Making Math

Developing Student Mathematicians

Now that students have a range of sketching skills, it is time to combine them with extrusion in more complicated multi-step efforts. This section of the CAD unit includes two projects: the highly structured Lego-Style Brick activity and the Initials Cube Project. Both should be done by you ahead of time to see where any tricky parts arise.

As you prepare for the upcoming more advanced 3D tools, you can watch any of these short tutorials and try using the demonstrated tools:

Sketching Basics: Lines and Rectangles, Circles and Arcs (no sound), polygons, and Trim and Extend.

Filleting and Chamfering: https://learn.onshape.com/learn/course/fundamentals-part-design-using-part-studios/creating-basic-part-features/fillet-and-chamfer

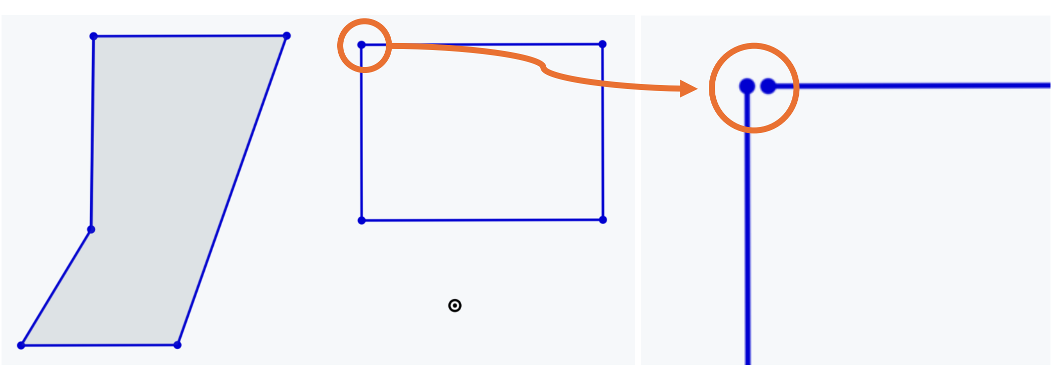
Extruding: https://learn.onshape.com/learn/course/fundamentals-part-design-using-part-studios/creating-basic-part-features/extrude

Revolving: https://learn.onshape.com/learn/course/fundamentals-part-design-using-part-studios/creating-basic-part-features/revolve

More advanced features include sweeps (like an extrude but along a more complicated path than a segment) and lofts (which benefit from understanding reference planes and Extend and Split).

Extruding

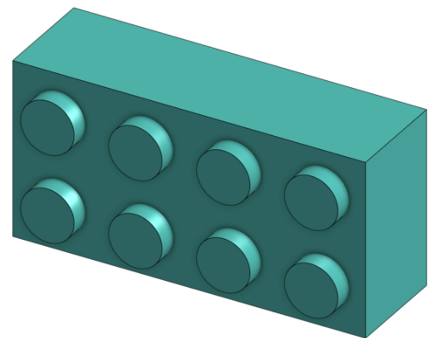
Tip – In order to extrude a sketch, you need closed figures with clear insides and outsides. Those insides and outsides can be nested. A figure with a gray interior can be extruded. Below, we see a convex pentagon that is fine as shown by its gray interior, but the rectangle, which looks fine, is not shaded and can't be extruded. This can happen when we think we have connected endpoints, but we haven't. With significant zooming in on the rectangle's upper left corner, we see that the figure was not completed. You can complete it using the coincident constraint or the extend tool.



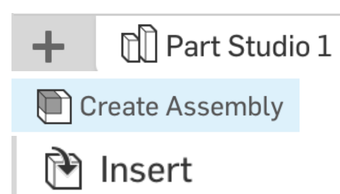
A Multi-step 3-D Shape

Activity 1: This activity requires one Lego-style 2x4 brick for each student. If you do not have access to any, you can get the generic version for about 1/8th the price as the name brand bricks (the only difference is that they don't say *Lego* on each bump). Distribute "The Lego-style Brick activity" handout and give students time to proceed through the steps. As with all tasks, students will work at different paces and need different levels of support as you move about the room. There are extensions listed on the third page for students who complete the main task sooner than others.

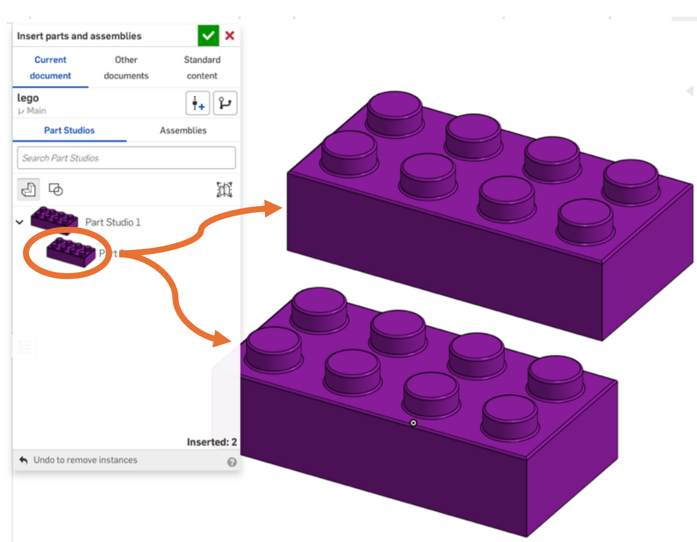
Assemblies and Interference



Activity 2: The point of building bricks is that they snap together to make different structures. Once students have completed their 2x4 brick parts, demonstrate for the class how to put copies of them together in an *assembly*. Assemblies allow either identical parts or different related parts of a more complicated design to be put together in one structure or device. Parts can be attached in a number of different ways called *mates*. Learning all of the ways to build an assembly is complicated and I will only address the simplest option, but OnShape has a course that can be worked through, with patience. The power of the other assembly options is that students can build one part at a time and then combine them in an assembly that even allows movements of parts within a device (e.g., a button that pushes, pieces that slide in grooves, or gears that turn each other).



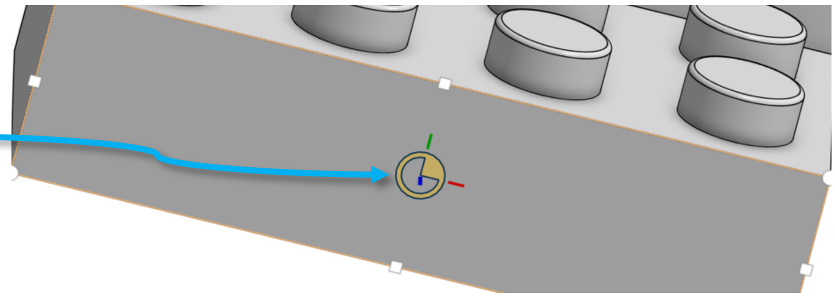
The following sequence of steps can be seen in action in the Assembly dem video. Instruct students to click the "Insert new tab" **+** symbol in the lower left corner and then choose Create Assembly. Once in the assembly window, click on Insert. A dialog box will appear that lists all parts tabs and the parts within each tab. For this project, students should only have one parts tab with one part. If a student 's brick has different color bumps or inner columns, then they used New and not Add when extruding these features. They should go back and edit that extrusion (double click on it in the features panel and choose Add). If they used New for the bumps, they will have 9 parts listed!



Everyone should drag two copies of their brick to the main assembly window from the insert panel and then click on the green check mark.

Next, they should click on the fastened mate 

and this window will appear:



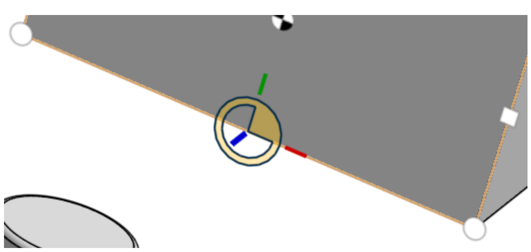
Now students should mouse over and click on the center of a longer side of the brick and the mate icon will appear.

This icon is like a bonding point, and it can be mated with a similar point on another part. When you add a mate, the part you clicked on will be listed in the Fastened mate window. Next, everyone should spin their view around 180° or so, so that they can add a mate in the middle of the long side of the other brick that is facing away from the first mated brick.

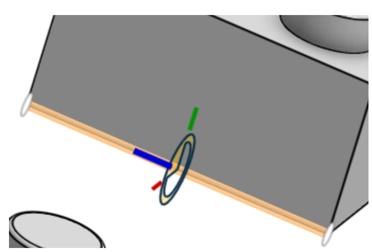
If that went well, clicking on and moving one brick should move both as if they were glued together on those surfaces. If, instead, the two bricks ended up superimposed in the same position, then the relationship between the mates can be adjusted using the Flip primary axis  and Reorient secondary axis buttons  in the mate window. One click of the first button will bring the brick outside, rather than inside, the other brick, but it may be upside down. Two clicks of the reorient button will rotate the brick around the axis perpendicular to the mates and then they will be joined together in the proper side-by-side way. Click on the green check to complete this mating.

Lastly, go back to Insert and add a third brick. We will stack this one, so choose Fastened mate again and click on a mate on the midpoint of a bottom edge of a short side of the third brick. The mate icon should be flat on the surface and not perpendicular to it.

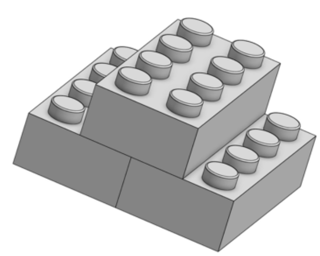
THIS



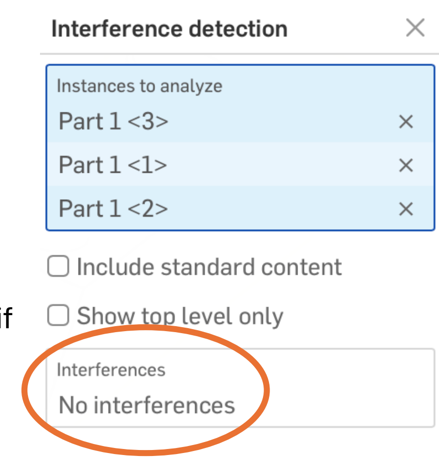
NOT THIS



Then click on the point where two top corners of the short sides of the brick pair meet (the video makes this clear, if my descriptions are not up to the challenge). This mate should be flat on the short sides and oriented in basically the same way as the one on the new brick. If all goes well, the stack should like the one at right. If not, click the undo arrow, watch the video, and try again. These steps take practice.

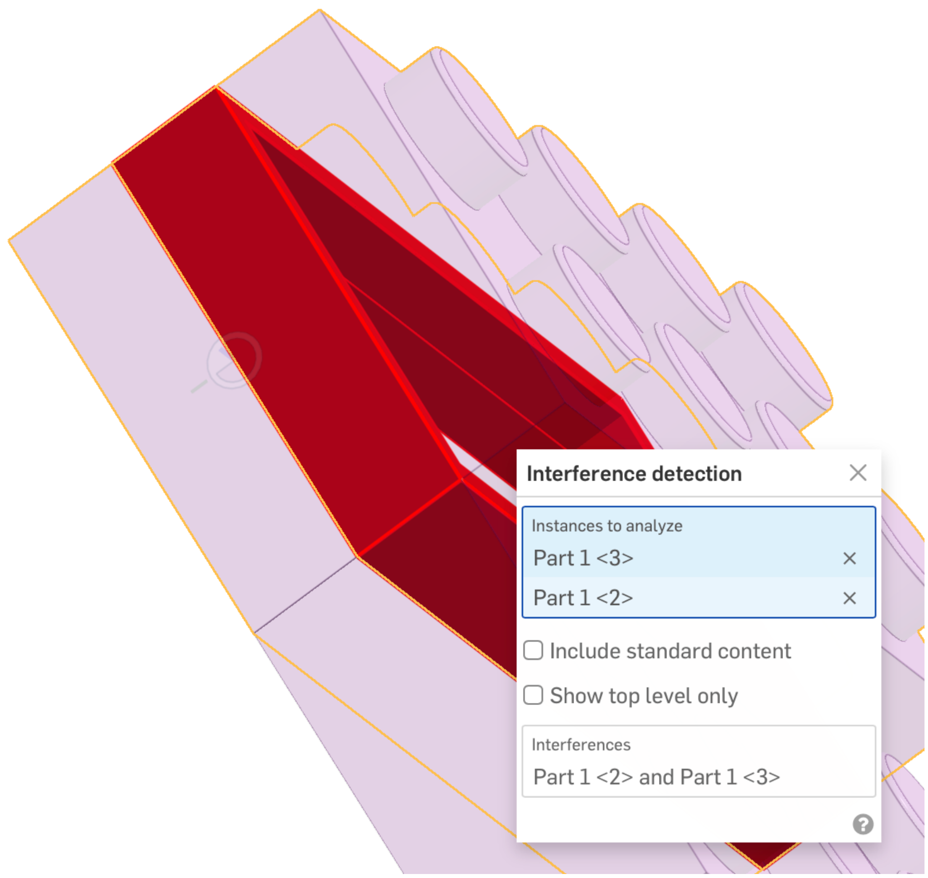


The final mating is easier if you don't fillet the edges of the brick as directed in step 12 of the handout. That step can be undone if the mate is proving too difficult by selecting that fillet in the features panel of the original part (go back to that tab) and choosing Suppress (you can Unsuppress it later, if you like).



Lastly, when we are building an assembly, we want to make sure the parts are not overlapping, since that means they won't actually fit together as pictured if we 3-D print them. Overlap is called interference. Everyone should click on the protractor symbol in the lower right-hand corner of the assembly window to get the analysis tools and choose "Inference detection…". Click on the parts in the assembly and the interference box will report in the Interferences box if there is any overlap.

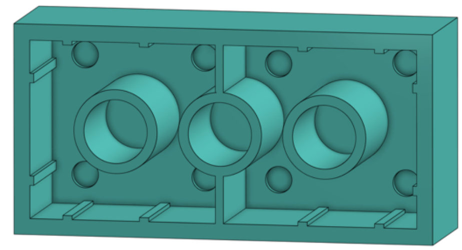
You can redo the third mate by x-ing out the second part in that mate and instead clicking on the middle of the face of one of the original two bricks. This choice will force the third brick to overlap. If you then check interferences, overlapping regions will be highlighted in red and the parts that are involved will be listed in the Interferences box as shown in the image below.



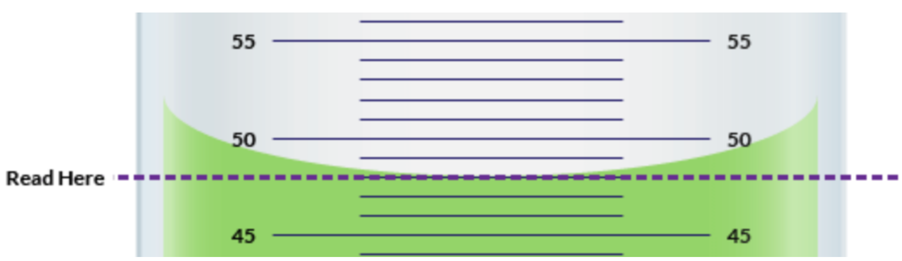
When students begin their own designs and assemblies, they will need to learn about other types of non-rigid mates. These more flexible mates, such as the often used Slider mate, have a Limits option that allows one to restrict how far the two parts can slide relative to each other. This is great, for example, with devices with physical buttons that can only go so far in or out.

Slider and other mates have a limit option so one piece can be allowed to slide back and forth in another but limited in a way that they not come apart.

Activity 3: The Brick Surface Area and Volume project is useful if you want to give the students practice measuring and calculating areas and volumes as well as figuring out how to break down a complex task into its sub-tasks. Distribute the Brick Surface Area and Volume handout and discuss how you want them to present and organize their work (handwritten or typed up, level of precisions, etc.). Students should include screen shots of their brick CAD from Activity 1. Sample images from a detailed student effort are shown at right that make it possible to see all surfaces (except for symmetrical duplication). For surface area, students can find the area of the rectangle on the top and that would account for the part of the rectangle around the bumps and the top of the bumps themselves. Alternatively, the top surface is a rectangle minus the area of 8 circles, and those same areas are added in for the surface area of the bumps. The orthographic top view helps students identify the simpler approach, but they can be left to figure out an accounting that works for themselves. In either case, they still need the surface area of the sides of the bumps (which are rectangles wrapped around the bumps with area $2\pi rh$).

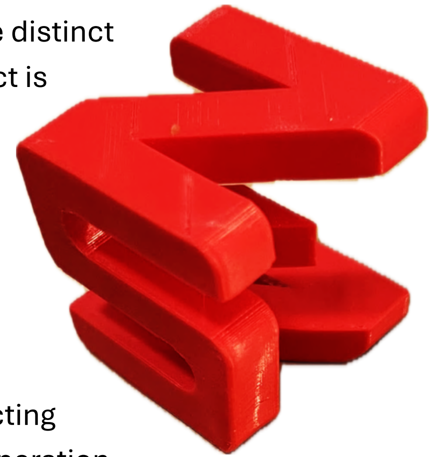


If you want, you can have the students check the reasonableness of their answers by doing a displacement measurement. You will need a couple of graduated cylinders (students will be ready to use them at different times, so you won't need a classroom set and you can probably borrow them from a science classroom). Have them fill the cylinder halfway and record the exact level of the meniscus (the bottom of the arc of the water as shown below), because that is how graduated cylinders are calibrated.



Next have them put in their 2x4 brick and shake it around a bit so any air bubbles escape. Record the new meniscus level and the difference is the volume in milliliters (ml). 1 milliliter is equal to one cubic centimeter (cm^3). How close are their calculations to the lab measurement?

The Initials Cube

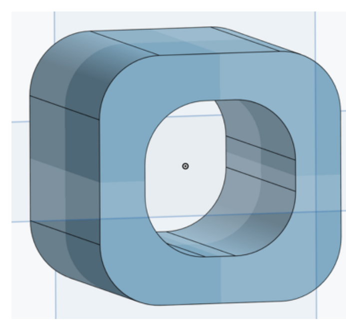


Activity 4: The Initials Cube Project involves making a shape with three distinct (unrelated, even) orthographic projections. Part of the fun of this project is that it shows that different views can be so different. An example of an initials cube is at right with the initials S, N, and E and you can download the posted example, which is an .stl file and you should be able to open it and rotate the image to see the initials B, I, and F.

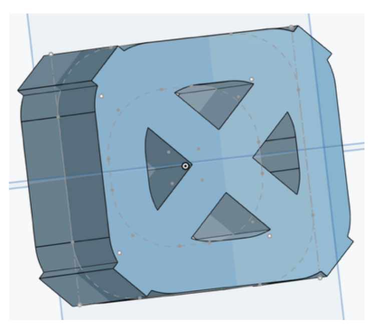
To make an initials cube, different letter outlines are made in three different directions (Top, Front, Right). When each of these is extruded using the Intersect setting, only points that are part of all three intersecting shapes are included (this is a geometric example of the Boolean *and* operation, which includes only elements that are in all of the sets that are being *and*ed). This video explains the New, Add, Subtract, and Intersect options. Add is equivalent to the Boolean operation *or*.

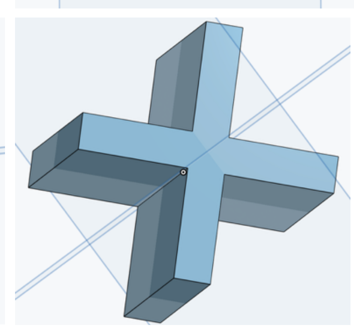
Initials cubes are great to share at a learning fair or evening event with parents using an overhead projector (if there is one in your building you can borrow). Put a cardboard box around three sides, so people cannot see the cube itself and then put the cube down on the projector and you will get great shadows (orthographic projections) of each view. Show all three and then say it is a single object with those shadows! Ask people to imagine what the shape could be and then show it to them.

Some letters don't work well together. Sometimes, making **thicker versions** of the letter can help. Sometimes, **the choice of which letter is used for each of the three mutually perpendicular directions** (the front, top, and right planes) and even how that **letter is oriented** (e.g., rotated 90°) can make a design work. Designs can fail when a needed part of a letter has nothing to intersect with given the other extruded letters. Sometimes, it "works" in the virtual CAD-world, but can't be 3-D printed, because not all pieces connect. Say I want to use the initials O, X, and T. In the first picture to the right, we have an extruded O. Below that, there is a separate extruded X.

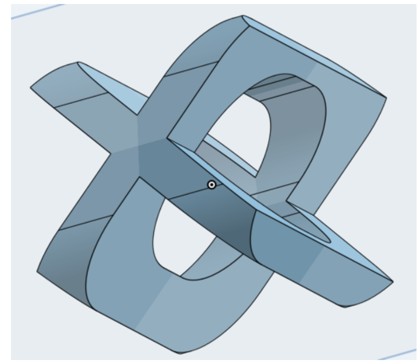


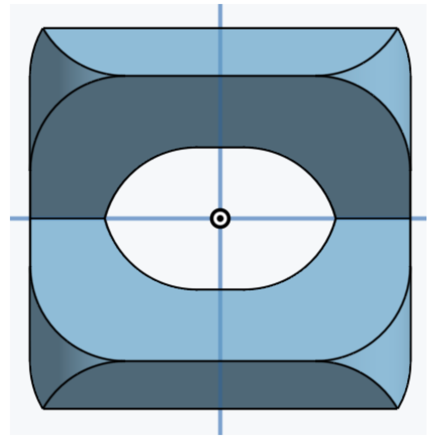
We can't add (take the union of) these two shapes or we get a figure that has the wrong orthographic projection in both directions (each letter interferes with the other) as shown here →



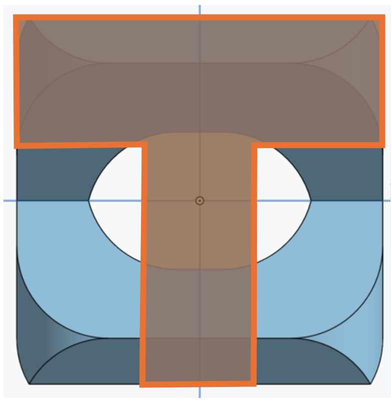


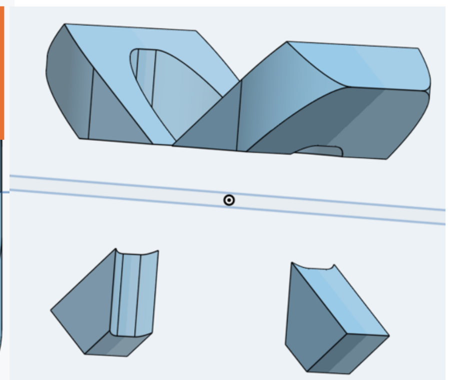
For initials cubes, we want to use Intersect when we extrude, but we have to hope that enough is left so that each letter still exists at some part of its extrusion. In the image at right, we can see that the X is well preserved when viewed from the front (the slightly to the left view) and the O is well preserved from the right view. When viewed from above, our final unused direction, we get what looks like a squished O (to the right and below). The problem for this particular combination of letters is that there is no way to extrude a T from the third direction and have it "survive" the intersection process. That large hole in the middle means that the stem of the T will not have any material to intersect with and, therefore, will not be represented in the final shape.





Here is what it like looks before and after we extrude a T:





Clearly, that doesn't give us the three orthographic projections we want (nor is it 3-D printable). When a student has initials that don't end up working even after swapping locations and orientations and making outlines chunkier, then you can recommend swapping out their middle initial for a symbol they like that is pretty space filling such as a squared-off heart like the one at right.