Curriculum Units by Fellows of the National Initiative
2017 Volume IV: Chemistry of Cooking

Being Corny: Using Popcorn to Explore Thermodynamics

Curriculum Unit 17.04.05, published September 2017
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Introduction

Popcorn. Depending on your age, different images spring to mind. Maybe it's a buttery bucket dancing across a drive-in theater screen or the magical Jiffy Pop commercial from the 1970s. For most students today, if it is made at home, it comes in a microwaveable bag, usually pre-seasoned. Americans eat 90% of all the popcorn produced in this country, yet very few ever stop to think about what makes popcorn pop.

As noted French anthropologist Claude Levi-Strauss once said, "the scientific mind does not so much provide the right answers as ask the right questions." As teachers, when we present students with a phenomenon, our goal should not be to have students give us a single textbook answer. Instead, what we really want is for them to generate a series of questions. It is from their own attempts to answer those questions that they will come to make sense of the world around them. In this unit, my goal is to demonstrate how investigating what makes popcorn pop can lead to a better understanding of thermodynamics and molecular interactions at the middle school level.

I am currently a sixth grade science teacher at Henry B. DuPont Middle School, a comprehensive public middle school in the Red Clay School District. It has approximately nine hundred students distributed over the sixth through eighth grade band. H. B. is located in a suburban setting but draws from both the city of Wilmington and the suburbs of Hockessin and Newark with a present composition of forty percent city and sixty percent suburban. Our feeder pattern consists of eight different elementary schools. There is a great disparity between the urban and suburban students on average when it comes to academic readiness and diversity of background knowledge. It is not a matter of potential ability but previous opportunities and, in some cases, differing expectations. The academic range in science has further been extended by increasing the amount of inclusion.

Rationale

Delaware’s science curriculum is in a transition phase which allows me some freedom to create learning opportunities that align to the Next Generation Science Standards (NGSS), even if they don’t align to the current grade level curriculum map. The aim of the three stranded approach of the NGSS is to more fully engage students in critically using science rather than memorizing facts. At the same time, science should be for all, including those that struggle with literacy. My job is to design experiences and share visual representations that will help students discover and understand key ideas relating to temperature and change of state in some cases with minimal reliance on text support.

This particular unit is designed to meet both the NGSS and a wide range of students’ abilities and backgrounds. Students will use science and engineering practices to answer a question of their own choosing while incorporating Common Core math and language standards. Although I will be implementing it in sixth grade, it could be used across the middle school grade bands.

The unit is divided into three parts. It will start with the phenomenon of popping corn. Students are provided with a variety of resources to build background knowledge. Then students will look at the thermodynamics of heat transfer as it relates to phase changes using water. Lastly, they will design, execute, and analyze their own experiments connected in some way to popcorn. Depending on readiness, students may do additional research on the structure of saturated and unsaturated fatty acids as it relates to both oils used in preparation and in flavoring.

As stated earlier, this unit serves as a bridge. In the Science Education for Public Understanding Program unit “Studying People Scientifically,” students learn about some aspects of investigation protocol such as the use of a control, multiple trials, sample size and data analysis. They learn about qualitative and quantitative data and how each type provides information. “Being Corny” increases the rigor by requiring the students to generate the questions, hypotheses, and procedures. The properties of water and its changes of state provide a link to the Earth History unit that follows. Whether as a source of weathering (frost wedging), erosion (glaciers, running water), or transpiration and evaporation, water’s changing states affect the Earth’s surface. Lastly, the concept of transformation of energy and energy and motion relate to the current Forces and Motion unit.

Objectives

There are several key science concepts that students will explore through the phenomenon of making popcorn. At the simplest level, they will discover that it is the structure and the percentage of water in the kernel of popcorn which allows the pressure of the water vapor to build until the hull bursts. Students will connect Gay-Lussac’s Law, which describes the relationship between pressure and temperature, given a constant volume of a gas to the pressure change inside the kernel. This change of state of the water is due to the change in the arrangement and movement of the molecules as a result of having energy added in the form of heat. Furthermore, there are different ways for electrical energy to be converted to heat energy which in turn affects how efficiently corn pops. On a more general level, students will discover that matter has different properties depending on whether it is in a solid, liquid, or gas phase. They will connect changes of temperature with the changing motion of molecules and how that relates to density. Lastly, they will see how the molecular structure of a substance determines its properties.

Content

Laws of Thermodynamics

Zeroth Law states that if two thermodynamic systems are each in thermal equilibrium with a third, then they are in equilibrium with each other. Putting it in algebraic terms, if A = C and B = C, then A = B. The First Law of Thermodynamics is that energy can neither be created nor destroyed. It can only change forms. In other words, the net heat given to a system equals the net work done by the system. The Second Law of Thermodynamics states that heat energy moves from less structure to more structure. In other words, heat will always be transferred from a higher source which is hotter and more disorganized to a lower one which is colder and more organized, until the two are in equilibrium. The Third Law of Thermodynamics is that as temperature approaches absolute zero, the disorder and randomness of a system approaches a constant minimum. In other words, at absolute zero, molecular movement is almost fixed in time and space.

Types of Heat Energy

Conduction is heat energy transferred from one thing to another through direct contact. Convection is heat energy transferred through indirect contact, for example through the flow of air or water. Radiation is heat energy transferred from one object to another through space by electromagnetic radiation.

Phases of Matter

There are five main phases of matter: solid, liquid, gas, plasma, and Bose-Einstein Condensates. For the purpose of this unit, I will focus on the first three. The main difference in the structures of each state is in the densities of the particles. In the solid phase, matter has a definite shape and volume. The particles that make it up, either atoms or molecules, are joined together by strong bonds which give it a fairly tight structure. Sometimes the bond arrangements create a repeating pattern known as a crystal lattice. Quartz, granulated sugar, table salt, and ice all display a crystal lattice pattern. From the outside, solids look static but inside, the molecules continue to vibrate but stay in place relative to each other. In some cases, like water, volume may be larger in the solid state than the liquid state due to the arrangement of the molecules. Matter in a liquid phase has a definite volume but no definite shape. The bonds are weaker than in the solid phase and the particles are able to move further apart. While volume remains constant, liquids take on the shape of their container. In the gas phase, matter has neither shape nor volume. The forces attracting the particles are so weak that the atoms and molecules can spread out to fill the available space.

Elements and compounds can move from one state to another when specific physical conditions change. A sufficient change in energy and/or pressure can cause a phase change. Most elementary students are familiar with “melting” and “boiling” to describe the state changes from a solid to a liquid and a liquid to a gas, respectively, as they are things they experience in their everyday lives; ice melts and water boils. They may also know “freezing” and “condensing,” liquid to solid and gas to liquid, from learning about the weather or the water cycle. Most, however, do not know that “sublimation” describes going from a solid phase to a gas phase, as in dry ice. When demonstrating sublimation with dry ice, I also discuss condensation because carbon dioxide gas is colorless and odorless. The smoke that students see is the water vapor in the air changing state from a gas to a liquid as the heat is transferred to the colder carbon dioxide gas.

The easiest way to add energy is to add heat. The more energy the atoms and molecules have, the more they move. When a substance transfers its heat, it loses energy and the particles move closer together. A second way to cause a phase change is to increase pressure. Examining the ideal gas law will help us to understand the relationship between pressure, volume, and temperature. The kinetic theory states that all gases are made up of very small particles with no forces of attraction or repulsion between them. These particles move randomly, independently, in straight lines until colliding with the walls of their container or each other, which causes them to mix uniformly. The temperature of the gas reflects the average kinetic energy of the gas particles. When looking at the mechanism of popping corn, the two most important variables are pressure and temperature. Since the water is contained within the pericarp, the popcorn hull, volume is constant. Gay-Lussac's Law states that the pressure of a given amount of gas held at constant volume is directly proportional to the Temperature in Kelvin units. As temperature rises, the pressure of the gas, water vapor, rises.[1]

The Kelvin scale is the logical extension of the relationship between temperature and volume. At absolute zero, theoretically there is no molecular movement. Each unit on the Kelvin scale equals one degree on the Celsius scale. Although my students will use the Celsius scale for collecting and analyzing data, I will give them the conversion formulas: $F = C \times 9/5 + 32$ and $C = (F – 32) \times 5/9$

Research

What makes popcorn pop? The short answer is water found inside the kernel. Yet science is as much, if not more, about the questions rather than just the answers. Lots of foods have water inside them, but they don't pop in the microwave. Or do they? Consider a watermelon; it has so much water that it is even part of the fruit's name, yet we don't put it in the microwave. Maybe it's a question of seeds. We don't expect the fruit to pop; however, neither do the watermelon seeds. In fact, there are very few seeds that meet the structural conditions needed to pop; amaranth is one, but none of them do it as well as popcorn.

History of Popcorn

Who invented this culinary marvel? Archeological evidence suggests that popcorn is a naturally-occurring variety of corn. In the 1940s, the Rockefeller Foundation, in conjunction with the Mexican Ministry of Agriculture, collected more than 2000 varieties of corn, *maize*, from Mexico. Among those listed were four "ancient indigenous" races of corn: Palomero Toloqueno, Arrocillo Amarillo, Chapalote, and Nal-Tel based on ear and kernel characteristics. Like modern popcorn varieties, all four have pine cone shaped ears and small dense kernels. Archeological findings support their claim of antiquity. Brown Kernels about 4000 years old related to Chapalote were discovered in the Bat Cave of New Mexico. In La Perra Cave, in northeastern Mexico, 2000 year old cobs related to Nal-Tel were found.[2]

There are five main types of corn: flint, sweet, dent, flour, and popcorn. Flint corn (*Zea mays indurata*) has kernels with hard outer shells and can range in color from white to red. This is the type associated with ornamental corn. It can also be used as animal feed. Central and South America are the largest growers of flint corn today. Sweet corn (*Zea saccharata or Zea rugosa*) is the type most eaten by people, either fresh on the cob or processed as a frozen or canned food. It gets its name because it has more natural sugars than other types of corn at the same developmental stages, 10% for sweet corn compared to 4% for field corn. However, once picked, the sugars begin converting to starch, losing up to 50% of its sweetness after one day. Dent corn (*Zea mays indenata*) is also known as field corn. It gets its name from the indentations on the kernels at maturity. It can be white or yellow, contains both hard and soft starches and is usually used as animal feed, in processed foods and in various industrial products including ethanol. The fourth type's name flour (*Zea mays amylacea*) explains its use. It has a soft, starch filled kernel, that easily grinds down to produce the starch flour that is used in many different food preparations. In addition to supplying nutrition, starch is what gives cooked food its shape. It is usually white but can also be other colors as in blue corn tortilla chips. Flour corn is one of the oldest cultivated types and the one mostly grown by Native Americans. Last, but certainly not least, is popcorn (*Zea mays everta*). Popcorn is related to flint corn in that it has a hard exterior shell, known as the pericarp. Inside is a soft endosperm and water.[3]

Agronomists classify the popcorn endosperm as everta because it turns inside out, or everts, when heated. The water inside the kernel is changed to steam. The increased pressure causes the pericarp to split and the starchy endosperm flakes producing the treat we call popcorn. In other types of corn, either the steam escapes gradually or the kernel splits without exploding.

That the everta class has remained distinct over so many centuries is due to a quirk in its genetics. Although its pollen can fertilize other types of corn, most but not all evertas have a gene, Gametophyte Factor I, that inhibits it from being pollinated by other types of corn. The gene comes in 2 forms, Gal-M gene slows down the pollination by other species, allowing time for everta pollen to sneak in and do the job. Gal-S gene is even more effective by completely blocking other varietal pollen.

Breeders use this one-way flow of genetic information by breeding their everta with purple dent corn. If the resulting ears have the purplish tinge then the everta lack the desired gene. If, however, the pigment is missing, then the trait is there. This test allows organic seed corn producers to exclude genetically modified pollen from dent and sweet corn types. As of this writing, although many other varieties of corn have been genetically modified to be more drought and disease resistant, the popcorn variety of corn has not.[4]

Physical Description

A popcorn kernel has three important parts: the pericarp, also known as the seed coat or hull, the endosperm, and the embryo. The pericarp provides protection for the endosperm and embryo. In the case of popcorn, damage to the pericarp can mean a loss of water and less popping. The endosperm fills most of the kernel and is the main energy source for the developing seedling. The embryo contains the miniature plant. It also contains a cotyledon, which provides energy for germination.[5] Popping corn kernels have a dense, hard translucent endosperm with a tiny bit of soft endosperm next to the embryo. Of all the grain corns, popcorn types have the smallest kernels, appearing as either pearl type or rice type. Pearl have a rounded top whereas rice come to a point. Some varieties may produce ears with both types but a single ear is always homogenous. There are anywhere from 14 to 28 rows of kernels on a cob and they appear in a variety of colors. The color of the kernels has no effect on the color of the popcorn as it is the white endosperm that explodes. So, while the gourmet colored popcorn will look prettier than its plain golden yellow cousin when displayed in the glass jar on the counter, there will be no color difference in appearance when popped. When fully dry, the kernels and pedicel, the portion of the pericarp attached to the cob, easily detach but the brittle nature of the kernels make gentle handling a must. Kernels with damaged pericarps will not pop as well because the steam inside will escape through the cracks before building up enough pressure to cause the endosperm to explode.[6]

Modern Cultivation

Commercial popcorn cultivation has existed in the United States for more than 150 years. In 1865, Fearing Burr (a noted seeds man) listed 5 "parching corn" varieties available: two with white kernels, two with yellow and a red rice type. As of 2011, the Seed Savers Exchange inventory listed 31 varieties of popcorn. Commercial popcorn today is bred for their flake types and popping expansion. The more the starchy endosperm expands, the softer the piece. There are two types of flakes: "Butterfly" and "Mushroom." Butterfly popped kernels are more angular, softer and are generally the shape most associated with the popcorn made at home and eaten in theaters. Mushroom type is compact and more rounded. Since it has less breakage, it is better suited for being kettle flavored i.e. caramel corn. Mass producers tend to favor hybrids that produce a bland neutral flavor so as not to interfere with the added flavorings. [7]

Recently, there seems to be a resurgence in interest in heirloom varieties and a backlash against the hybrids. In the *New York Times* article "Heirloom Popcorn Helps a Snack Reinvent Itself,"[8] Kim Severson suggests that this may be the latest example of popcorn's renaissance. In the 1880s, steam popping machines brought the treat from the farm kitchen to the cities. It was an integral part of movie escapism in the Great Depression. Jiffy Pop, with its ease of preparation, brought new life to the snack in the late 1960s after television replaced going to the movies. The nature of the popping mechanism and the way that a microwave works were a perfect match. Most microwave ovens still have a popcorn setting. A walk through the supermarket aisle reveals at least a dozen different brands and types of microwave popcorn. Yet even as the popularity seemed to be increasing, there were a few people wanting something different: a popcorn whose taste comes from the seed without any added oils, butters, flavorings, or salts. Gene Mealhow, farmer and owner of "Tiny but Mighty" heirloom popcorn, blames Orville Redenbacher for the change in emphasis from taste to size. Redenbacher, a 1928 graduate of Purdue University, used genetic material developed through his university's alumni seed improvement association to create a hybrid seed that produces bigger kernels with a higher popping rate—all at the cost of taste. According to Mealhow, "Orville produced a giant popcorn to be a delivery vehicle for butter and salt."[9]

As part of developing this unit, I obtained several different types of popcorn kernels to see for myself what, if any, differences existed. I won't influence the reader by sharing my opinions, but the experience did affect my planned teaching of this unit.

Globally, the United States is the largest producer of popcorn, but we consume 90% of it almost exclusively as snack food. This leaves only 10% for export. Argentina ranks second in production, though their yield is approximately half of the U.S. total. Their domestic use is much lower, being largely limited to public places like movie theaters and bars but little home consumption. As a result, they export 95% of their yield, making them the largest exporter of un-popped corn in the world.[10]

Ways to "Heat" Popcorn: Historical to Present

If we had a time machine, we'd probably discover that the first instances of "popping" corn were accidental. Tomie DePaoli's *Popcorn Book*, an almost mandatory elementary school read around Thanksgiving, states that Native Americans used to throw kernels directly into a fire and then try to catch the morsels as they popped and flew back out. While it seems fanciful, scientifically it is possible. However, De Paoli also depicts popcorn as being served at the First Thanksgiving.[11] According to Stephanie Butler, writer for the History Channel, there are no contemporary accounts that reference popcorn. What she does verify is that in 1612, French explorers saw some Iroquois women popping corn in clay pots. They would fill the pots with hot sand, then add the kernels before stirring it with a stick. When the corn popped, it came to the top of the sand.[12] Holding the dried ear of corn over a fire is another method presented by de Paola and verified by *National Geographic*.[13] However, I wasn't able to verify tossing the kernels directly into the flames as a cooking method.

Until the invention of the microwave, all methods of popping corn were basically the same. Heat was applied to the outside of the popcorn kernel, either directly or through oil. That heat energy was then conducted through the pericarp, the hull, and transferred to the starchy endosperm and water found inside the seed. Two physical changes occur. The endosperm becomes a gelatinous starch that solidifies when released. The water molecules go through a change of state from a liquid to a gas. When the pressure of the water vapor exceeds the internal strength of the pericarp, the kernel breaks open, turning itself inside out in the process with the starchy endosperm now the fluffy outside and the brittle pericarp reduced to almost nothing.

The first widely successful commercial poppers appeared in the United States in the late 1800s. Just as Edison is associated with the light bulb, Charles Cretors was the man for roasting and popping machines. He wasn't an engineer but a shopkeeper who sold candy. Disappointed with a peanut roaster he'd purchased, he decided to make a few adjustments. He was so successful that one of his providers decided to sell his improved version, thus starting C. Cretors and Company, which continues to make popcorn poppers today largely for commercial venues. The history of popcorn machines is fascinating and there are even two museums devoted to them: J.H. Fentress Antique Popcorn Machine Museum in Holland, Ohio and the Wyandot Popcorn Museum in Marion, Ohio.[14] A common element of most of the early machines was the use of oil to enhance the flavor and the aroma and it is still the method used most often today in non-microwave popping.

Contemporary non-commercial popcorn poppers fall into two main types: those that use air and those that use an "arm" to move the kernels along and away from the heated surfaces. Rather than discuss both, I want to focus on the air popper as it generates the most student misconceptions. The name is misleading as it gives the impression that the popping comes from heating the air rather than the kernel. Like other stand-alone electric poppers, the kernels are heated by coming in contact with a metal plate, either directly or through the heated oil. Under the plate is a heating element which is connected to both a thermostat and a thermal fuse. The thermostat consists of two different metal arms that react differently to changing temperatures. As the thermostat gets heated, one arm will expand and break the circuit as it bends away from the other. As it cools, it returns to position and current can flow again. It's what helps regulate the temperature for optimum popping. The thermal fuse is a safety feature. In case of dangerous overheating, it melts and the circuit is permanently broken until a replacement piece can be installed. The purpose of the air is to move the popped kernels away from the heat source. Since they have greater surface area, they are lifted out of the way, making room for the un-popped kernels. This is done with a small fan powered by a direct current motor. Four diodes, placed on the circuit board, keep the current moving in only one direction, in effect, turning the alternating current from the wall to the direct current needed to power the motor. As the motor spins, it turns a small plastic disc with fan blades molded into it. The air then escapes from slots in the heating element portion.[15] In a rotating "arm" model, the oil, if used, heats up first and then the heat energy is transferred, conducted, to the popcorn seed. The arm helps to insure more even heat by turning the kernel over and moving the lighter popped pieces out of the way of the heavier un-popped kernels.

Microwave energy works completely different. Instead of the heat being applied externally, the rays directly excite the water molecules inside the pericarp. Popcorn played an important role in the development of the microwave oven as a cooking device. The first patent for microwave popcorn actually belongs to a company that provided magnetron tubes, an essential part of the radar systems used in World War II. The story goes that one day, Percy Spencer, a scientist at Raytheon, was experimenting with magnetrons in his lab, looking for new uses. He noticed that the candy bar in his pocket had melted and wondered if it was due to the device. He sent out for popcorn kernels, put them in a paper bag and held them next to a magnetron. Voila! Popcorn. Spencer then built a rudimentary metal box with a magnetron in it, creating the first microwave oven. After researching further and conducting more experiments, Percy Spencer filed for and successfully received a patent in 1945. For his invention, Spencer received no royalties, but he was paid a one-time, two-dollar gratuity from Raytheon—the same token payment the company made to all inventors on its payroll at that time for company patents.[16] Before you think bad of Raytheon, it was and still is the way things work in industry. As a research scientist with Hercules, my father developed many innovative processes and was paid the same two dollars for each time he had his name on the patent.

In 1954, Raytheon produced the first commercially built microwave oven which was a little under six feet tall and weighed around seven hundred and fifty pounds. It cost between two and three thousand dollars and was initially used in restaurants, railways and ships as they were too bulky and expensive for home use. It also had some shortcomings; for instance, meat, while it cooked, wouldn't brown, and not all things heated evenly. After further research and modification in design, the first microwave oven for home use was put on the market by Amana, a Raytheon subsidiary, under the name "RadarRange" in 1967. It could be had for around five hundred dollars and fit on a kitchen counter.[17]

As I researched the origin of the microwave oven, I was taken back in time to Christmas of 1971. There was a large wrapped box sitting in the dining room addressed to my mother from my father. For weeks, she had tried to guess its contents: sheets and towels, clothes, a whole lot of smaller boxes inside one big box. Each time, my dad only smiled and said no. He was definitely more excited than she was when the gift was finally opened: a brand new microwave oven! I can still remember the first thing we made in it, cups of water for either tea or hot chocolate. Yes, we could have used a tea kettle, and usually did, both before and after, but this was a new way of cooking.

I'll confess that up until designing this unit, the microwave oven had remained a magic box to me. So how exactly does a microwave oven work? It all starts with electricity, a transformer and a magnetron. The alternating current from the wall needs to be transformed to a high voltage direct current of 2000-3000 volts which is the job of the transformer. This current is then sent to the Magnetron, which is a kind of vacuum tube. Before there were transistors, many electronic devices had tubes. They are made of glass with a filament that allows for a controlled flow of electrons. Inside the magnetron, voltage is applied to a filament sending a stream of electrons down the inside of the metal tube. As the electrons move, circular magnets cause them to spiral. The spiraling beam passes by holes in the side of the tube which causes high frequency radiation to be emitted from the end of the tube. This radiation has a wavelength of about 12 cm, 5 inches, and can pass through glass and transparent plastic, which is why glass lids aren't a problem. The radiation, however, doesn't pass through food but is absorbed by it, causing the food molecules to vibrate. They vibrate because they are not symmetric which produces a positive and a negative end, which aligns with the electric field. Since the electric field created by the microwaves is constantly changing, so are the food molecules. Think of it as watching a magnet flip over and over, as a stronger magnet's pole orientations keep shifting. The back and forth motion creates the heat that cooks the food. To help things cook more evenly, many microwave ovens have a fan that interrupts the flow of radiation to spread it more throughout the cooking chamber.[18]

That explanation helped a little in identifying the hidden parts of the microwave oven, but I still struggled with the science part of it. I readily tell my students that I don't have all, or even most, of the answers, but my own observations of how different foods heated told me that I was missing something important in the way microwave ovens work. I also needed to clarify what electromagnetic radiation was and how microwaves were different than other forms of radiation. Electromagnetic radiation are waves of pure energy that travel through space at the speed of light. The properties of electromagnetic radiation waves are determined by their specific wavelength and energy. It is an inverse relationship; the shorter the wavelength, the greater the energy. When comparing the potential cooking power of two microwave ovens, one needs to consider both the power output, which is usually between six hundred and nine hundred watts and the size of the cooking space. Magnetron power is a measure of watts produced not the amount of electricity used. To compare efficiencies, you need to divide power by cubic feet.[19]

So why doesn't all food heat up the same? The answer is water content, or something else that is hydrophilic, attracted to water and also polarized. The molecular structure of water is a dipole, which means that it lines up with an electric field, like a compass. The microwaves produce an electric field that shifts polarity almost five billion times per second. Likewise, the individual water molecules shift their orientations. This causes them to bang against each other and gain speed. Faster moving molecules mean hotter molecules. Although they have a lot of energy, microwaves don't penetrate very far which is why there are two other heating mechanisms occurring. Think back to popping corn. Even though there are recommended times, we use our ears to decide when we should stop the cooking.

The radiation causes the water molecules in the food to heat up. Even before they pop, kernels get warm. This warmth is then conducted to the adjacent less hot molecules; The Second law of Thermodynamics in action. At the same time, the water is being turned into steam. In most cases, the water vapor goes through the rest of the food, transferring its heat. In the case of popcorn, the steam builds up inside the pericarp until the internal pressure exceeds the hull capacity, approximately 135 psi, pounds per square inch. At that point, the hull ruptures, releasing both the steam and the starchy endosperm. The steam now acts as convection heat so that the remaining kernels are being heated from within and without. After the initial few pop, we hear most of the rest pop shortly after. When popping slows down, it is because the bulk of the steam energy has been used. A way to demonstrate this is to pop popcorn in a microwave safe container with a lid and without. Since we know that the waves can penetrate glass, any difference in efficiency will be due to the steam and not the microwaves.

As Spencer had demonstrated back in 1945, microwave energy could be used to cook popcorn but it would require a change in the food packaging to increase its popularity. The first patent for a microwave popcorn bag was issued to General Mills in 1981, and home popcorn consumption increased by tens of thousands of pounds in the years following.[20] The modern microwave popcorn bag was actually the center of a very big lawsuit between Hunt Wesson, Orville Redenbacher brand, and General Mills, Act 11 brand. While it is possible to use a plain folded paper bag to hold the kernels, companies soon saw the added value of creating a better vessel. People loved the convenience of Jiffy Pop as it contained the oil, popcorn, and seasonings all in one. What if the same could be done with a coated bag that could be used in a microwave oven? Act 1 popcorn went so far as to use real butter, oil and salt but that required refrigeration. Act 11 solves the problem by using synthetics. Adding flavoring agents also meant coating the inside of the bags. Flavor was better but there were still too many un-popped kernels. What was needed was a way to distribute the heat more evenly. Although microwave ovens operate at higher efficiency ratings and can cook food quicker, the nature of the heat means that the waves are not always evenly distributed. To get that effect, you need a material that absorbs a small portion of the radiation and converts it to heat.[21] Metal, used correctly, can do that job. If it is too thin, it overheats and melts. If it has sharp points, it can cause sparks. The metal threads now found in most microwave popcorn bags, have been designed to avoid both issues while still providing a conduction heat source. As a result, the modern microwave popcorn bag utilizes all three times of heat: radiation from the magnetron, conduction from the bottom of the bag and convection from the steam released by the bursting pericarps. Evidence of the latter two can be found in heat outside the “floor” of the bag, the inflation of the bag during cooking and the release of steam when opened carefully.

Teaching Strategies

Instruction will incorporate the following eight Science and Engineering Practices. Students will obtain, evaluate, and communicate information as they use multimedia to build background knowledge and answer the question of what makes popcorn pop. They will use mathematics and computational thinking as they conduct an investigation looking at water content and popcorn volume, kernel size, and percentage of popped kernels. They will develop and use models to show the molecular structure of water and its polarity. They will create density models to show change of phase and use technology as they collect and graph temperature/time data. Defining problems and designing solutions will be used as students strive to create insulators for ice cubes with the goal of keeping them from melting the longest. Lastly, they will plan and carry out an investigation of their own choosing in some way connected to popcorn, analyzing and interpreting their data before engaging in argument with evidence. Specific strategies chosen to best meet the needs of this age group and diverse population include flexible grouping depending on the nature of the activity, rotating roles and responsibilities, encouraging participation and building vocabulary and content knowledge through think, talk, write, pair, share, modify writing. The emphasis will be on formative assessment using focus questions and providing multiple pathways to demonstrate knowledge for summative assessments. The three strands of the Next Generation Science Standards (NGSS) will be the basis of creating assessments that incorporate the cross cutting concepts and science and engineering practices along with the disciplinary core ideas on matter and its interactions.

Student Activities Popcorn Science

Introduction

Phenomena-Popcorn

Day 1 Activating Prior Knowledge

Warm up activity: Supply each student with a piece of 8 1/2 by 11 inch scrap paper, blank on one side. On it, have them label three columns: know, sense data, questions, but instruct them not to put their names on the paper. Give students 3 minutes to write down as much as they can in the know column about popcorn and any questions that they might have in the third column. For the students who respond “I don’t know anything” or “I don’t have any questions” prompt them by asking them to think back on the last time they either ate or saw popcorn. Then show a clip of an old style popcorn ad either from a drive-in, movie theater, or school house rock.

Then teacher makes the popcorn using a non-microwave method. Depending on resources available it could be a stand-alone popper, either oil or air, jiffy pop over a hot plate, a regular lidded pan with kernels over a hot plate or the specialized cookware needed with an induction burner. Most students have only had popcorn at the movies or from a microwave so they will be interested in the cooking as well as the prospect of eating. As the process occurs, ask students to note what they see, hear, or smell as well as any additional questions that come to mind. Give two minutes at the end for students to add to notes. Then have students do a "popcorn" share. Each student crumples up his/her paper, form a circle and then "pop" the corn by tossing papers in the air into the center of circle. Repeat 2 times and then have students open up and share what is on the paper in front of them. While passing out the popcorn, have students write any questions from the claimed paper on a sticky note and add to a class chart. Show students the short video of the popcorn expanding and then ask them to explain the phenomena. Use I think, he thinks, we think strategy where each student writes their explanation; then students partner up and restate their partner's explanation; then they come up with one explanation to present to the group.

Day 2 and 3 Investigating the Influence of Water on Popping Rate

Warm up activity: Have students discuss ways with their shoulder partners to prove that the amount of water inside the pericarp affects how the popcorn pops. Through Socratic questioning techniques, lead them into the following experiment. Working in teacher-selected heterogeneous groups of three to four students with clearly defined roles, students will carry out the following experiment. Students will count out 6 bags of 50 kernels each of the same type of un-popped corn. They will weigh and record the starting weights of each bag. Three of the bags will be the controls, three of the bags will have 20 ml of water added, and three will have their contents removed, put in a 200 degree oven for an hour, allowed to cool and then replaced in the bag. On day 2, students will reweigh each of the three bags, after pouring off and measuring any remaining water. There should be a difference in weight. The soaked seeds should weigh more, the dried seeds less and the control should be the same. Students will then try to pop each of the six batches using the same method. They are collecting three pieces of data for each sample: the percentage popped, the average kernel size (measure a random line of 10 using centimeters, then divide) and the total popped volume. Depending on the readiness of the students, different averages could be considered. It would make sense to use the mean for volume and length as both can be fractional parts whereas it doesn't make sense to use it for number/percentage popped. Students could also use the median for all three. Again depending on the readiness of the students, students could create bar graphs for each category. More mathematically advanced students could create box and whisker plots which will show how reliable the data are.

Day 4: Claim, Evidence, Reasoning Literature/Experiment Connection

Students will read the *New York Times* article[22] and evaluate for bias. They will then take part in a double blind teacher designed experiment to evaluate claims from within the article. Students will collect qualitative data in the form of taste preference and quantitative data in the form of volume, popped kernel size, and percentage of kernels popped. They will then write a persuasive essay either supporting or refuting the content of the article using experimental evidence.

Days 5-14 Investigating Water and Change of State

In this middle part of the unit, the focus switches from popcorn and the change of state of the water in the kernel to a much broader look at the relationship between energy, temperature and change of state, using water as the medium.

Water Investigations

Part 1: Hot—demonstrating that heating water causes it to bubble and then turn into steam so that eventually all of the water will be gone from the container as the gas expands to fill the area. To raise the rigor, have students collect temperature readings and graph over time and/or measure the amount of water remaining after a few minutes of boiling and/or do in a pot with a clear lid so that students can see the water vapor condensing. This first set of water experiment links to popcorn by letting students see what is happening inside the kernel. To demonstrate that the water vapor takes more room and so increases the pressure inside the hull, attach a non-latex glove securely to the mouth of a flask. As the water changes phase, the glove will inflate. Adding rice to a clear pot will allow the students to see more clearly how the hottest water rises but then starts to cool as it moves away from the heat source and begins to fall back down lacking the energy to transition to water vapor. This cycle is repeated until all of the water reaches the required energy state. On a side note, the rice experiment will also help students develop an understanding of plate movement due to the very slow movement of magma under the crust.

Part 2: Cold—fill a plastic container to the top with water, lay the cover on top but don't seal it, put in the freezer and check the next morning. This activity helps students to discover that water expands when it freezes and that if you let the ice thaw it will fit back into the container. As an extension, have students fill plastic water bottles to the very top and put them in the freezers. In most cases, the ice will expand enough to crack the plastic bottle. This demonstration of filling, freezing and cracking sets students up to understand frost wedging as a principle force of weathering later. This is a good place to look at the molecular structure of water and have students make simple models using toothpicks and marshmallows. More advanced students could consider the valence models of the two elements, and their electronegativity patterns from the periodic chart. This is also a good place to revisit the idea of density. In elementary school, students develop the idea that heavy things sink and lighter things float. In middle school, that understanding is expanded to include the idea of density. Heavy things can float as long as their overall density is less than the substance in which they are floating. The phenomenon of water floating on water is a great entry point. Students can then build density columns using only water, food coloring, and either salt or sugar. As in the heat experiment, students can also collect temperature data over time as a cup of ice changes state to room temperature water. Since my students will all have Chrome books this year, I will incorporate technology by using temperature probes and the Sparkvue software that will collect and graph temperature changes over time. It will allow students to see that there isn't a temperature change until there is a complete phase change.

Part 3: Heat by the Numbers—why do animals huddle together in the cold? This set of experiments is designed to help students discover that heat energy always moves from higher energy to lower energy, hot to cold. To start, heat water until it steams. Then stop and pour into a jar, cover with plastic wrap, and then take the temperature every two minutes until there is no change over three successive readings. Repeat experiment but this time do it with four jars that touch, wait until the four are at the same temperature as the one, then record temperatures every two minutes. Continue until the four jars match the temperature of the one jar. Students can then graph both sets of data as temperature compared to elapsed time. The last experiment gets into the idea of surface area. It isn't that heat is only being lost on the outside. It is that the temperature difference is much less where the surfaces are touching. A variation would be to use five jars, one in the center and four outside and note any differences. To demonstrate that different substances react to heat and cold differently, students could investigate how other substances, like most metals, expand when hot but contract when cold. The differing expansion of metals when heated is behind most thermostats, including the ones found in many popcorn poppers. To discover that water is not the only substance that expands when cooled, students should do the following rubber band experiment. Suspend a paper clip in a shoebox from a rubber band at room temperature and mark the placement. The box assembly is then put in the refrigerator for 20 minutes and then the clip position is marked. Lastly, the room temperature rubber band is heated with a hair dryer for 5 minutes and then the clip position is marked. Students will see that although most substances get larger when they are heated and smaller when they are cooled (think of how we demonstrate increased kinetic activity) rubber bands do the opposite.

Part 4: Engineering a Solution—putting it all together.

Using what they have learned about the transfer of heat energy from hot to cold, students will work in groups to create an insulated drink cooler from commonly found materials. Each group will start with the same size ice cube in a small paper cup. In order to monitor the state of the ice cube, the cooler must have an easily removable and replaceable lid. Students will have to create a design plan before they "shop" for materials. Whenever I give a design challenge, I try and provide a variety of items, some that I know will be more useful than others but I still let students decide. For this challenge, items would include cups of different sizes in paper, plastic, and Styrofoam. Fastening materials would include glue, scotch tape, masking tape, duct tape, string/yarn and a stapler. Insulating materials would include old file folders, plastic wrap, aluminum foil, wax paper, bubble wrap, plastic straws and pieces of material-cotton, wool, and synthetic blends. Paper would be available in both copy weight, construction and cardstock in a variety of colors. As in the real world, there are different costs associated with each. Styrofoam, aluminum wrap and duct tape will be more expensive than file folders, plastic wrap and masking tape. The "coolers" will be tested outside on the tennis courts. Graphic design is a huge thing in middle school. Different colors and types of paper will be available for decorating their containers. Although I won't talk directly about color and heat absorption, some students may have background knowledge from elementary school. As part of the weather kit in first grade, students took temperature readings of thermometers left in the sun in either white or black sleeves. For each item chosen, students have to justify why that material was selected. An example might be that even though Styrofoam is four times the cost of the file folder, it is a better insulator and is also water tight. The winning container will have the longest ice cube melt time at the lowest cost. This is similar to another activity that comes later in the semester when students create earthquake resistant houses. To encourage students to do more thinking in the design phase rather than guess and try, I institute fees for both additional shopping trips and restocking.

Days 15-19 Student Designed Investigation

Students design, conduct, and analyze the results of a question of their own choosing connected to popcorn. This investigation has been broken down into several parts as shown.

The Science of Popcorn

Students will use the science and engineering practices of the NGSS to investigate a question of their own choosing connected to the science of popcorn.

Students have a choice to share their work as a power point/Google slide presentation, a poster, a written lab report, an oral presentation with visual aids or another format discussed with and approved by the teacher.

My topic is:

I plan to share my work as:

Teacher's signature

Step 1: Generating a Testable Question

What would you like to know? Question needs to relate in some way to popcorn.

Requires Teacher signature before moving on to next step.

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Step 2: Personal Background Knowledge

What do you think you already know about this topic that might help you form your hypothesis? Write three to five sentences in one paragraph about your prior knowledge **before** you do any other background research.

Requires Teacher signature before moving on to next step.

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Step 3: Background research

Your work must be at least two paragraphs of four to six sentences. It must contain at least four facts and details related to your topic. Information needs to be in your own words and not just copied and pasted from your sources. You need to use and cite at least 2 sources. Sources may include books, web sites, videos, articles and/or interviews with experts in the field. Make sure that your source is credible. Wikipedia may only be used as a starting point to get sources; it does not count as one of your two sources.

Requires teacher signature before moving on to next step.

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Step 4: Develop a Testable Hypothesis related to the Topic of Popcorn

This may differ from your original testable question. Remember a testable hypothesis is a statement that can be supported by data.

Requires Teacher signature before moving on to next step.

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Step 5: Design an experiment to test your hypothesis. **Describe any anticipated safety issues and how you plan to address them.**

Be sure to only look at one variable at a time and keep the other variables the same. Include clearly labeled data table(s) with units. Remember multiple trials. My goal is for students to do their investigations in the classroom. I will have heat sources and a microwave available. I will also provide basic popping corn. Since they are student designed, it may be possible that a home component is needed. If that is the case, it needs to be approved by both the parents and myself in this stage of the project.

Requires parent signature before moving on to next step.

Step 6: Conduct your experiment.Prior to doing any experiments, we will review the science safety rules.

Gather the data.

Requires teacher signature before moving on to next step.

Step 7: Analyze your data.

What patterns do you see? How can you use graphs, pictures and math to better convey your findings?

Requires teacher signature before moving on to next step.

Step 8: Write your Conclusion

Revisit your hypothesis. Do your data support or not support it? What is your evidence? How does the evidence connect to your claim?

Step 9: Experimental Notes

Reflect qualitatively on the experience. What, if anything, happened that you didn't anticipate? What affect do you think it had on your results?

Step 10: Next Steps

Based on what you learned from this experiment, what question would you like to investigate next? Write a brief three to five sentence paragraph about your new question and possible investigation.

Popcorn Science Investigation Ideas (Scaffolding for students who are unable to generate their own question)

Possible Questions:

Which pops more, Orville Redenbacher or Paragon?

Options-microwave, pot on "stove", table top popcorn maker

Which pops bigger, Orville Redenbacher or Paragon?

Options-microwave, pot on "stove", tabletop popcorn maker

-bigger in average popped kernel size or bigger in total volume

Which heat source pops loose corn better?

Options-microwave compared to either pot on “stove” or tabletop popcorn maker

How does using oil affect the amount of kernels popped?

Options-pot on “stove,” tabletop popcorn maker

How does using oil affect the size of kernels popped?

Options-pot on “stove,” tabletop popcorn maker

-bigger in average popped kernel size or bigger in total volume

How does the type of oil affect the amount of kernels popped?

Options-corn, canola, coconut

How does the type of oil affect the size of kernels popped?

Options-corn, canola, coconut

-bigger in average popped kernel size or bigger in total volume

How does the type of oil affect the taste of kernels popped?

Options-corn, canola, coconut

Scoring Rubric for Popcorn Science Investigation

Students are to design, conduct and analyze the results of an experiment of their own choosing connected to Popcorn. The plan is to do the bulk of the work in class. There are built-in checkpoints along the way.

	All of available points	⅔ of available points	½ of available points
Thinking and planning Testable Question Personal background knowledge Background research Testable Hypothesis 10 points	Did all 4 steps on time and initialed by teacher	Did 3 steps on time and initialed by teacher	Did 2 or less steps on time or missing teacher initials.
Designed an experiment that tests hypothesis Clearly written procedure including materials Only changed 1 variable Controlled for other variables Considered sample size/multiple trials Data Table Including Units 40 points	Correctly and completely did 4-5 parts	Did 3 parts completely and correctly	Did 2 or less parts completely and correctly

Conducted experiment following safety rules and collected data as planned 10 points	Collected all data as planned in safe way	Partial collection of data (time/materials/safety)	Didn’t collect data
Analyzed Data Used fractions, percentages, graphs (bar and/or line) to interpret data as appropriate. 20 points	Full use of data i.e. fractions to percentages, comparison between variables	Incomplete data analysis for both or only one set of data analyzed.	Little to no specific data used in analysis.
Wrote Conclusion Restated Hypothesis Stated whether data supported/did not support Evidence 15 points	Correctly and completely included all 3 parts	Correctly and completely included 2 parts	Less than 2 parts included that were complete and correct.
Experimental notes Reflect on what happened Briefly describe possible next step 5 points	Included both parts	Only included 1 part	Omitted

Teacher Resources

Education World: Popcorn Science. Accessed July 17, 2017. http://www.educationworld.com/a_lesson/03/lp324-05.shtml.

Provides descriptions of several k-8 student investigations with the nature of math, nature of language and nature of science standards. Easy to read teacher format but standards need to be aligned to common core and NGSS.

16 Indian Inventions, From Popcorn to Parkas, Accessed July 27, 2017. http://news.nationalgeographic.com/news/2004/09.

Types of Corn. Accessed July 17, 2017. http://www2.kenyon.edu/projects/farmschool/food/corntyp.htm.

On-line resource that discusses the different types of corn and the properties of each.

Beauchamp, Arthur, Judi Kusnick, Rick McCallum, and Jim Hollander. *Success in Science through Dialogue, Reading and Writing*. Davis, CA: University of California, Davis, 2011.

BolderImage. "History." Cretors. Accessed July 17, 2017. http://www.cretors.com/page.asp?i=12.

Provided the history of commercial popcorn machines.

Bybee, R. W. *Next Generation Science Standards. for States, by States*. Washington, D.C.: National Academies Press, 2013.

Boutard, A. *Beautiful Corn: America's Original Grain from Seed to Plate*. Gabriola Island, B.C.: New Society Publishers, 2012.

This is a comprehensive book on corn. It provided most of the background knowledge on the different types of corn with the emphasis on everta.

Butler, S. "A History of Popcorn." History.com. December 06, 2013. Accessed July 17, 2017. http://www.history.com/news/hungry-history/a-history-of-popcorn.

Good background information on the history of popcorn.

Czerski, H. *Storm in a Teacup: The Physics of Everyday Life*. S.l.: W. W. Norton, 2018.

Hardback book that explains the physics of everyday events including what makes popcorn pop. The author does an excellent job connecting the physics of thermodynamics through different phenomena.

Cooper-White, M. "The Secret Science Behind Popcorn, Finally Revealed." *The Huffington Post*. February 12, 2015. Accessed July 17, 2017. http://www.huffingtonpost.com/2015/02/12/popcorn-physics-science-pops-video_n_6664166.html.

Straightforward description of the process and slow motion video of a kernel popping.

Evans-Hylton, P. *Popcorn*. Seattle, WA: Sasquatch Books, 2008.

Provides some background knowledge but is mainly a recipe book of more than 60 ways to serve popcorn.

"General Mills v. Hunt-Wesson, Inc., 917 F. Supp. 663 (D. Minn. 1996)." Justia Law. Accessed July 17, 2017. http://law.justia.com/cases/federal/district-courts/FSupp/917/663/2140347/.

Transcript of the court case. It provides interesting information and might also be used as background knowledge as part of an invention unit as well as this popcorn unit.

Jorgenson, O., Vanosdall, R., Massey, V., and Cleveland, J. *Doing Good Science in Middle School: A Practical STEM Guide: Including 10 New & Updated Activities*. Arlington, VA: NSTA Press, National Science Teachers Association, 2014.

Excellent resource that describes different effective strategies on doing science with middle schoolers.

Koss, A. G., and Bryant, L. J. *Where Fish Go in Winter: And Other Great Mysteries*. New York: Dial Books for Young Readers, 2002.

This book is the source of the poem “Why does popcorn pop?” With simple language and rhyme, it captures the science of popcorn.

Levy, J. *Incredible Elements: A Totally Non-scary Guide to Chemistry and Why It Matters*. New York: Metro Books, 2017.

This book provides simple explanations with strong graphic support for several of the key concepts of my research including phases, the nature of water, the application of heat and heat capacity.

Moulding, Brett D., Rodger Bybee, and Nicole Paulson. *A Vision and Plan for Science Teaching and Learning: An Educator's Guide to a Framework for K-12 Science Education, next Generation Science Standards, and State Science Standards*. Place of Publication Not Identified: Essential Teaching and Learning, 2015.

Nuwer, R. "Popcorn Physics 101: How a Kernel Pops." *Scientific American*. Accessed July 17, 2017. https://www.scientificamerican.com/article/popcorn-physics-101-how-a-kernel-pops/.

Explains both the sound and the spring like action. Using slow motion camera identifies the starch molecules reforming into leg like appendages.

"Percy Spencer." NNDB. Accessed July 17, 2017. http://www.nndb.com/people/766/000165271/.

Background information on the inventor of the microwave oven.

"Percy Spencer." Famous Inventors. Accessed July 17, 2017. http://www.famousinventors.org/percy-spencer.

Background information on the invention and inventor of the microwave oven.

Perlman, S. "The Physics of Popcorn." Prezi.com. May 19, 2015. Accessed July 17, 2017. https://prezi.com/v1tmfz0ovt_x/the-physics-of-popcorn/.

Could be used by teacher as part of a flipped classroom or introduction. One caution is the use of Charles' Law which deals with the change in volume rather than the change in pressure.

"Popcorn." Andreoli S.A. Accessed July 17, 2017. http://www.andreolisa.com.ar/popcorn.html.

Gives information about the export of popcorn from Argentina.

"The Science of Popcorn." Carolina Biological Supply: World-Class Support for Science & Math. Accessed July 17, 2017. http://www.carolina.com/teacher-resources/Interactive/the-science-of-popcorn/tr23952.tr.

Step by step lab to investigate pressure using popcorn. Would not be suitable for middle schoolers as it involves Bunsen burners. May be able to do it as a demonstration with either a hot plate or convection burner. Safety concerns over the heat source, high temperatures of the oil and popcorn breaking free of its aluminum foil cover

Severson, K. "Heirloom Popcorn Helps a Snack Reinvent Itself." The New York Times. September 30, 2014. Accessed July 27, 2017. https://www.nytimes.com/2014/10/01/dining/heirloom-popcorn-helps-a-snack-reinvent-itself.html.

News article that could serve as a close reading piece for bias and also as background research for a taste test experiment.

Sobey, E. J. C. *The Way Kitchens Work: The Science behind the Microwave, Teflon Pan, Garbage Disposal, and More*. Chicago, IL: Chicago Review Press, 2010.

"The Thermodynamics of Popcorn." YouTube. December 10, 2014. Accessed July 17, 2017. https://www.youtube.com/watch?v=TZTpSZsS9mo Dec 10, 2014 - Uploaded by Jenni Domanowski.

Good video with slow motion capture of popcorn popping. It also has an extensive reference list.

Wolke, R. L., and Parrish, M. *What Einstein Told His Cook: Kitchen Science Explained*. New York: W.W. Norton & Co., 2008. In addition to discussing popcorn, this book also explains the way magnetic induction and microwave ovens work as two of the sources I will look at to generate the heat.

Webmaster@icecube.wisc.edu. "Popcorn Neutrinos." Ice Cube - South Pole Neutrino Detector. Accessed July 17, 2017. https://icecube.wisc.edu/outreach/activity/popcorn_neutrinos.

This lab uses closed air poppers as it seeks to connect the change in mass from before and after popping to neutrinos. In a middle school level, the focus could be change in mass due to the loss of the water as it changed state from a liquid to steam. It presents an interesting extension in using a motion detector to look at energy or doing different things to the seed coat to try and affect the outcome of the experiment.

Student Resources

Amy Cowen on August 19, 2016 7:30 AM. "Popcorn Popping Science." Science Buddies. Accessed July 17, 2017. http://www.sciencebuddies.org/blog/2016/08/popcorn-popping-science.php.

Linked to Scientific American, it presents a stem lesson that students can do at home or in a home economics classroom as it requires an oven.

Cobb, V. *Science Experiments You Can Eat*. New York: Lippincott, 1972.

Describes experiments that students can do using popcorn and other items found in the kitchen.

DePaola, T. *The Popcorn Book*. New York: Scholastic, 1978.

For many years, this has been the most popular of the elementary school books about popcorn. It has colorful illustrations and presents a great deal of information about popcorn in student friendly language.

Doudna, K. *The Kid's Book of Simple Everyday Science: Amazing Experiments--no Lab Required*. Minneapolis, MN: Scarletta Kids, 2013.

Provides experiments that look at heat transfer in a variety of ways, including making popcorn.

Higgins, N. *Fun Food Inventions*. Minneapolis: Lerner Publications Company, 2014.

Provides background information that is written at a middle school level.

Kudlinski, K. V., and Wexler J. *Popcorn Plants*. Minneapolis, MN: Lerner Publications, 1998.

For students who have had little exposure to a traditional science textbook, this is a great start. It has a table of contents, an index and a glossary. There is even a section aimed at adults/parents on how to share the book with a child. The author does a very good job of describing the biology of the popcorn plant. There is strong visual support with clear pictures of the parts of the plant at various stages with additional labeled diagrams that show the overall structure, the process of pollination and even how the plant makes its own food. Kudlinski does a thorough job covering the material while keeping it accessible to children through the use of shorter sentences and the repetition of key nouns.

Landau, E., and Lies, B. *Popcorn!* Boston, MA: Houghton Mifflin, 2003.

It presents the mostly non-fiction material in a variety of ways including a mini popcorn quiz with the explanations included. It then goes on to describe the corn plant, the popping mechanism, and the history of popcorn with humor and relatable language. Each section is clearly labeled by title and consists of just a few pages with strong visual support. There is even a small section toward the end labelled “Top Secret For Parents Only” that describes the nutritional value. To encourage students to do their own research, the last page lists both books and websites the author has found useful.

McCallum, A., and Hernandez, L. *Eat Your Science Homework: Recipes for Inquiring Minds*. Watertown, MA: Charlesbridge, 2014.

Students resource for information about the science of making corn pop with some suggested exploration activities.

"Science Fair Projects." Popcorn Board Learn For Kids Science Fair Projects. Accessed July 17, 2017.

https://www.popcorn.org/Learn/For-Kids/Science-Fair-Projects.

Provides ideas and in some cases, details on science projects for students connected with popcorn.

"What Makes Popcorn Pop?" Wonderopolis. Accessed July 17, 2017. http://wonderopolis.org/wonder/what-makes-popcorn-pop.

Excellent resource to use in a flipped classroom. It provides solid facts with a reading that highlights key vocabulary words. There is even a quiz feature that students can use to test their comprehension. It also has student friendly text and even includes the myth of the demon living inside each kernel of popcorn. It would lend itself to a language arts extension of either reading other myths or creating other food myths. Would also lend itself to an art extension.

What Makes Popcorn Pop?: First Questions and Answers about Food. Alexandria, VA: Time-Life for Children, 1994.

Factual information presented using lower level vocabulary. It also discusses other foods besides popcorn.

Wood, R. W., and Brown, R. E. *Heat Fundamentals: Funtastic Science Activities for Kids*. Philadelphia, PA: Chelsea House, 1999.

Presents a variety of experiments that students can do using common materials that look at changes in state due to temperature changes.

Wyler, R., and Stewart, P. *Science Fun with Peanuts and Popcorn*. New York: Messner, 1986.

Gives background information and presents several different experiments that students can do with popcorn.

Appendix

Next Generation Science Standards (NGSS)

MS-PS1-1 Matter and Its Interactions

Develop models to describe the atomic composition of simple molecules and extended structures.

MS-PS1-4 Matter and Its Interactions

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.

MS-PS3-3 Energy

Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.

MS-PS3-4 Energy

Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

MS-PS3-5 Energy

Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

Common Core Math Standards

MP.2 Reason abstractly and quantitatively

6.RP.A.1 Understand the concept of ration and use ratio language to describe a ration relationship between two quantities

6.SP.B.5 Summarize numerical data sets in relation to their context

Common Core ELA Standards

RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions

RST.6-8.3 Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

WHST.6-8.1 Write arguments focused on discipline content

WHST.6-8.7 Conduct short research projects to answer a question (including a self- generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.

Endnotes

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1. Levy, J. *Incredible Elements: A Totally Non-scary Guide to Chemistry and Why It Matters*. New York: Metro Books, 2017.
2. Boutard, A. *Beautiful Corn: America's Original Grain from Seed to Plate*. Gabriola Island, B.C.: New Society Publishers, 2012.
3. Types of Corn. Accessed July 17, 2017. http://www2.kenyon.edu/projects/farmschool/food/corntyp.htm.
4. Boutard, A. *Beautiful Corn: America's Original Grain from Seed to Plate*. Gabriola Island, B.C.: New Society Publishers, 2012.
5. Kudlinski, K. V., and Jerome W. *Popcorn Plants*. Minneapolis, MN: Lerner Publications, 1998.
6. Boutard, A. *Beautiful Corn: America's Original Grain from Seed to Plate*. Gabriola Island, B.C.: New Society Publishers, 2012.
7. Boutard, A. *Beautiful Corn: America's Original Grain from Seed to Plate*. Gabriola Island, B.C.: New Society Publishers, 2012.
8. Severson, K. "Heirloom Popcorn Helps a Snack Reinvent Itself." The New York Times. September 30, 2014. Accessed July 27, 2017. https://www.nytimes.com/2014/10/01/dining/heirloom-popcorn-helps-a-snack-reinvent-itself.html
9. Severson, K. "Heirloom Popcorn Helps a Snack Reinvent Itself." The New York Times. September 30, 2014. Accessed July 27, 2017. https://www.nytimes.com/2014/10/01/dining/heirloom-popcorn-helps-a-snack-reinvent-itself.html
10. Andreoli S.A. "Popcorn." Accessed July 17, 2017. http://www.andreolisa.com.ar/popcorn.html
11. DePaola, T. *The Popcorn Book*. New York: Scholastic, 1978.
12. Butler, S. "A History of Popcorn." History.com. December 06, 2013. Accessed July 17, 2017. http://www.history.com/news/hungry-history/a-history-of-popcorn
13. 16 Indian Inventions, From Popcorn to Parkas, Accessed July 27, 2017. http://news.nationalgeographic.com/news/2004/09.

14. BolderImage. "History." Cretors. Accessed July 17, 2017. http://www.cretors.com/page.asp?i=12.
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