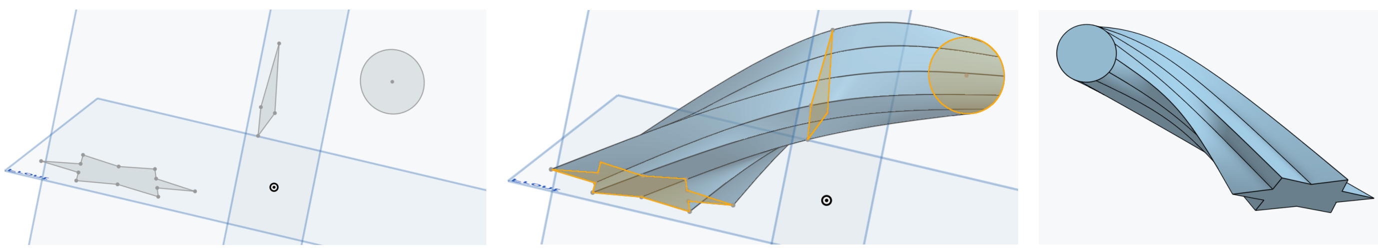
Making Math

Developing Student Mathematicians

Going Beyond Extrude and Revolve

In addition to the first two tools that build three-dimensional shapes from two-dimensional ones, there are others that will be particularly useful for students as they recreate pre-existing forms and develop their own.

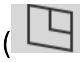
More advanced features include sweeps, which are like an extrude but along a more complicated path than a segment, and lofts, which flexibly fill in the gaps between a series of potentially unrelated cross sections set up at almost any angle and distance that is desired. A spring is an example of a sweep; it is a circle swept along a spiral path. Below are three views of a random loft connecting a six-pointed star, a quadrilateral, and a circle that show different shapes in different planes being connected. The program interpolates shapes that transition from each fixed sketch to the next.



I typically teach lofts to my classes, but I only show sweeps to students who need them for a particular task. I skip sweeps because many of the same tasks can be done with lofts (perhaps less efficiently), while countless forms can be done by lofts but not sweeps. Building lofts requires an understanding of reference planes and Extend and Split.

Here are some helpful videos from the wonderful Teach Product Design site:

- **Lofts**
  - Introduction: How to do a simple loft between two sketches: https://www.youtube.com/watch?v=qE5rP_DS5rs.
  - How to do a loft between multiple sketches: https://www.youtube.com/watch?v=z_ksYegw2c8.
  - How to put a twist into a loft: https://www.youtube.com/watch?v=nNhK9A5MJaI. This video shows how to match points between two hexagons, but it helps understand how to match points when lofting between very different shapes.
- **Chamfering and Filleting in 3D**: https://www.youtube.com/watch?v=0-SOLZyhiS0
- **Sweeps**: https://www.youtube.com/watch?v=JqsE131uElk.

Activity 1: Before you introduce assemblies, I encourage you to use the above videos and give students some time to experiment making simple lofts (from just one shape to a second one parallel to it, from one shape to a second one in a non-parallel plane, and then between three of more shapes). These experiments do not have to necessarily be in response to a design challenge – they are just about getting used to the loft tool () and the tool for creating new planes (), both of which are in the main OnShape window's menus (not the sketch menus).

Bringing It All Together With Assemblies

Most objects consist of multiple parts, and most parts involve complex forms that may be most readily assembled from simpler parts. CAD programs allow you to assemble these parts with different types of relationships, called mates, that control how the parts work together. The simplest mate, the fasten mate, fixes two parts together. No movement, sliding or turning in any direction, is permitted for the two parts relative to each other. Other mates permit different levels of movement that correspond to different degrees of freedom of movement. As you introduce different mate types, you can ask students which of the 6 degrees of freedom are locked and which are permitted. For example, a slider mate blocks all relative rotations and allows translational movement (a slide) along only one axis. You can see these relationships described at Onshape's site here.

Here are some helpful videos on assemblies:

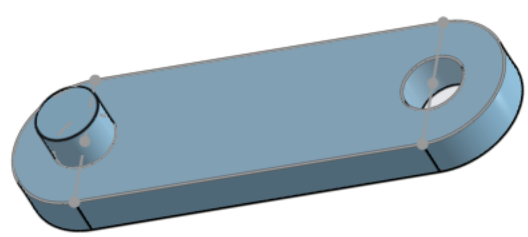
Teach Product Design:

- Introduction to the different types of assembly mates: https://www.youtube.com/watch?v=_DhoWn6llGM. You can rebuild the starting sketches shown in the video, but if you want access to the OnShape files shown, you can email Teach Product Design at teachproductdesign@gmail.com and request access to their public OnShape files.
- How to animate assemblies (to show the function of the design): https://www.youtube.com/watch?v=z5GiB55ovwE.
- How to set limits on mate movements in an assembly: https://www.youtube.com/watch?v=a0X8keFAF2o.

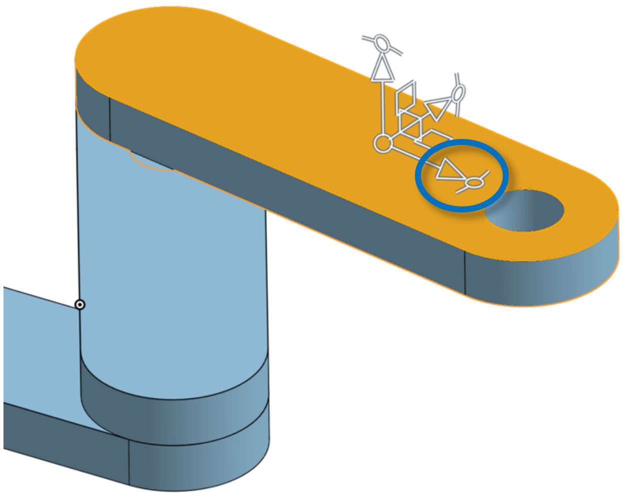
Teaching Tech's Onshape Assemblies 101 - Beginner and advanced examples: https://www.youtube.com/watch?v=cHXK91gtknE.

As part of the Lego-style brick project, students were shown how to do a fasten mate and stick bricks together. For the first activity, we will introduce a mate that allows some motion.

Activity 2: Students will develop a simple shape that they can then link to copies of itself to make a chain. Have everyone start a new OnShape file. They will do



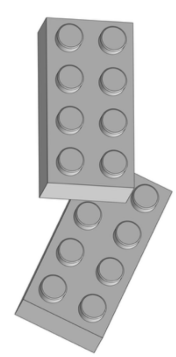
sketches and then use the plus symbol in the lower left corner to start an assembly once the object is ready. You can use the [Revolute mate demo video] to practice the steps yourself and have students follow along or use the video in class and just pause it after each step so that students have time to carry out that step while you walk about the room making sure everyone is in a good place and ready to continue. When students have their mini-chain of three of more assembled links, they can select and move one link and see how the other links rotate relative to each other.



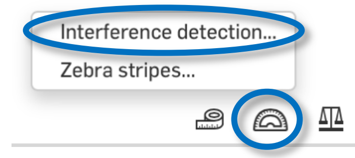
To move shapes in an assembly, click on one part and handles will appear as shown at left that allow you to slide or rotate that part. The arrows limit movement to that axis. The squares allow movement within that plane (two axes), and the arcs with circles allow rotation. For this assembly, only the circled rotation handle will lead to changes in the angles in the parts. The other two will just rotate the entire assembly as a fixed entity. All six of the translational handles (axes and planes) will produce action at the hinges.

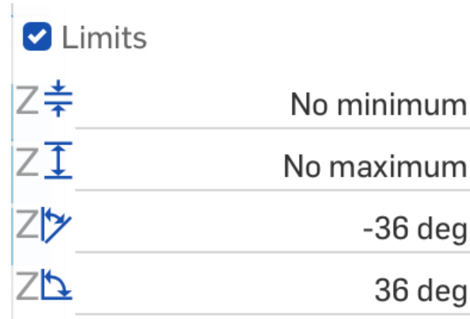
Activity 3: Back to the bricks! Have students reopen their brick files. This time we will only attach two bricks at a single bump. Have students start a new assembly and follow these steps:

1) Have them choose a planar mate and connect the bottom rim (the area, not an edge) of one brick with the main top face of the other. This should roughly stack (but not necessarily align) the two bricks. If the bricks don't both have their bumps facing "upward" (in the same direction), they can click on the arrow in the mate window to reverse the direction of the mating. Have them check the green check to finalize the mate.
2) Students can now click on one part and see how the 9 different motions affect the position of the two bricks. The one thing that should not change is that the bricks should remain parallel with the bottom of one and top of the other coplanar (even if they are far apart).
3) Next, we want to make sure that one corner bump is always above another corner bump as shown at right. Students should add a cylindrical mate and click on the center of one corner bump on each brick. This forces those bumps to keep their centers on the same axis. With just this mate, the two bricks could still move up and down relative to each other, but that motion is precluded by the above planar mate. Again, have them check the green check to approve the mate and test it out by seeing what motions remain possible.

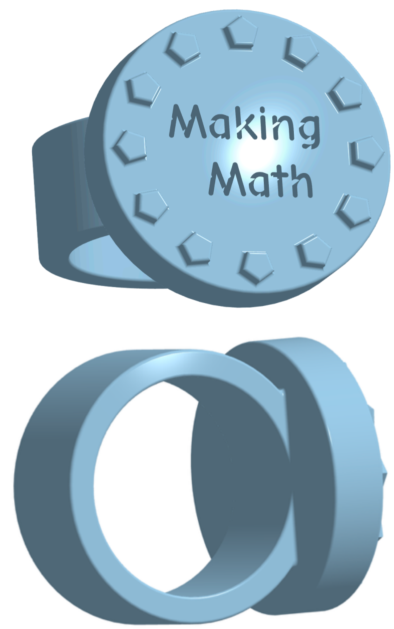


4) Students may have noticed that the bricks can still swing around and the sides of the upper brick can magically pass through the other bumps of the lower brick. OnShape does not prevent parts from intersecting (interfering) with each other. Students can see this interference by using the interference tool as described in the Teacher Notes: Combining Steps and demonstrated in the Assembly demo video. This kind of unwelcome behavior can be manually corrected. Students should edit the cylindrical mate. Have them double click the mate and check the Limits box (see this video for examples). They can then put in angles for the range of motion. After experimenting with different values (by entering them, approving the mate, and then trying to move the top one and look for interference either visually or with the interference tool), I found setting the minimum angle to -36 degrees and the maximum angle to 36 degrees avoided interference and made it look like the bumps were blocking further rotation.





Activity 4: A personalized ring. Students will design a ring that has some details with personal relevance (e.g., the outline of a favorite animal, a flower, etc.). This activity is best done in pairs unless a student is looking particularly competent in all of the steps explored thus far. At right is my not particularly attractive design for a ring. If your class has access to a 3-D printer, then they should design their ring so that it fits their fingers when printed out. They should measure the diameter or circumference of their finger (and knuckle) and use those measurements as they dimension their design. Before they work in OnShape, they should make an orthographic drawing (at least the front and side) and an outline of the steps they plan to follow to make their shape. Have them type up a list that says what each sketch will contain, how they will extrude or rotate or loft it, how they will combine the steps, etc.



Here are the steps for my ring:

1) Make a sketch in the Top plane with two concentric circles about the origin, the inner one with a radius 1 mm larger than Josh's knuckle and the outer circle with a radius 4 mm larger than that.
2) Extrude that sketch 1 cm to make the main ring part.
3) Use the Right plane or a new plane parallel to it that intersects the outside of the extruded ring for a sketch of a circle and extrude that in the direction of the inside of the ring 4 mm. This makes the setting or platform part of the ring.

4) Fillet all edges so they are rounded.

5) Start a new sketch on the face of the second extrusion. Make a regular pentagon and use the circular pattern tool to make 12 copies.
6) Extrude that sketch outward 1 mm and fillet the new edges.
7) Make another sketch on the face and use the text tool.
8) Extrude Remove that sketch 1 mm. Make sure it is going into the face.

Once students have an approved outline, they should begin their work in OnShape. Approval should be based with an appreciation that as they work, it is fine if they discover missing steps or the need for alignment of components in ways they did not initially visualize. You are just looking for a reasonable first draft/analysis. As students work, they may get new ideas and that is great. The question “Can I…?” should be responded with “Yes! How will you go about that? What tools will help you?”

The next section of teacher notes (see the PDF The Power of Variables) presents how to use variables to make models that are well-coordinated between different parts and that can change flexibly in terms of scale and proportion. It describes a final project, The Virtual Version that pulls all of the CAD skills in this unit together and also as starting efforts with Computer-Aided Manufacturing (CAM) in the classroom.