



**Tools and Resources**

***“Making Sense of Milk”***

February/March 2019

<http://www.acs.org/chemmatters>

**Teacher’s Guide:**



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**Tools and Resources**

***“Making Sense of Milk”***

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# Connections to Chemistry Concepts

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| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Mixtures** | The graphics of whole milk and homogenized milk in this article are useful while discussing the concept of mixtures. Milk is used as an example of both a homogeneous mixture, due to the sugars dissolved in the water portion, and a heterogeneous mixture, due to the dispersion of fat particles throughout the milk. |
| **Molecular attractions** | The descriptions of the hydrophobic and hydrophilic actions of the spherical micelles in milk provide an example of polar and nonpolar attractions in molecules. |
| **Aqueous systems** | During a unit on aqueous systems, the article’s discussion of milk as a suspension, a colloid, and an emulsion provides a unique example of one such system. |
| **Biochemistry** | The article shows that milk contains many of the types of molecules covered in a unit on biochemistry. The comparison of the contents of the dairy and non-dairy milks in terms of proteins, carbohydrates, lipids, and the micronutrients such as minerals and vitamins provides an example of a commercial application of these compounds. |
| **Proteins** | The discussion of the protein quality of cow’s milk compared to that of the non-dairy milks complements lessons about complete proteins and the nine amino acids not produced by the human body. |
| **Density** | The description of non-homogenized milk separating into a fatty cream fraction on top of a watery fraction can be used during a lesson about density. |

# Teaching Strategies and Tools

## Standards

* Links to **Common Core Standards for Reading**:
	+ **ELA-Literacy.RST.9-10.1:** Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
	+ **ELA-Literacy.RST.9-10.5:** Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).
	+ **ELA-Literacy.RST.11-12.1:** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
	+ **ELA-Literacy.RST.11-12.4:** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
* Links to **Common Core Standards for Writing**:
	+ **ELA-Literacy.WHST.9-10.2F:** Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
	+ **ELA-Literacy.WHST.11-12.1E:** Provide a concluding statement or section that follows from or supports the argument presented.

## Vocabulary

**Vocabulary** and **concepts** that are reinforced in the February/March 2019 issue:

Mixtures

Structural formulas

Environmental impacts of personal and societal decisions

Nanoparticles

Periodic properties

Phase changes

Green chemistry

* Consider asking students to read “Open for Discussion: Unpacking the Paleo Diet” on page 4 before they read “Making Sense of Milk” to learn why some people might choose not to consume dairy products.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles, and what they would like to explore further.
* Ask students if they have questions about some of the issues discussed in the articles.
* Encourage students to watch the videos and try the simulations suggested in some of the articles.

# Possible Student Misconceptions

1. **“Milk is milk. Plant-based milk is the same nutritionally as cow’s milk.”** Just because a product is labeled “milk” does not mean it has the same nutritional content as cow’s milk. Very few plant-based milks have the same nutritional profile that cow’s milk does. Except for soy and pea protein milk, most plant-based milks have very little protein. Other protein components, like immunoglobulins, are exclusive to cow, goat, or sheep milk. To come closer to the vitamin and mineral profile of milk, some plant-based products are fortified with the vitamins and minerals found in cow’s milk. Some of the milk alternatives have sugar added to them to improve their taste. When shopping for an alternative to milk, reading the labels is very important.
2. **“If young children do not drink milk they will not develop strong bones or teeth.”** Children do not necessarily have to drink milk in order to develop strong bones or teeth. As long as children’s’ diets contain the appropriate amounts of calcium, protein, and vitamin D necessary for bone development, they should develop normally. Some children do not drink milk but love cheese and yogurt. They get most of the same nutrients in milk products as they do from milk. But if a child cannot eat dairy, dark green vegetables provide a good source of calcium, and oatmeal and beans provide a good source of protein. Spending time outdoors should give a child enough vitamin D, but vitamins can also be supplemented in a multivitamin.
3. **“I’m lactose intolerant, so I can’t drink milk at all.”** A lot of people who are lactose intolerant can still drink cow’s milk if the lactose is removed. Lactase tablets can be taken when ingesting milk or milk products. The lactase enzyme will break down the lactose present into glucose and galactose. So, unless you’re also galactose intolerant, you should be able to drink cow’s milk after adding the enzyme lactase. There is also a type of milk on the market called Lactaid. It is cow’s milk that has had the lactose removed. Many people who have problems with lactose intolerance do not have a problem with dairy products that have been fermented, like cheese and yogurt, because they do not contain as much lactose. People who are lactose intolerant should be able to drink any of the non-dairy milks.
4. **“The majority of humans do not have a problem with digesting lactose.”** When you consider the worldwide population, there are more people who are lactose *in*tolerant than lactose tolerant. The enzyme lactase is produced in the human small intestine prior to birth and typically slowly decreases during childhood. A mutation in the gene responsible for lactase production caused the production to persist past weaning, into adulthood. One mutation that allows for lactase persistence (meaning, lactose *tolerance*) is seen in persons of ancient central European ancestry, while other variations of the gene mutation are seen in populations from North Africa. It is estimated that the mutation occurred in populations around central Europe around 7,500 years ago. When you compare current world populations for lactase persistence, over 90% of northern Europeans, Scandinavians, and Irish are lactase persistent while only 5% of Asians and Africans have the mutation for lactase persistence. Therefore, 95% of Asians and Africans, who constitute the bulk of the world’s population, are lactose *in*tolerant. Native Americans also do not exhibit the mutation for lactase persistence and most are lactose intolerant. In the United States, you would have to attribute to your ancestry your ability to produce lactase and, thus, your lactose tolerance, as an adult. <https://www.sciencedaily.com/releases/2009/08/090827202513.htm> <https://en.wikipedia.org/wiki/Milk>
5. **“Lactose intolerance and milk allergies are the same thing”.** Milk allergies are different from lactose intolerance, even though they have some of the same symptoms. With either lactose intolerance or milk allergies you may have diarrhea, nausea, abdominal cramps, bloating, or gas but, with milk allergies, you may also have a rash, hives, swelling of the lips and face, as well as tightness in the throat and trouble swallowing. Lactose intolerance is caused by a lack of lactase production, while milk allergies are caused by a sensitivity to a protein specific to milk. They are more dangerous and can be life-threatening. Milk allergies are definitively diagnosed with allergy testing. Lactose intolerance can be definitively diagnosed by monitoring the serum glucose level after administering lactose. Persons who do not make lactase do not have a change in their glucose level while those who do make lactase will exhibit an increase in serum glucose.

# Anticipating Student Questions

1. **“Milk contains hormones? Are these in there naturally or are they in milk because the cows are receiving supplements? What hormones are in milk?”** The hormones found in milk are there naturally. Cows, like humans, produce a multitude of hormones that can pass into their milk. Pregnant cows produce almost 20 times more estrogen than nonpregnant cows; therefore, the greater the number of pregnant cows in the herd being milked, the higher the estrogen content of the milk will be. Besides estrogen, some of the other hormones that cross over into milk are progesterone, androgens, corticosteroids, cortisol, gonadotropin-releasing hormone, luteinizing hormone, thyrotropin-releasing hormone, somatostatin, insulin, calcitonin, parathyroid hormone-related protein, erythropoietin, and melatonin**.** Most hormones are fat soluble and are dissolved in the fatty portion of milk. When you drink milk, any of the hormones that are absorbed in the digestive tract are broken down by the liver, so these hormones in milk are never active in humans. Some farmers give their cows bovine growth hormone (BGH) or bovine somatotropin (BST) because it causes the cows to produce more milk. BST is not active in humans, and any that remains intact after pasteurization is digested like any other protein in the diet. However, the BST causes an increase in insulin-like growth factor-1 (IGF-1), which is the same as that produced by humans. The increased IGF-1 in milk from treated cows is still less than 1% of what the human body normally produces, so, statistically, it does not increase the amount of circulating IGF-1 in the body. If you are still concerned about hormones in your milk, you could switch to skim milk which is hormone free since it does not have any of the fat that contains the hormones. (<http://igrow.org/livestock/dairy/hormones-whats-in-your-milk/>)
2. **“What are immunoglobulins and cytokines?”** Immunoglobulins and cytokines are two classes of protein molecules that are involved with the body’s immune response. Before an infant can produce its own immunoglobulins, he/she receives them from the mother through the placenta. After birth, the infant receives immunoglobulins from the mother’s milk. Immunoglobulins are the antibodies that recognize a pathogen and attach to it to mark it for destruction by other cells. The immunoglobulins in human milk and in cow’s milk help protect the newborn from gastrointestinal infection and inflammation. Cytokines are protein hormones produced by numerous types of cells. These molecules mediate and regulate the inflammatory responses that are associated with the immune response. It takes over a year for an infant to develop a mature immune system. Until then, the immunoglobulins and cytokines present, first, in mother’s milk and, later, in cow’s milk (when it is added to the child’s diet), protect the infant and young child from infections.
3. **“The milk carton says the milk is pasteurized. Is that the same as homogenized?”** Pasteurization and homogenization are not the same thing. Pasteurization is a heat process invented by the French scientist Louis Pasteur in 1864 to kill the bacteria that was spoiling wine and beer. The process was soon applied to milk as well. During pasteurization milk is heated to 162 °F for 15 seconds, killing most of the bacteria present. Pasteurized milk needs to be refrigerated and has a shelf life of 2–3 weeks. Milk that has been heated to 280 °F for 2 seconds is ultra-pasteurized and has a non-refrigerated shelf life of nine months. Milk is generally pasteurized before it is homogenized. Homogenization is a mechanical process, where milk under pressure is forced through a very fine screen, breaking the milk fat into smaller particles that remain evenly suspended in the milk rather than separate out.
4. **“Besides milk, what are some other examples of emulsions?”** An emulsion is a dispersion of one liquid into another liquid that normally do not mix. Examples besides milk are
* butter—a mix of water and fat
* mayonnaise—a mix of oil and vinegar with egg yolk as the emulsifying agent
* crema on espresso—a dispersion of water and coffee oil
1. **“Do the micelles contain anything other than calcium phosphate in their middles? How does the calcium get out?”** The micelles’ chief biological function is to carry large amounts of highly-insoluble calcium phosphate to mammalian young. They are porous structures and hold a considerable amount of water or milk serum. They also contain citrate, minor ions, lipase and plasmin enzymes. In an acidic environment such as the stomach, the casein micelles are denatured and their contents released.
2. **“My sister is lactose intolerant. Do any of the plant-based milks contain lactose?”** None of the plant-based milks contain lactose. Lactose is a disaccharide sugar specifically found in animal milk. It is composed of the monosaccharides glucose and galactose. The enzyme lactase (which is often missing in people who are lactose intolerant) reduces lactose to glucose and galactose, which can then be absorbed through the intestine. When lactose does not get broken down, it can ferment in the large intestine, leading to bloating and abdominal discomfort.
3. **“What are isoflavones? How do they protect against cardiovascular disease and osteoporosis?”** Isoflavones are compounds derived from plants that are referred to as phytoestrogens because they can weakly act like estrogen. Estrogen has many functions in the body, one of them related to bone health. It protects against bone loss by preventing the bones from losing calcium. As women age, they produce less estrogen and are susceptible to osteoporosis. Adding soy isoflavones to the diet can result in up to a 7.6% increase in bone calcium retention. Isoflavones also have antioxidant properties and, as such, can promote good heart health. They prevent the buildup of arterial plaques (lipid deposits on the lining of the arteries) by preventing the oxidation of LDLs (low-density lipoproteins).
4. **“What is lauric acid and how does it affect my brain?”** Lauric acid is a medium-chain (C12) fatty acid that is 5.5% of the fat found in human breast milk and is also in some plant oils. Lauric acid, shown to have antibacterial and antiviral properties, is present in coconut milk and in coconut oil. Because of its shorter carbon chain, it can be absorbed into the bloodstream quickly, providing the fuel for energy, like a carbohydrate, but without the sugar spike. Lauric acid is metabolized into ketones that can be used by the brain for energy in place of glucose. In the brains of patients with Alzheimer’s disease, where the neurons seem to suffer an energy deficiency, the increased availability of ketones has been shown to improve neuron function. While coconut milk is a good source of lauric acid, it also has a higher overall fat content than the other milks and zero protein.
5. **“Which milk overall is best for human health?”** The gold standard among milks is still cow’s milk. Dietitian and nutrition specialist Amy Goodson states, “When looking for vitamins, minerals, protein, and a lower cost, cow’s milk is your best option. Cow’s milk contains 1 gram of protein per ounce, or 8 grams for 1 cup. The other milks don’t measure up, protein-wise, with 0–1 grams for 1 cup (8 ounces).” Soy milk contains a similar nutrient profile for vegans or those who are lactose intolerant.
(<https://aaptiv.com/magazine/milk-varieties-101>)

# Activities

**Labs and demos**

**“Salad Dressing Science: Emulsions” lab:** Students use different substances as emulsifiers in salad dressing. The materials include background information on hydrophobic and hydrophilic concepts and how emulsifiers bring these two different molecules together. (Access is restricted to AACT members, but the article will be available for free until April 1, 2019, at <https://teachchemistry.org/classroom-resources/salad-dressing-science-emulsions>.)

**“Analyzing Mixtures” demonstration:** While introducing the concepts of heterogeneous and homogeneous solutions and emulsions, the teacher creates a sequence of mixtures with water, oil, food coloring, and soap in a single test tube. (Access is restricted to AACT members, but the article will be available for free until April 1, 2019, at <https://teachchemistry.org/classroom-resources/analyzing-mixtures>.)

**Simulations**

**“Miscibility of Liquids”:** In this simulation, students can mix water and oil; water and alcohol; and water, alcohol, and oil to observe which liquids are miscible or immiscible. (<http://www.physics-chemistry-interactive-flash-animation.com/matter_change_state_measurement_mass_volume/miscibility_of_liquids.htm>)

**Media**

**“Are Milk Substitutes Healthier Than Cow’s Milk?” (4:14 video):** The moderator in this British video compares dairy milk to soy and almond milks in terms of protein, calcium, vitamin D, and iodine content. She also discusses the chemistry surrounding lactose intolerance. (<https://www.youtube.com/watch?v=TUpQpWxMYtk>)

**“Milk Minus Moo: A Look at Milk Alternatives” (4:16 video):** In this *Today Show* video segment, a nutritionist reviews alternative milks—almond, hemp, coconut, rice, and soy. Besides the nutritional content of each product, she also discusses their best uses. (<https://www.today.com/video/milk-minus-moo-a-look-at-milk-alternatives-44510787759>)

**Lessons and lesson plans**

**“What Type of Mixture is Paint?”:** This lesson presents solutions, suspensions, and colloids, with a scheme for identifying each one. The lesson has an inquiry component where the students design their own paint from a variety of teacher supplied materials and then test the paint to determine what type of mixture they have created. (Access is restricted to AACT members, but the article will be available for free until April 1, 2019, at <https://teachchemistry.org/classroom-resources/what-type-of-mixture-is-paint>.)

“**Solutions, Suspensions, Colloids”:** In this lesson students make a variety of mixtures, observe and test them, and then classify them as solutions, suspensions, or colloids. Making mayonnaise is an extension activity placed at the end of the lesson. <https://www.woodstown.org/cms/lib4/NJ01001783/Centricity/Domain/8/Texts/ACS/resources/ac/ch6/act3.pdf>

**Projects and extension activities**

**“Magic Milk”:** Students add detergent to a mixture of milk and food coloring and then attempt to explain their observations. The activity could be done with the different milk alternatives to see how their reactions compare with those in whole milk and, as an extension, students could be tasked with explaining what is happening on a molecular level, accompanying their explanation with particle drawings. (Access is restricted to AACT members, but the article will be available for free until April 1, 2019, at <https://teachchemistry.org/classroom-resources/magic-milk>.)

A video of this lab can be found here: <https://www.stevespanglerscience.com/lab/experiments/milk-color-explosion/>.

The graphics in the explanation of this activity at the site below could be used as an example of using particle drawings to illustrate an explanation. <https://www.acs.org/content/acs/en/education/whatischemistry/adventures-in-chemistry/experiments/colors-move.html>

**“Milk Posters” project:** Students working individually or in groups could be assigned a type of milk or milk alternative to research and make a poster presentation of the pros and cons associated with their assigned milk. They should include the caloric value and nutrient values on their poster, as well as the health benefits of the milk and the persons that would be most attracted to their product.

# References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles and Teacher’s Guides published from the first issue in October 1983 through April 2013.**

**The DVD is available from the ACS for $42 ($135 for a site/ school license) here:** [***http://www.acs.org/chemmatters***](http://www.acs.org/chemmatters)***.***

In “Yogurt”, author Evans presents the history of yogurt and discusses the casein micelles’ role, as well as that of bacteria in the formation of yogurt. (Evans. G. D. Yogurt. *ChemMatters*. 1989, *7* (3), pp 9–12)

“Poisoned Milk” is an interesting story about how chemists solved the mystery of why thousands of pioneers died after drinking cow’s milk. Cows that eat the white snakeroot weed produce toxic milk. (Plummer. C. M. Poisoned Milk. *ChemMatters*. 1992, *10* (4), pp 10–13)

The article “Say Cheese” contains a good discussion of milk components, including casein micelles, which separate out during cheese formation. A recipe for making lemon cheese in class is given at the end of the article. (Baxter, R. Say Cheese. *ChemMatters*. 1995, *13* (1), pp 4–7)

Author Baxter discusses the chemistry of ice cream, including a discussion about colloids and emulsions. She includes a recipe for making ice cream within the article. (Baxter. R. Making Ice Cream: Cool Chemistry. *ChemMatters*. 1995, *13* (4), pp 4–7)

The Teacher’s Guide for the December 1995 *ChemMatters* article above provides additional instructions for making several variations of ice cream in class.

In “Hold the Meat! Meat-free Food Takes a Seat at the Table”, author Nolte includes information about complete proteins and protein chemistry, while discussing food products made from soy milk. (Nolte. B. Hold the Meat! Meat-free Food Takes a Seat at the Table. *ChemMatters*. 2011, *29* (4), pp 9–11)

“Who Put the Cheddar in Cheese?” contains a discussion about milk as a colloid, as well as the concept of diffusion in the salting process in cheese production. (DeAntonis. K. Who Put the Cheddar in Cheese? *ChemMatters*. 2012, *30* (1), pp 12–13)

In “Ice Cream … And Chemistry”, author Rohrig describes ice cream as an emulsion and discusses the components of milk that act as emulsifiers. (Rohrig. B. Ice Cream … And Chemistry. *ChemMatters*. 2014, *32* (1), pp 6–9)

“The Protein Myth: Getting the Right Balance” contains information about the nine essential amino acids that are required for complete protein sources, as well as protein synthesis. (Tyrell. K. The Protein Myth: Getting the Right Balance. *ChemMatters*. 2018, *36* (2), pp 5–7)

The Teacher’s Guide for the April 2018 *ChemMatters* article above contains a lesson about isolating and testing milk proteins that could be adapted to use with milk alternatives.

# Web Resources for More Information

**Milk alternatives, almond, soy, rice, and coconut**

“Comparing Milks: Almond, Dairy, Soy, Rice, and Coconut” describes each milk, summarizes their pros and cons, and displays the comparative nutrient profiles in table format.

(<https://www.healthline.com/health/milk-almond-cow-soy-rice>)

“Dairy Milk Substitutes: Soy, almond, and others” discusses the nutrient profile of each milk substitute, as well as their pros and cons. Links to related articles is an added bonus.

(<https://www.medicalnewstoday.com/articles/273982.php>)

**Other non-dairy milk alternatives**

“The Best and Worst Milks and Milk Substitute Types” analyzes the pros and cons of several alternative milk products and gives recommendations for a specific brand of each one.

(<https://www.eatthis.com/best-worst-milk-alternatives/>)

The pros and cons of several nut-free, non-dairy milk alternatives are discussed at this site.

(<https://www.thekitchn.com/nut-free-non-dairy-milk-256963>)

**Soy isoflavones**

“The Healing Power of Soy’s Isoflavones” discusses the many health benefits derived from a diet rich in soy.

(<https://www.fwhc.org/health/soy.htm>)

A number of scientific articles about isoflavones and their application to a variety of medical conditions can be found at this site.

(<https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/isoflavones>)

**Coconut milk and lauric acid**

In “Lauric acid-rich medium-chain triglycerides can substitute for other oils in cooking applications and may have limited pathogenicity”, the author presents the chemistry of lauric acid metabolism and the effects of the resulting ketones on the brain and body.

(<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4975867/>)

“The Health Benefits of Coconut Milk” briefly explains the benefits of the medium-chain fatty acids like lauric acid that are found in coconut milk.

(<https://www.bbcgoodfood.com/howto/guide/ingredient-focus-coconut-milk>)

**Casein micelles**

This site includes more in-depth information about casein micelles.

(<https://www.uoguelph.ca/foodscience/book-page/structure-casein-micelle>)

Information about the composition of the milk proteins casein and whey can be found at this site.

(<http://ansci.illinois.edu/static/ansc438/Milkcompsynth/milkcomp_protein.html>)

**Hormones in milk**

“How does dairy affect your hormone levels?” discusses the hormones naturally occurring in milk and how they affect your own hormone levels.

(<https://www.quickanddirtytips.com/health-fitness/womens-health/how-does-dairy-affect-your-hormone-levels>)

In “Hormones: What’s in your Milk?” the author includes a table of the origins of the hormones that are present in cow’s milk and provides information about the hormones.

(<http://igrow.org/livestock/dairy/hormones-whats-in-your-milk/>)

**Mixtures chemistry**

This source contains multiple links where students can find additional information on chemistry topics related to mixtures.

(<https://www.thoughtco.com/solutions-suspensions-colloids-and-dispersions-608177>)

In the short article “Colloid Chemistry in the Coffee Shop”, the author presents the chemistry concepts of colloids, solutions, and emulsions while discussing the composition of different coffees and even donuts.

(<https://eic.rsc.org/opinion/colloid-chemistry-at-the-coffee-shop/2020990.article>)

**Immunoglobulins and cytokines**

“Effects of Bovine Immunoglobulins on Immune Function, Allergy, and Infection” reports on the research into the effect of bovine immunoglobulins from milk on human infants.

(<https://www.frontiersin.org/articles/10.3389/fnut.2018.00052/full>)

“Cytokines in Human Milk” presents information on the role of cytokines in mediating the immune response to pathogens.

(<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.603.7183&rep=rep1&type=pdf>)

**Homogenization and pasteurization**

“Pasteurized vs Homogenized Milk: What’s the Difference?” explains the pasteurization and homogenization processes used by the milk industry.

(<https://www.huffpost.com/entry/pasteurized-homogenized-milk_n_5606168>)

**Dairy milk vs nut and seed milks (Oh, the politics!)**

“Nut Milks are Milk Says Almost Every Culture Across the Globe” exposes students to the culture and politics surrounding the dairy milk industry vs the nut milk industries.

(<https://www.smithsonianmag.com/history/nut-milks-are-milk-says-almost-every-culture-across-globe-180970008/>)