Helping all students, especially girls, to be interested in engineering as a possible future can be challenging. Research suggests that role models are important for helping students to see themselves in jobs where they have been underrepresented. In addition, having challenging and fun engineering experiences help students to want to become engineers.

ETS1.C: Optimizing the Design Solution
PE MS-PS1-4. Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.
PE HS-PS1-3. Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.

Many engineering projects though are focused on competitions, but that isn't the essence of engineering. The cycle of determining a problem, identifying what's needed to solve the problem, trying and testing possible solutions, and

optimizing and iterating to find the best solution is what makes an engineering project.

In this lesson plan, students will watch a video where Lane Daley explains how she became a successful engineer. After figuring out what she says are some key factors to being a great engineer, they will embark on an engineering project where they will try to determine the key factors to making a water ice, sometimes called an Italian ice. Finally, they will look back at their work habits to determine how closely they matched skills that the engineer suggested were important.

Part I: Watching the Lane Daley Video

Before the students watch the video, the teacher should explain that in this video an engineer will explain what makes her a successful engineer. The teacher should ask students to record what personality traits, desires, and behaviors are important to becoming an engineer.

For younger students, you may need to use sentence starters like

Lane Daley said that she had to overcome the obstacles of _____

Lane Daley said that she wants to _____

The video has on-screen icons that will help students when she is saying key components of her success. For some students, pausing the video at those moments will help them better record what is going on.

In small groups have the students summarize what they saw and then make sure that the entire class has all of the points. While they may have more than these, they should at least note:

- Lane Daley has made engineering her career.
- Lane Daley is an engineer because it gives her a chance to be creative.
- Lane Daley persevered to overcome obstacles.
- Lane Daley works with others as a team.

Making a Great Engineer Checklist

Students now should now make a checklist of things for themselves to do if they want to be a good engineer. Then when they do something on the checklist, they should mark it off. For example,

Activity	
I helped someone	𝍸 I
I didn't give up when something didn't go the way I planned	𝍸 II

Students will use this checklist several times in the following projects. Don't assign points or give too much praise, otherwise students will just game the system. We just want them noting when they are doing something a good engineer does, helping them to internalize that they can be an engineer. Alternatively, you can make it the task of one of the members of the group to note when their groupmates are being good engineers.

Part II: Engineering Cycle

Frozen fruit and sugar water ices consist of water (sometimes fruit juice), sugar, and sometimes an acid. Groups will mix together a batch of nine cups with varying amounts of sugar, from no sugar to a 2:3 ratio of sugar to water. Students will select which cups most closely match their preferences. Afterward, they will repeat the task by making lemon (or other fruit juice) ice. Students will plan how much lemon juice to add and how much sugar. Students won't be given an unlimited amount of trials so students will have to figure out how to do the tests they need to find a satisfactory combination.

Making an Acceptable Italian Ice

Materials

- 9 small, approximately 2 ounce (60 mL), cups
- Water
- Food coloring
- 200 grams of granulated white sugar
- Artificial sweetener like sucralose (optional)
- Fresh squeezed lemon juice, bottled lemon juice, or citric acid (available in health stores, sometimes called, "Sour Salt") mixed with water (47 grams per liter is the equivalent acidity to lemon juice)
- Spoons
- Scale
- Marker

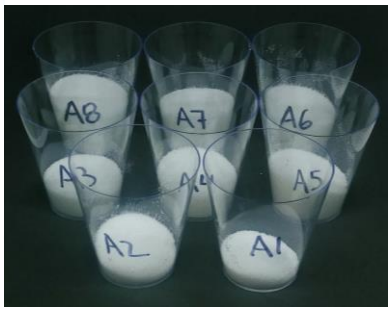
Making a First Batch

Label the cups with both the concentration (see below) and the group letter.

Mix 300 mL of water with 10 drops of food coloring. Pour 30 grams (approximately 1 ounces or 1/8 cup) into each cup.

Cup	Water (grams)	Sugar (grams)
0	30	0
1	30	2.5
2	30	5.0
3	30	7.5
4	30	10
5	30	12.5
6	30	15
7	30	17.5
8	30	20

Add the sugar specified by the table above and stir until dissolved. The highest sugar concentrations may take a fair bit of time for them to dissolve. You might have students measure out the sugar in a separate set of cups before adding to the liquid so that you can check their work.



Place in freezer overnight. This many cups can be hard to handle if you have many students and groups. Moving the cups on cafeteria trays can help. In some cases it might be easier to make fewer, but larger, cups with more of the sugar and water solution in each cup. The recipe works fine scaled up.

Characterizing the Ices

Students will probably notice the differences in the cups as soons as the removed from the freezer, but putting a spoon in each will help show off the differences more. After tasting the ices, students should be able to characterize the different ratios. They might say that more sugar is sweeter, but also softer. They may notice that the highest sugar ratios have droplets of syrupy liquid. Students can then characterize what their preferences are. Not all the students will have the same preferences and that is fine.

A Little Bit About the Science of Freezing

Adding sugar to water decreases the temperature at which the water will start to freeze. In a sense the sugar gets in the way of the water molecules moving into position and forming ice crystals. This is known as a colligative property.

For small amounts of sugar that tells most of the story, but for the amounts of sugar we are using, the situation is more complicated. The structure the ice crystals doesn't allow molecules of sugar to be incorporated. The sugar is squeezed out of ice, leaving the remaining water that has yet to be frozen with an even higher concentration of sugar, lowering its freezing point even more. Eventually the solution becomes so concentrated that the freezer temperature isn't low enough and can no longer freeze the remaining solution.

So while water without any sugar forms a solid block, sugar interferes with a big block forming, and smaller grains get formed. As the sugar level keeps going up, more water never gets frozen, leaving a lubricating syrup. As sugar is added, it not only gets sweeter, it also gets progressively slushier.

You can show that it is the sugar and not the sweetness with students by using artificial sweetener rather than sugar to sweeten the water. Since artificial sweeteners are hundreds of times sweeter than sugar, you will only need a tiny amount of it to sweeten the water. All the ices will freeze nearly like Cup 0 or 1.

Other chemicals can change the freezing point as well. The citric acid in lemon juice can also reduce the freezing point of water and make it softer without increasing the sweetness. In fact, the sourness of citric acid can make the solution seem less sweet.

Making a Lemon Ice

The ices made in the first part are unflavored, but ices usually come in flavors. A typical flavor is lemon, but making a lemon ice can be complicated because the citric acid in lemon juice also lowers the freezing point and the sourness makes things taste less sweet. In this section, students will try to make a lemon ice that they find delicious.

Students could make a big matrix with say nine different amounts of lemon juice and nine different amounts of sugar, but that would require 81 different cups. That is a lot of work and wastes material. Ask the groups to determine a smaller set of options to test.

Typically students would normally work out a matrix like the one below, but it often varied among groups. That's even better. Since duplicates help confirm conclusions and differences open up new areas of possible investigation.

	10 g sugar	12.5 g sugar	15 g sugar
5 g lemon juice (25 g water)			
10 g lemon juice (20 g water)			
15 g lemon juice (15 g water)			

Extensions

You can try a different form of lemon juice. For example, if you used fresh squeezed you could try bottled lemon juice or citric acid. Citric acid is usually the cheapest by far followed by bottled juice. You can see how well your students can tell the difference between the various forms and decide if the difference in cost is worth it.

Italian ices often come in other flavors. While lemon juice is nearly sugarless, other fruits can have considerable sugar. Having students figure out how much sugar to add to apple or grape juice and if they want to acid can be a fruitful experience acting like a food engineer.

Part III: Evaluation

While many kinds of assessment work, the students and the teacher should assess how well they approached their Italian ice. What did they learn about how freezing sugar solutions work? You could write an assessment that offers possible changes and asks students to predict how that will change the flavor of their ice.

In addition, each group should report out on how well they worked together. Even for classes that didn't have time for the groups to work on their own project, having the students briefly present their work to their classmates tends to give the best opportunity to figure out what happened in their group. They should explain

- What their problem/goal was
- What they tried
- Whether or not it was successful
- How they could tell if it was working
- What they did if they didn't all agree on what to do
- How often did they get to put a mark on their checklists