Search for the Best Ice Cream

Part of: Inquiry Science with Dartmouth (a new program!)
Developed by: Molly Carpenter (and Jen Stainton)
Adapted from: McGee, H. On Food and Cooking. Scribener, 2004
Young, S. Gourmet Lab. NSTA press, 2011

Overview
Freezing point depression, heat transfer, hydrogen bonding, materials science

Science Standards (NGSS)

Disciplinary Core Ideas
PS1.A Structure and properties of matter
PS1.B Types of interactions

Science and Engineering Practices
Planning and Carrying out Investigations
Obtaining, Evaluating, and Communicating Information
Using Computational Thinking
Constructing Explanations and designing Solutions.

Focus Question
Why does ice cream have a smooth, soft consistency, while frozen water or milk is hard?

Objectives
Through this lesson, students will:
• Practice writing a hypothesis
• Work as a team to test hypothesis
• Gain first hand experience with freezing point depression
• Practice graphing data
The Structure and Consistency of Ice Cream

Ice Creams, Concentrated Cream, Air Ice cream consists of three basic elements: ice crystals made of pure water, the concentrated cream that the crystals leave behind as they form from the prepared mix, and tiny air cells formed as the mix is churned during the freezing.

- The ice crystals form from water molecules as the mix freezes, and give ice cream its solidity; they're its backbone. And their size determines whether it is fine and smooth or coarse and grainy. But they account for only a fraction of its volume.
- The concentrated cream is what is left of the mix when the ice crystals form. Thanks to all the dissolved sugar, about a fifth of the water in the mix remains unfrozen even at 0°F/-18°C. The result is a very thick fluid that's about equal portions of liquid water, milk fat, milk proteins, and sugar. This fluid coats each of the many millions of ice crystals, and sticks them together—but not too strongly.
- Air cells are trapped in the ice cream mix when it's agitated during the freezing. They interrupt and weaken the matrix of ice crystals and cream, making the mixture lighter and easier to scoop and bite into. The air cells inflate the volume of the ice cream over the volume of the original mix. The increase is called overrun, and in a fluffy ice cream can be as much as 100%; that is, the final ice cream volume is half mix and half air. The lower the overrun, the denser the ice cream.

Balance The key to making a good ice cream is to formulate a mix that will freeze into a balanced structure of ice crystals, concentrated cream, and air. The consistency of a balanced, well made ice cream is creamy, smooth, firm, almost chewy. The smaller the proportion of water in the mix, the easier it is to make small crystals and a smooth texture. However, too much sugar and milk solids gives a heavy, soggy, syrupy result, and too much fat can end up churning into butter. Most good ice cream recipes produce a mix with a water content around 60%, a sugar content around 15%, and a milk-fat content between 10%—the minimum for commercial U.S. ice cream—and 20%.

Ice cream, a semisolid foam. The process of freezing the ice-cream mix forms ice crystals—solid masses of pure water—and concentrates the remaining mix into a liquid rich in sugar and milk proteins. Churning fills the mix with air bubbles, which are stabilized by layers of clustered fat globules.
**Materials** (for 50 students working in pairs, for one batch of ice cream)
- 5 cups sugar
- 2 gallons whole milk
- 1 bottle vanilla extract
- 4 bags of ice
- 25 quart size ziplock bags
- 25-50 gallon size ziplock bags
- 1 non-mercury thermometer per group (must be able to measure below 0 degrees celcius)
- plastic spoons

**Optional**
- 2 cans condensed milk
- 1 quart soy milk
- 1 bag NaCl rock salt
- other salts if you want to let the students play with this variable could be – Epsom salt, CaCl₂, MgCl₂
- 150 paper cups

**Preparation**
* A trip to the grocery store! This activity works best if the salt and ice station is away from the food items. If you have any fairly vigorous ice cream shakers, double bagging is recommended.

*The way this experiment has been designed students can test various components of the ice cream making. To shorten the duration of the activity, the complexity or to remove some cost, one might limit the number of components the students test, or give the students one procedure to follow.*

**Background:**
Have you ever accidently frozen some milk or cream? Usually plain frozen milk or cream has the consistency of a brick, so how do we get the smooth, soft consistency that we love so much in ice cream? Today we will explore ice cream making in order to better understand the chemistry of this delicious treat.

According to lore, the Roman Emperor Nero Claudius Caesar sent slaves to the mountains to bring snow to make frozen fruit drinks. During his journeys to the Far East, Marco Polo recorded recipes for making water ices that resemble modern sherbets. ‘Ice Cream’ was first made by a French chef in King Charles I’s royal kitchen in England. Apparently, when the king tasted the treat he immediately called in the chef and agreed to pay the chef 500 pounds a year to keep the recipe secret so that only people invited to court could taste ice cream. Several years later the people of England had Charles I beheaded – letting the chef out of his terrible predicament.
**Goal:**
- Design an excellent ice cream making procedure.

To accomplish this, each pair will join with two other pairs to create a group of 6. Each group of 6 will study one component of ice cream making by assigning a small adjustment to the procedure to each pair. For example, if my group is studying vanilla flavoring content in ice cream, pair A might add half the called for amount of vanilla, pair B the exact amount, while pair C might double the amount of vanilla. Then our group can report to the class on the effect of vanilla on the ice cream mix.

**Procedure:**
With your group pick one of the following components of ice cream making to study with your group:
- Type and amount of salt used in the ice bath
- Whole milk vs condensed milk
- Soy milk vs whole milk
- Air introduction in mixture
- Amount of sugar added to the mixture

Design a way for each pair in your group to test your component and modify the following procedure as you see fit.

1. Before you begin please write a hypothesis or guess of how you think the ice cream will change as you vary your component and which pair’s ice cream will turn out the best (“best” can be due to taste, consistency, etc...)
2. Add 30 mL of sucrose into the small plastic bag (2 T)
3. Measure 250 mL of whole milk and place the milk in the bag (1 cup)
4. Measure 2.5 mL of vanilla and pour into the plastic bag (1/2 t)
5. Seal the bag and gently mix the ingredients together
6. Using a larger plastic bag fill with about 1000 mL of ice
7. Carefully place a thermometer in the larger bag and record the temperature of just the ice
8. Insert your ice cream mix into your ice bath
9. Add 180 mL NaCl to the ice in the larger bag (3/4 cup), seal the ice bath as much as possible, and mix the salt and the ice together.
10. Gently rock the bags holding the top seals – Take temperature measurements every minute for six minutes and then every 3 minutes noting when your ice cream freezes.
11. Once the cream has solidified, record the final temperature, discontinue your measurements and remove the small plastic bag and rinse the salt off the bag with cold water.

12. Using a clean plastic spoon scoop your 3 varieties of ice cream into paper cups. Discuss with your group how the variations in the procedure changed your ice cream and which variation was the best.

13. Be prepared, as a group, to share your results with the class.

Hypothesis:

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Please graph your data in a scatter plot below.

Think about what your independent and dependent variables are. Remember to label the x and y axes and to record the units.

Sample questions:
1. What was the final temperature of the ice bath? Is that above or below the temperature of freezing water?

2. Describe the phase state of the ice cream – Is it a liquid? Or a solid? Something else?

3. If you could do this experiment over again what would you improve?

4. Using the information shared by the other groups, what recipe will make the best ice cream?
If there is time, lead a discussion about which components make the best ice cream. Discuss the chemistry to explain why those components are important.

Things that came up when I taught this:

- More sugar makes the ice cream creamier – this is because water hydrogen bonding to the sugar is less likely to form big ice crystals
- Epsoms Salts don’t work as well (the T doesn’t get as low) as NaCl – this because you add less salt ions per volume when you add Epsom salt than when you add rock salt.
- Playing with the amount of protein and fat will change the consistency of the ice cream – see description above – so soy milk and condensed milk will effect the ice cream, but depends how much you add and what you add --- Experiment!

After the discussion, as a class write up the perfect ice cream recipe based on what the class learned in the first round. If time allows, make the perfect recipe and try it.

Extensions:

Ricotta is a simple, quick cheese to make. Use different chemistry to make another change to the physical properties of milk in a different way to make a very different solid treat!