Making Math

Developing Student Mathematicians

The Power of Variables

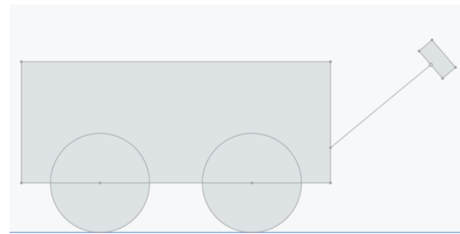
Variables are an essential feature of effective and efficient CAD designs. They also provide opportunities for CAD lessons to enhance students' understanding and appreciation of algebra, of similarity and proportion, and of thoughtful planning before diving into a task. Variables can be used when dimensioning or in the windows for extrusions and other features to control most aspects of a sketch or part. They can determine lengths, angles, number of repetitions, position in an assembly, and more. If set up in advance and used throughout the steps of dimensioning a part, they make it possible to modify a design without having to directly edit sketches or assemblies. For example, a model of a car with a given width might have numerous parts (such as the axle, the seats, the wiring, etc.) that base their size on that width variable. Those parts can have measurements that are formulas based on the width variable. For example, a seat might be (width – 60 cm) / 2 wide. When a variable's value is changed in the variable table, any feature that is based on it will automatically update. Students get to see a physical (well, virtual physical) representation of a variable or algebraic expression as it changes. They also get to practice developing original formulas for specific situations.

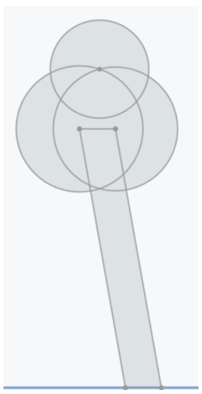
In addition to using variables to set up each sketch and part for easy modification, variables used throughout a design make models that are coordinated between different parts and that can change flexibly in terms of scale and proportion. Each feature where parts meet needs to change in the same way so that the parts still fit together. When they are based on a variable, mates in assemblies will continue to work without introducing unwanted gaps or interference (overlap) between parts.

Also of benefit, use of the variables table (accessible through the tab on the right side of the window) keeps key information all in one place rather than distributed throughout numerous sketches. Students should be encouraged to use meaningful variable names (e.g., handle_angle) that describe the feature and relevant measurement. When a name has more than one word, they can make names readable by either using CamelCase (capitalizing each word) or snake_case (putting an underline between each word). Variables defined before a sketch is begun will be accessible in that sketch. If a variable is created after a sketch, it will appear in the features list on the left after the sketch and will not be recognized. When you type "#" in a dimension window, a drop-down list of all accessible variables will appear. If a variable that is needed is not listed, exit the sketch and drag the needed variable above the sketch in the features list and then re-enter the sketch and it will appear in your drop-down menus.

The first three videos use sketches that you can view [here](). You can create an editable version for activities and then share that link with students. However, they will then be able to edit that original document, so they must be instructed to go to the three-bar menu in the upper left, 

, and choose Copy Workspace… and work on their own copy. I recommend that you send students the link in class and have them make their copies then. I also recommend making a back-up copy yourself ahead of time so when a student accidentally changes the original, it is not ruined for everyone else or for future use.





Activity 1: Show the video "Variables demo 1" or do a similar demonstration yourself. Have students pick an object they would like to do a simplified 2-dimensional sketch of (e.g., the *profile* of a toy wagon, tree, pencil, or chair). They should make it a quick and simple design. Before they begin, they should identify at least two lengths and one angle they plan to control with a variable and set up their variable table. When they dimension their sketch, they should use those three variables and then complete the sketch (check the green check mark). They should then demonstrate for a classmate how their shape changes as they experiment with the values in the table.

Activity 2: Show the video "Variables demo 2" or do a similar demonstration yourself. Have them now add a new #scale variable to their variables table and set it to something other than 1 (e.g., 0.6 or 2). They can add it at the bottom and then click and drag it to the top. Once it is the first variable, they can include it in formulas for their other variables. For example, if they have a variable #StemHeight equal to 6 cm, they can change it to a formula (6 * #scale) cm. OnShape will add the "cm" unit automatically if that is your default unit for the project. Ask them to just change #scale and see if their designs remain proportional to the original one.

Students may have added scale to all of the variables in their table, including the angle. Let them, but they will then discover that the new versions are not similar to the original. When figures are scaled, lengths change proportionally, but angles are preserved. So, to make their figures similar, #scale should not be in the angle variable. If, after removing #scale for any angles, their figures are still not similar, they may see that there are other lengths or distances that they did not use a variable for and that are not scaling. Have them incorporate new variables until the only thing that seems to change with changes in #scale is size. The design should not distort in any other way. For the house in the video, the top of the roof is dimensioned to be 1.25 * #height. If I had instead dimensioned the roof to be at a certain angle, it would not have needed to respond to height to retain proportionality. That would be a demonstration of the angle-angle (AA) similarity theorem for a triangle.

Activity 3: Show the video "Variables demo 3" or do a similar demonstration yourself. In this video, variables are not just simply formulas that scale, they can be defined in terms of several other variables to respond conditionally different object parameters. In this example, we are adding more or fewer windows depending on the width of the house and width and spacing that we desire for the windows. The sketch is the third tab in this file. Note, that the function floor has nothing to do with houses. It means to round down. So, the floor(3.9) is 3. Rather than rounding to the nearest whole number, it always truncates any decimal portion. Despite my claim about houses not being relevant, its partner function that always rounds up is called ceiling! The formula for window_count:

floor(#width / (#window_size + #window_spacing))

works well because, in my sketch, I put the first little window rather close to the left edge of the house. If I had put it farther away, then the formula should have also accounted for that gap. If it is not close, then there are n+1 spacing distances for n windows. We can fix our formula for window_count by subtracting one spacing amount from the numerator:

floor((#width - #window_spacing) / (#window_size + #window_spacing))

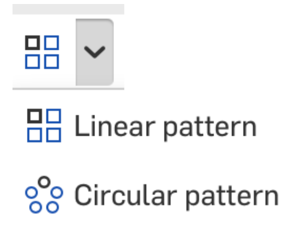
Again, it is great to note to students that, with well-designed formulas, no manual adjustments other than within the variables table will be needed to make a whole new functioning version of a part design or entire object assembly. It is also helpful to name the different roles variables are playing. The variables which are just given numerical values are **independent** variables. They are whatever we want. The variables that are based on formulas are **dependent** variables. In CAD, we will also say that independent variables **drive** the other variables and that dependent variables are **driven**. Again, this is a great opportunity for students to see concrete examples of what function relationships between variables means. The independent variables are the input and the dependent variables are the output.

For the activity, share an OnShape sketch of the house with a single small window above and ask them to build a variable table where they (the user) will choose how many windows they want and either the width of the windows or the spacing and then they will determine the formula for the missing variable (spacing or width). They might also try coming up with formulas that they like for both window_width and spacing that work just given the number of windows.

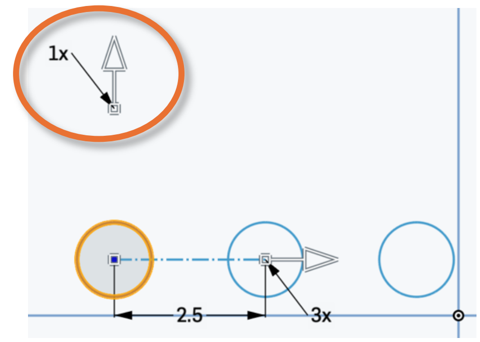
In the video, I just started the first window way to the left. If we want to center the windows, we can dimension the distance from the left edge of the house to the left edge of the first window with a new variable, #center_pad:

(#width - #window_count * #window_size - (#window_count - 1) * #window_spacing) / 2

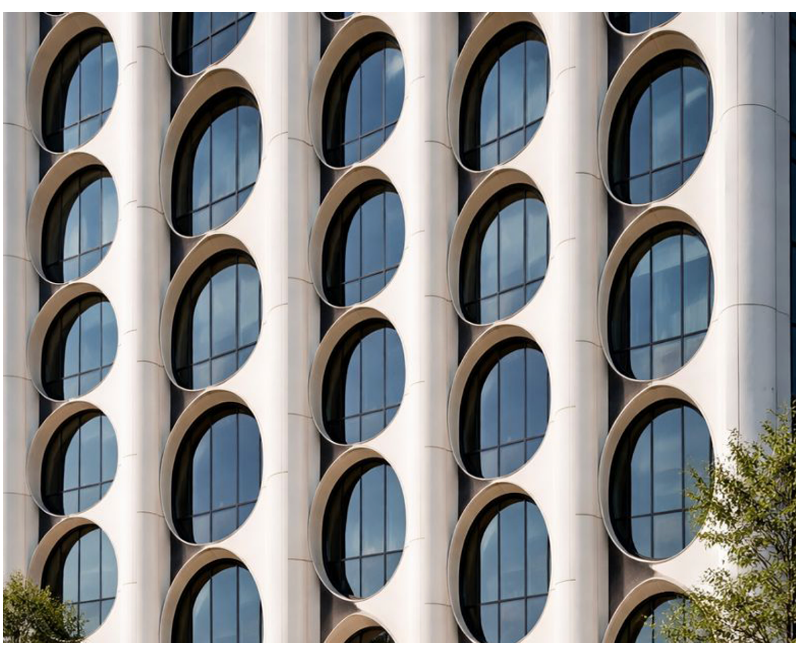
Now the windows will always be centered in the house. See if students can explain this formula (or figure it out themselves!). In general, when asking them to develop a formula, have them pick numeric values first and see what operations they would follow and then apply that same sequence of calculations with the variables in place of their corresponding numerical example. See the Making Math section on [Introducing Expressions](#) for more information on how to help students make the transition from concrete numerical situations to abstract formulas.

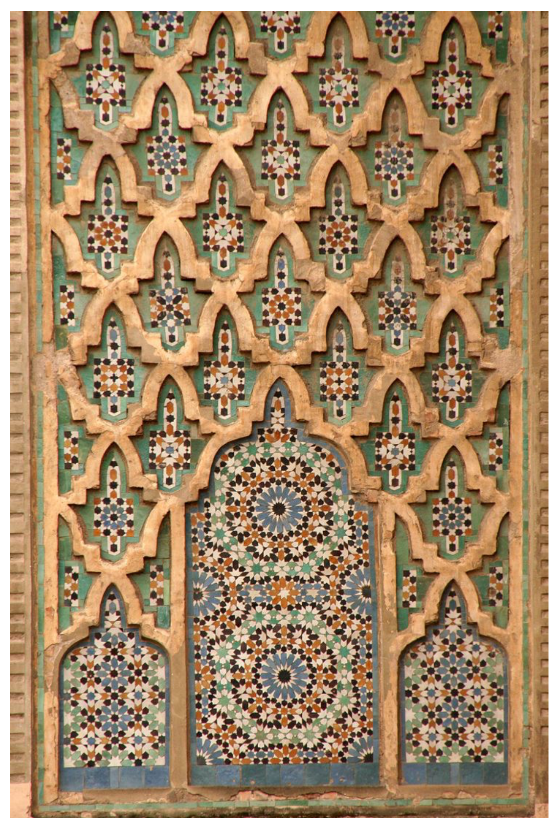


For an additional challenge, you can have students come up with their own designs that involve a linear or circular pattern. Linear patterns can be one-dimensional, as they were for the row of house windows, but they can also be two-dimensional. In OnShape, when you start a linear pattern and select an object to repeat, it not only shows three repetitions horizontally, it also shows a vertical arrow "repeating" once. If you click on the "1x" label and change it to 2 or more, you will get a repeating grid instead of only a repeating line. The open arrows control the directions of the repetitions, so you can get repetitions on a slant.



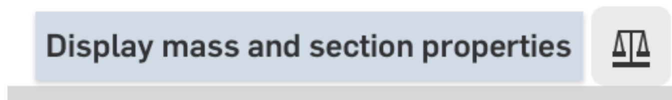
Works of architecture (see below), a skyscraper or multi-floor building, a tiled floor, a packed box of drinking straws or oranges, or other objects with repetitive patterns are good inspirations.





Activity 4: Show the final video on variables "Variables demo 4". This video shows how use of variables propagates through to completed parts and assemblies. Now that students have had experience seeing how variables enable them to develop a solution to a whole set of problems instead of a single case, they are ready to do complex work. Have them each design a two-part assembly (such as the can in this video) that fits, snaps, or slides together in some fashion and is driven by one or more variables. Encourage them to use variables for all significant dimensions and especially for dimensions that impact both parts in their assembly. They should begin with an orthographic view or two of each part and a list of variables on a copy of the CAD Part Orthographic Diagram handout before diving into OnShape.

Once students have working models, they can explore the impact of their variables not just on the appearance of an object, but on its physical properties as well. To learn more about their part, they can click on the Mass and Section Properties tab in the lower right corner. When they click on a 3-D part, the object's volume and surface area will be displayed. If the part is also assigned a material (control-click on the part's name in the listing on the left and choose "Assign material…"), then its mass (based on the density of the material times the volume) will also be listed. Ask students how surface area and volume change as their variables do. If variable :x doubles, how much does the surface area grow by? What about the volume? Does either double? Does either increase by more than double or less? Why? Which variables impact the amount of material needed to make the object more and why? Have them experiment and make a table of their findings. Have them focus on ratios (such as new volume / original volume) rather than absolute change.



Ask students to try to optimize a design. Can they use the least material while still making what they consider to be a structurally sound design? How can they reduce (thin, shorten, carve out, etc.) while still achieving their purpose? They can check the volume as they proceed. This work is sped up considerably when a variable table has been put in place effectively.

As you have navigated OnShape, you have probably noted that there are numerous tools both within sketches and particularly in the main three-dimensional view that Making Math's CAD lessons have not addressed. One can spend years mastering not just the range of tools, but also creative ways to use them. It is worth just mousing over the many icons in the main tools menu and their submenus just to get a glimpse of the possibilities in case the need for one or another of them arises. At the end of the menu is a button for adding custom features (some for free, some not) that are part of a large library of additional tools. One set of 3-D tools that you may want to share with students as they get into more complex designs for the Virtual Version of a Real-World Object Project is Boolean operations introduced here and applied here.