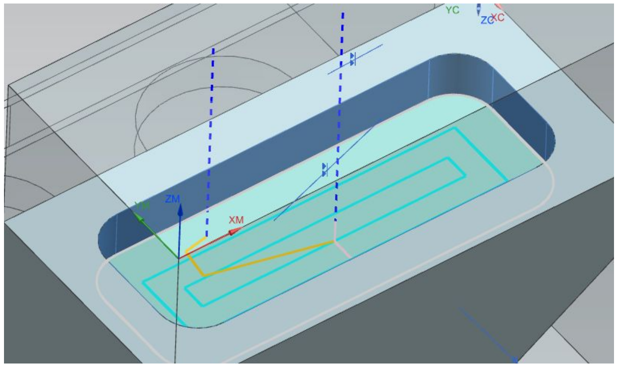
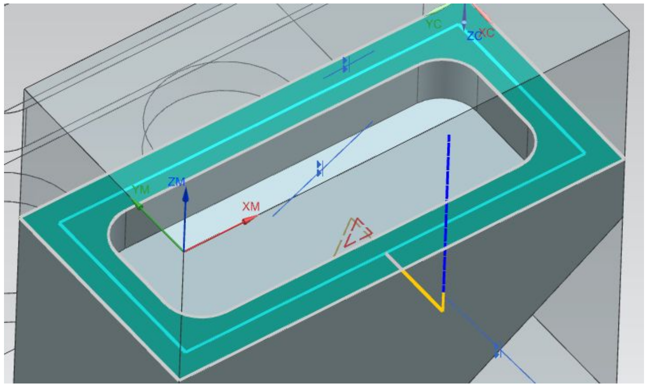
*Slope Bottom (Original + New changes)*

| **Old Operation Specs** | **New Operation Specs** |
|---|---|
| 1 - Cavity Mill | |
| <br><br>*purpose*: initial cut into tube cavity<br>*tool*: ***EM0.3125***, I knew the pass would have to be trochoidal going into the cavity, so a smaller (than the existing EM0.5) tool made more sense. 0.3125 to match fillet radius, and EM rather than BM due to the cavity's perpendicular floor and walls.<br>*method*: ***rough***, to remove material quickly, and as first operation of the program<br>*feeds & speeds*: 13 ipm, 4000 rpm<br>*misc*: trochoidal to avoid full width cuts | <br><br>*purpose*: remove bulk material of added stock<br>*tool*: ***BM0.625***, largest tool to remove bulk material from remaining stock<br>*method*: ***rough***, to remove material quickly, and as first operation of the program<br>*feeds & speeds*: 15ipm, 2500rpm<br>*misc*: floor cut area was selected to avoid full width cuts into the cavity |
| 2 - Cavity Mill | |
| <br><br>*purpose:* clean up tube cavity material left from previous operation<br>*tool*: ***EM0.3125***, matches fillet radius and finishes the previous operation of the same tool<br>*method*: ***finish***, to clean any material left from previous roughing<br>*feeds & speeds*: 13 ipm, 4000 rpm<br>*misc*: trochoidal to avoid full width cuts | <br><br>*purpose:* rough operation of tube cavity<br>*tool*: ***EM0.3125***, matches fillet radius<br>*method*: ***rough***, first pass into the cavity<br>*feeds & speeds*: 13 ipm, 4000 rpm<br>*misc*: trochoidal to avoid full width cuts |

<table>
<tr><td colspan="2">3 - <u>Floor/Wall</u></td></tr>
<tr><td>


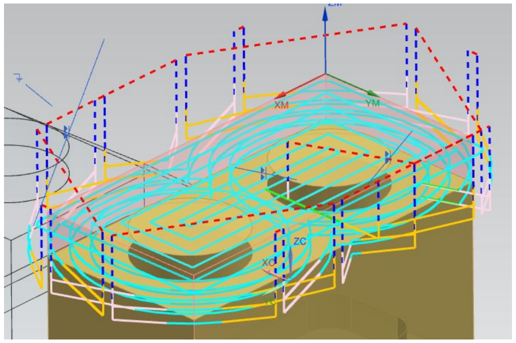

<u>purpose</u>: finishing pass to clean up fillet/corners left by previous operations<br>
<u>tool</u>: EM0.3125, matches fillet radius<br>
<u>method</u>: finish, final operation<br>
<u>feeds & speeds</u>: 13 ipm, 4000 rpm<br>
<u>misc</u>: wall geometry specified (dark blue areas in picture)
</td><td>



<u>purpose</u>: finishing pass to clean up floors/wall/corner material left from previous operation<br>
<u>tool</u>: EM0.3125, matches fillet radius<br>
<u>method</u>: finish, final operation for tubes<br>
<u>feeds & speeds</u>: 13 ipm, 4000 rpm<br>
<u>misc</u>: wall geometry specified (dark blue areas in picture)
</td></tr>
<tr><td colspan="2">4 - <u>Floor/Wall</u> - to finish up the top surface left over by the previous roughing operation</td></tr>
<tr><td>N/A</td><td>



<u>tool</u>: EM0.3125, flat end mill for flat finished surface<br>
<u>method</u>: finish, final operation<br>
<u>feeds & speeds</u>: 13 ipm, 4000 rpm<br>
<u>misc</u>: floor geometry specified (turquoise areas in picture)
</td></tr>
</table>

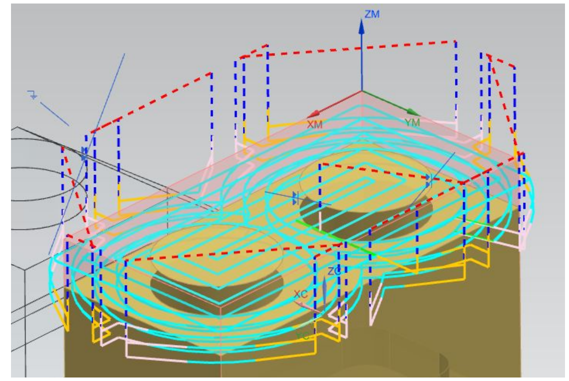
*Brick Top*

1 - <u>Cavity Mill</u> - removes material (with depth) around studs before the final pass



*<u>tool</u>*: ***EM0.3125***, end mill to match flat & perpendicular geometries of final part
*<u>method</u>*: ***rough***, to remove material quickly as first pass
*<u>feeds & speeds</u>*: 13 ipm, 3000 rpm

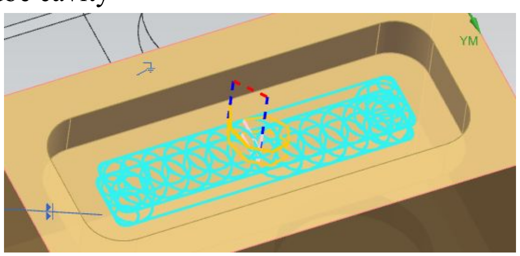
2 - <u>Cavity Mill</u> - finishes off material removal (with depth) around the studs



*<u>tool</u>*: ***EM0.3125***, end mill to match flat & perpendicular geometries of final part
*<u>method</u>*: ***finish***, final pass, clean up material leftover from previous roughing
*<u>feeds & speeds</u>*: 13 ipm, 4000 rpm

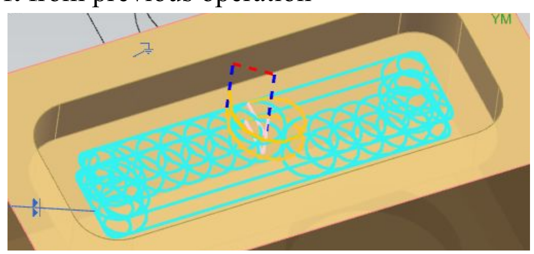
*Brick Bottom*

1 - <u>Cavity Mill</u> - removes initial material (with depth) into tube cavity



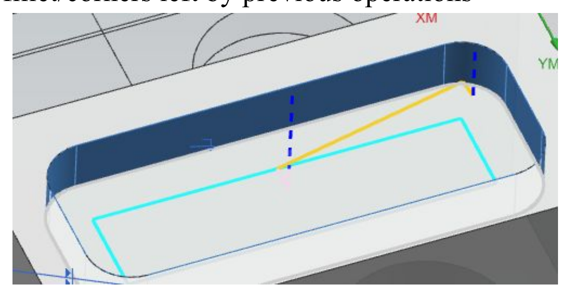
*<u>tool</u>*: ***EM0.3125***, I knew the pass would have to be trochoidal going into the cavity, so a smaller (than the existing EM0.5) tool made more sense. 0.3125 to match fillet radius, and EM rather than BM due to the cavity's perpendicular floor and walls.
*<u>method</u>*: ***rough***, to remove material quickly, and as first operation of the program
*<u>feeds & speeds</u>*: 13 ipm, 4000 rpm
*<u>misc</u>*: trochoidal to avoid full width cuts

2 - <u>Cavity Mill</u> - clean up tube cavity material left from previous operation



*<u>tool</u>*: ***EM0.3125***, matches fillet radius and finishes the previous operation of the same tool
*<u>method</u>*: ***finish***, to clean any material left from previous roughing
*<u>feeds & speeds</u>*: 13 ipm, 4000 rpm
*<u>misc</u>*: trochoidal to avoid full width cuts

3 - <u>Floor/Wall</u> - finishing pass to clean up fillet/corners left by previous operations



*<u>tool</u>*: ***EM0.3125***, matches fillet radius
*<u>method</u>*: ***finish***, final operation
*<u>feeds & speeds</u>*: 13 ipm, 4000 rpm
*<u>misc</u>*: wall geometry specified (blue in picture)

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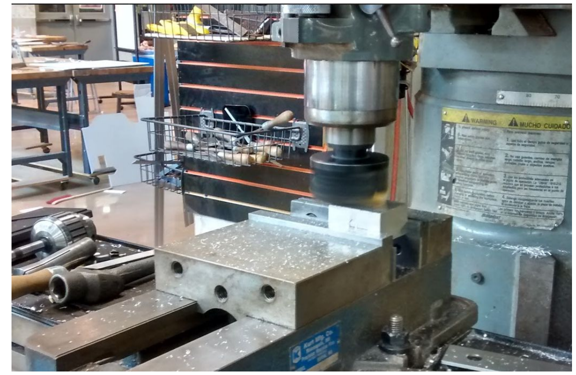
**Manufacturing Process**

*Stock preparation*

About 6 hours (over half) of the time spent manufacturing this project was spent on preparing the stock material.
The two stocks (1 x 2 x 1.97in[1] and 1 x 2 x 1.25in) were prepared with the horizontal bandsaw, vertical bandsaw, and manual mill. They were cut from a 4 x 4 in block, fly cut to proper dimensions, and finished with an endmill to square the faces.



*preparing the stock material for my "slope" block on the manual mill*

*CNC Manufacturing*

All 4 programs ran with the same tool set, so the tools were put into the toolholders only once. Each of the 4 setups required a repeated process of edgefinding and setting the z-values of each tool. For efficiency, I only set the z-values for the tools used in the current operation. (For example, the slope and brick bottom operations only use EM0.3125, tool #3, so I only set the z-value for that one tool).

*setup of "brick bottom"*

After properly mounting on parallels, edgefinding, find setting z-values, the program was run on single block mode (30% feed, 5% rapid) until I was sure things were correctly aligned. Then, each of the programs were run at full feed and rapid speeds. The one exception to this was the "slope bottom" program, which I ran at 80% feed as a precaution to how the part was mounted at a smaller area than the cut area (due to the geometry of the slope).

During the manufacturing process, two issues occurred.

[1] the arbitrary dimension for the height of the stock for the slope block is due the the fact that I planned to saw off the bottom after the top was milled, so I did not aim for a specific dimension. It's purpose was to provide grip for proper mounting into the machine vice. 1.97 was the dimension measured before it was put into the machine for its first operation.

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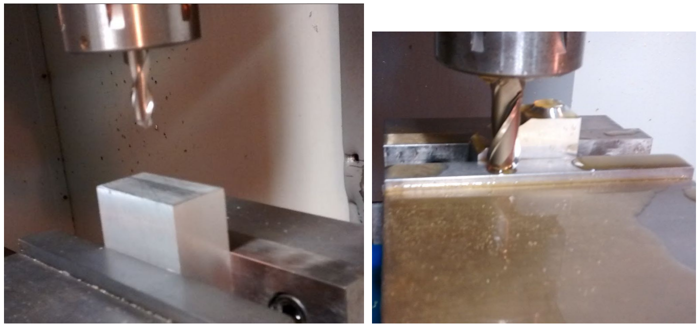
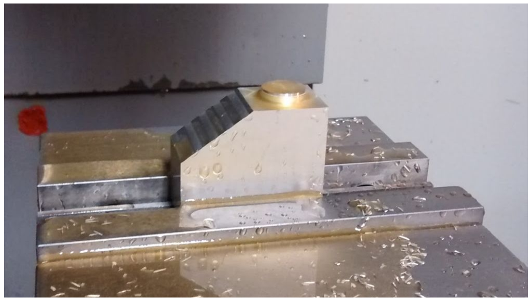
*Issue: tool running into vice*

For my slope top program, I had accounted for the fact that I would need to mount my stock high enough so that the tool would not collide with the vice -- I did so by adding a large margin (0.67in of material height) to the bottom of the stock for extra grip. However, I was careless when I placed the part into my vice by only eyeballing the height rather than measuring it. I misestimated the height, and had to stop the program midway when the tool approached the vice to finish the initial cavity milling of my sloped surface. (I was aware of the chance that I may have misestimated after the program had started, so I watched carefully at the tool path and was able to stop the program as soon as I realized the tool was going to hit the vice).



*setup of "slope top" before it started & where I stopped the program after it approached the vice*

To fix this issue, I reset the program, removed the part, and raised it to a higher parallel. I took the height difference of the parallels that I swapped and added it to each of my tool z-values, because the stock's top surface was no longer existent. For the edges, the x value was found using the opposite face of my stock, as the edge corresponding to x=0 was also gone. The width of the stock was subtracted from the new x-value to estimate the 0 position for x. The y-edge was found as usual. Then, I ran the program from the beginning, and visually confirmed that the edges and tool height was accurate. When the surface milling began and noise was heard, I knew that the adjustments were successful.



*finished "slope top" operation after the fix*

*Issue: coolant concentration*

Throughout all my programs, the coolant pressure seemed to constantly decrease, until the final program ran and the coolant would not come out. It turns out the coolant inside the machine was too concentrated and was clogged, so Maddie and Scott helped me refill the machine with water to dilute the coolant. In the future, I can spot concentrated coolant by looking at the color, which had a strong orange tint, rather than a "milky" appearance.

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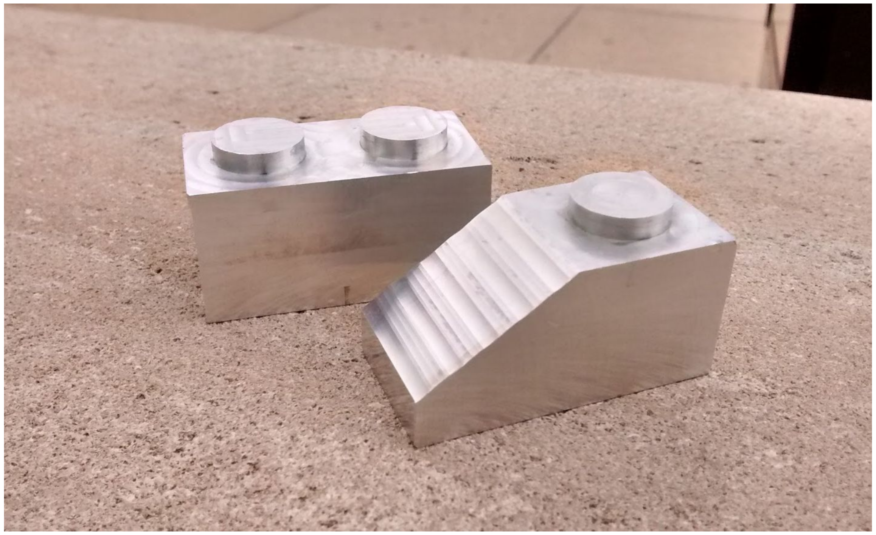
**Final Results and Observations**



*final manufactured parts*

*Fit*
The final manufactured parts were beyond my expectations when it came to fit -- there is a satisfying suction feel when the parts are stacked together, which shows me that the CNC machine may be capable of making the legos with a tighter fit had I designed it to be so.

*Surface Mill*
The final surface finish of the surface milling was below my expectations -- there are obvious ridges and scallops that were present. This was probably due to the issue I had with mounting the part, because it resulted in me needing to reset the z-values of the tools with estimates before the surface milling began. I believe the scallops are due to the fact that my estimate for the difference in heights of the parallels were only to the order of hundredths of an inch, whereas the machine operated in ten thousandths of an inch. Had I ran the program in one go with the proper edges found and z-values set, I'd expect a smoother surface finish from the operation.

*Surface Finish - aesthetics*
On the top surfaces of each part, you can see the paths the tool made during it's final pass. This gives way to a confusing aesthetic when it comes to looking at the blocks, because it's hard to perceive the geometry and depth of the part. In industry, the part could be anodized (among other processes) to achieve a better aesthetic finish. It was also suggested that I use ScotchBrite to polish the surface, which I might consider in the future.

**Conclusions/Final Remarks**
I'd love to be able to model a more accurate representation of the Lego block tubes in the future, in hopes that I might be able to get locking aluminum blocks with the right tolerances. (However, it was pointed out to me the elasticity of the aluminum compared to the plastic of normal Legos might need to be considered). All in all, this project resulted in a product that's a lot of fun to play around with and even has allowed me to introduce CAM to non-engineering friends. With 4 CNC machine setups and 6 hrs of stock prep, I feel a lot more confident using the CNC machine as well as other manual skills as a result of this project.