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The Science Teacher

SIMULATIONS & GAMES

DESIGN YOUR OWN NAVY

DO PLANTS BREATHE?

FROM BEAN TO CUP

75 NSTA National Science Teachers Association

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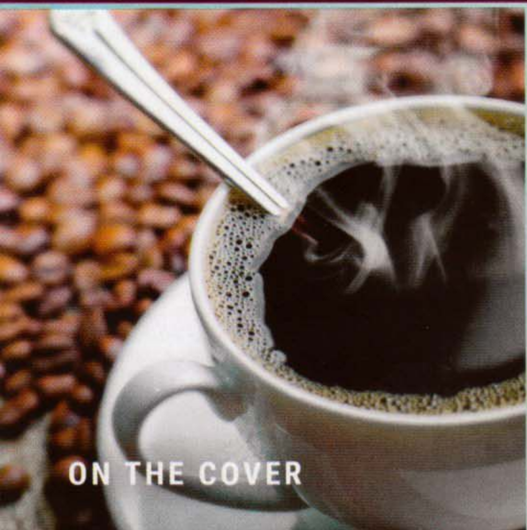

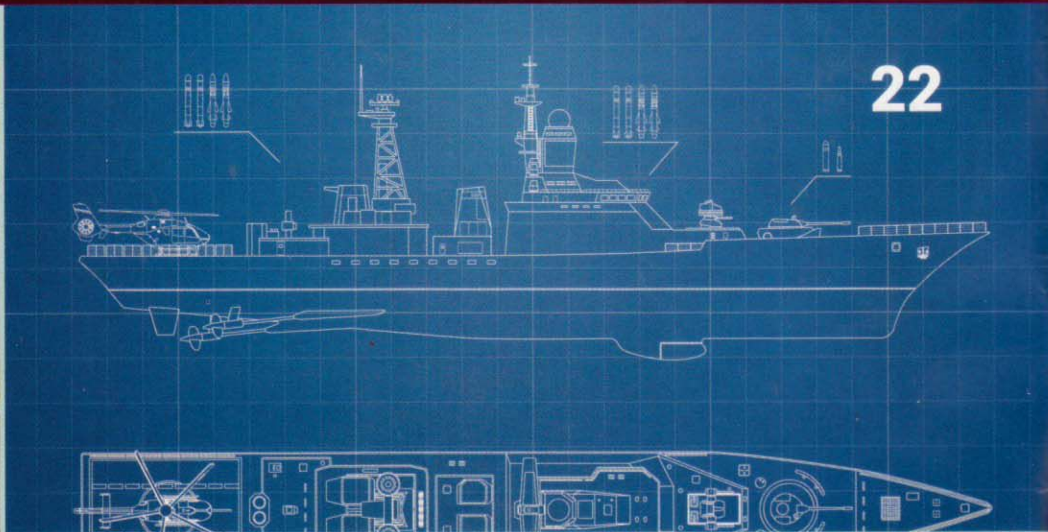

This issue's focus:
EDUCATIONAL SIMULATIONS AND GAMES

Computer simulations have become essential to scientific investigation and engineering design, thanks to advances in mathematical modeling, game theory, and computing technology. Simulations now provide an indispensable tool for investigating the properties of natural and built systems in science, engineering, economics, and social science.

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FEATURES

From Bean to Cup

Coffee comes to the science lab

TOM CUBBAGE

For most people, coffee roasting is a mysterious process. Chemically, it's equally mysterious; the roasting process gives rise to over 800 compounds. The science of coffee, from seed to bean to cup of aromatic brew, includes multiple areas of science content for students, and actively engages them in many science and engineering practices.

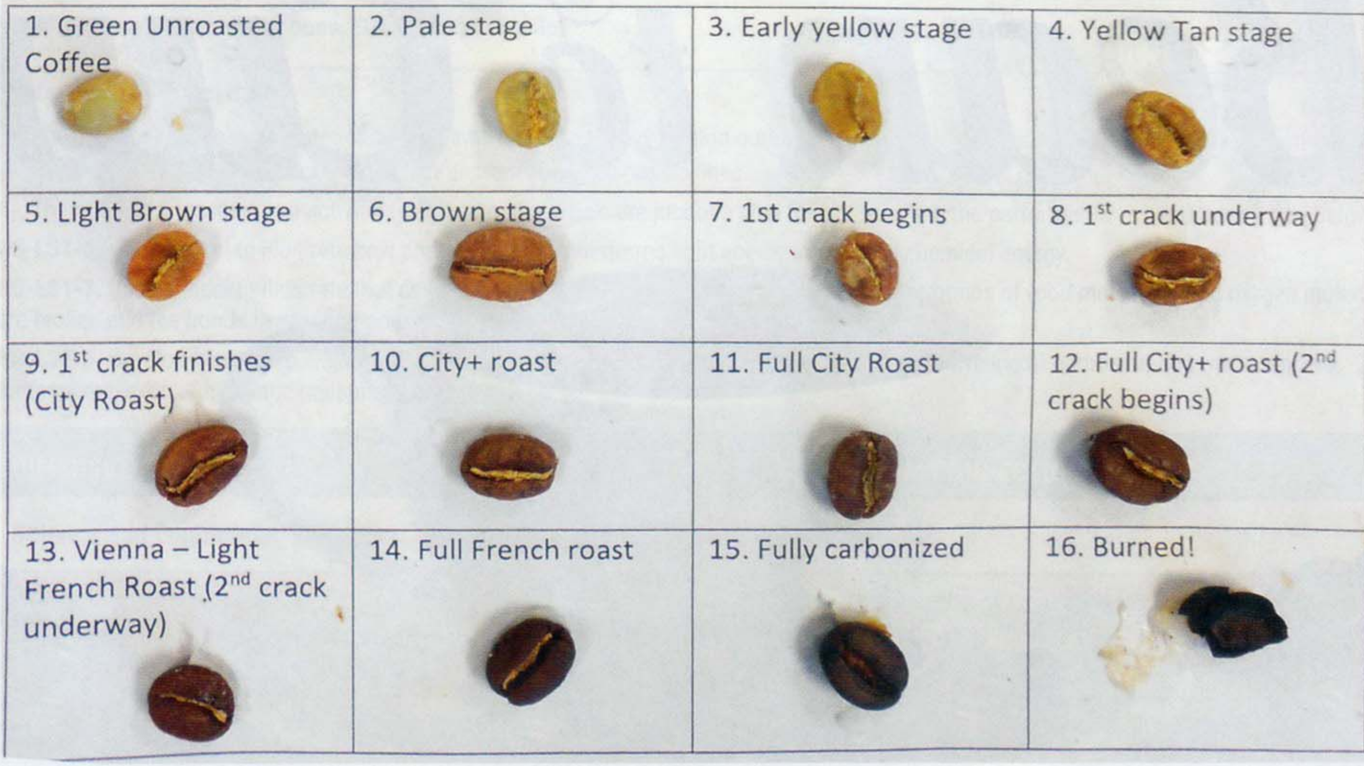
Ask most students what chemical compounds are contained in coffee and most will say caffeine. It also contains antioxidants and aromatic compounds that together give coffee its characteristic but highly varied scent. Then there is the popping of the beans, called cracking, which coffee roasting can cause to occur not once, like popcorn, but twice. Every aspect of the roasting, grinding, and brewing processes—from temperature, pressure, timing, and the source of the beginning (green coffee beans or coffee seeds)—can make something that is terrible or something that people are willing to pay hundreds of dollars for.

Adolescents and young adults are the largest growing segment of coffee drinkers. A study published in the journal *Pediatrics* found a 14% increase in coffee consumption among U.S. citizens ages 2–22, from 10% in 2000 to 24% in 2010, and the trend is increasing as companies market to teens (Branum et al. 2014). With more students drinking coffee beverages, it makes sense that they would be interested in coffee, what it contains, how it's grown and made, and the potential health risks to teens.

After hearing about two local science teachers having their students study and roast coffee as a lab activity, I decided to begin doing my coffee lab. It didn't hurt that I already roasted my own coffee beans at home and, a few years ago, had started a morning coffee shop in my school as a fundraiser. I had recently taken over the teaching of the Advanced Placement Biology course and was looking for an activity to do with my students after they had taken their exams, but with a few weeks of school left.

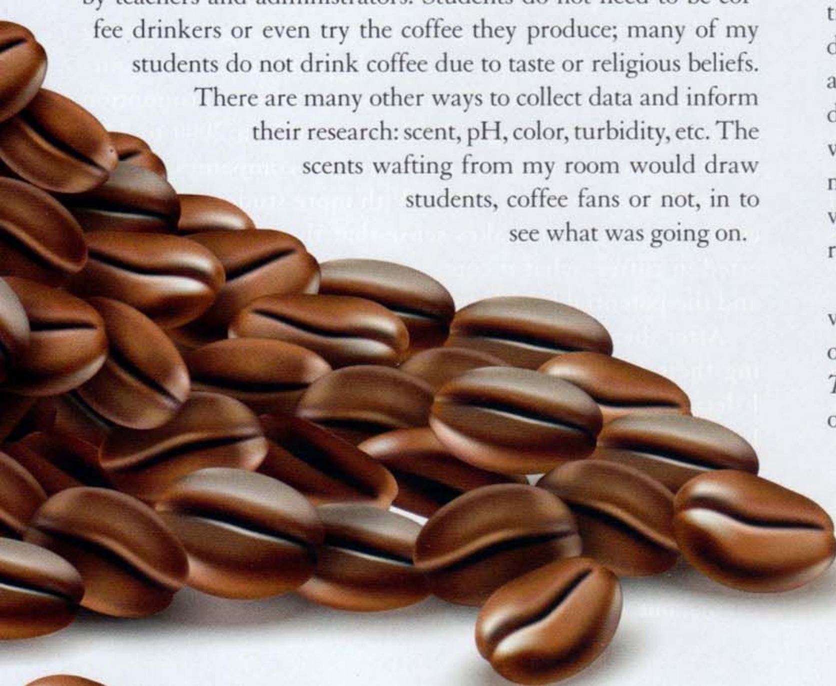
FIGURE 1

Coffee bean roasting stages.



PHOTOS COURTESY OF TOM CUBBAGE

I wanted to keep the students engaged in the content and move them to more open-ended inquiry scientific research. With so many variables, and so much rich data to collect and inform student experimentation, coffee science was a perfect fit. The Coffee Lab became something students looked forward to, and culminated in a coffee roasting and brewing competition judged by teachers and administrators. Students do not need to be coffee drinkers or even try the coffee they produce; many of my students do not drink coffee due to taste or religious beliefs. There are many other ways to collect data and inform their research: scent, pH, color, turbidity, etc. The scents wafting from my room would draw students, coffee fans or not, in to see what was going on.



The botany of the coffee plant

While coffee originated in Africa, it now grows in all the tropical regions of the world. Coffee plants have specific growing conditions that students study, and the first part of the lab involves becoming familiar with this important commodity (the second most important product exported from developing nations) that accounts for billions of dollars in world trade. Students learn about the two main varieties of coffee, Arabica and Caniphora (also called Robusta), which have considerable differences in characteristics and price. They also investigate where coffee is grown, what environmental conditions are needed for coffee shrubs to thrive and grow, and how the advent of full-sun grown coffee has negatively affected the natural environment where coffee plants are grown.

A list of websites and videos (see "On the web") can be provided to the students as outside-of-class preparation for the lab, or in-class research time. The PBS video series *Black Coffee: The Irresistible Bean* provides a good overview of many aspects of coffee. (This can be viewed in class or assigned as homework using the lab handout.)

The chemistry of coffee

Students appreciate the complexity of the chemistry involved in coffee and quickly discover that it has a lot more going on than caffeine content. Green (unroasted) coffee beans have been analyzed extensively by chemists, and they have discovered a number of compounds students will be familiar with, such as chlorophyll, antioxidants, and carbohydrates.

In this part of the lab, students learn that the coffee seed (or cherry) usually contains two parts (or beans). The green color and grassy scent allows the use of student's senses to begin their analysis of the chemistry, continues with simple pH testing, and, depending on equipment availability, can allow students to delve into the truly complex chemical nature of the unroasted bean. Students learn that the roasting process changes literally everything, creating hundreds of new compounds, reducing moisture, and even physically changing the appearance and size of the beans.

While my students rarely go beyond testing pH and testing for the presence of carbohydrates and other nutrients, students could analyze organic and inorganic compounds with more sophisticated equipment.

AeroPress forces water through a filter to separate the extract.

Roasting the beans

Once students have an idea of how many chemical reactions are taking place during the process of turning the green cherries into the brown or shiny black beans prepared for brewing coffee drinks, they begin roasting their own coffee. Using an online guide or color picture of the roasting stages (Figure 1), students take their beans from green to yellow, then tan, then brown, shiny black, and eventually burned to crisp chunks of charcoal. Taking samples as they go, they develop a chart of real beans to guide the later process of roasting a batch of beans for brewing.

Each group of students uses one of several methods of roasting; there are numerous ways coffee is turned from the green inedible product into the aromatic roast that can be brewed into the ideal coffee drink. In Africa, where the plant originated, the roasting method is over open fire in a pan. In Asia, a ceramic bowl is often used for coffee roasting. Here in the United States, the preferred method is often hot air or metal barrel roasting over a heat source. I offer my students four options for roasting their beans: whirly pop stovetop corn poppers, electric hot-air corn poppers, cast-iron pans, and commercial air roasting machines.

To add some real-world science equipment availability issues to the scenario, I label the roasting apparatus 1 to 4, put numbers into a hat, and have students draw their roasting tools at random. Each process will work to roast the beans to each of the stages on the chart, but each

FIGURE 2

Monitoring the roast.

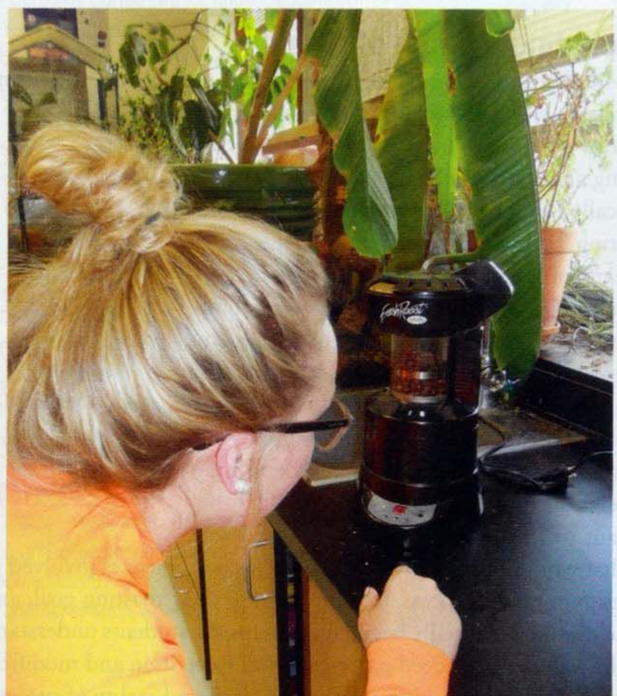


FIGURE 3

Testing for pH.

FIGURE 4

The pour-over method.

method has unique advantages and drawbacks.

Safety note: Hot plates for heating pans and poppers, hot air jets, and the potential for burns necessitates some safety precautions. Students doing the roasting wear safety goggles, use heat pads or gloves, and cover open containers with mesh screens to prevent accidental burns.

Roasting a batch of beans

Now that the students have experienced the process of roasting beans to each of the stages on the chart, they move on to roasting a small batch for cupping and testing. The roast they will aim for is called Full City Roast, and involves monitoring both color and sound as the coffee beans progress through both crack or popping stages to achieve the proper combination of chemicals. In this stage of the lab, students may use the roasting process they used earlier or choose another method (Figure 2, p. 37). Because there is a learning curve in switching to a new technique, students must weigh their options and decide whether they want to learn a new method or stick with what worked for them already. The science practices involved in designing their process, fine-tuning it to their roasting goal, and the need to potentially begin again helps the students understand why failures are indeed part of science. Repetition and modification lead to critical thinking, the hallmark and reality of successful scientific endeavors (Osborne 2007).

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Brewing, cupping, and testing

The students now move on to the second variable-filled process of making a cup of coffee. The final product, a rich, flavorful cup of coffee, involves deciding on how long to let the beans *de-gas* (leaving them open to the air to release volatile aromatic compounds), how fine to grind them, what temperature of and time for water to extract the chemicals from the beans, and what type of process to use to do that extraction (Fuller and Rao 2017).

I provide burr grinders that adjust sizes from very coarse to very fine, increasing or decreasing the surface area of the coffee beans. (Students can use household grinders and determine grind size and texture, visually adjusting the time and pulses to get the right-size coffee particles.)

For this first brewing process, everyone uses a medium grind, and everyone chooses two extraction methods to try. The choices for brewing extraction are: French press (a glass pitcher arrangement with a plunger filter to separate the grounds to the bottom of the pot once the extraction is complete), pour-over filter (a ceramic funnel arrangement with a paper filter in the bottom emptying into a pot), traditional automatic drip coffee maker (pour in the water, add coffee to the filtered basket, plug in, and let the machine do the rest), AeroPress (a syringe-type arrangement which forces water through a filter to separate the extract from the grounds), and steam extraction espresso (manual espresso pot with water reservoir on the bottom tube and funnel arrangement for steam direction through grounds and top pitcher for extracted coffee collection).

Each team then tests their resulting brew for pH, color, scent, taste (if they choose), and/or other testing the students think of (Figures 3 and 4).

Safety note: Because some students will be tasting the coffee produced, this can be done in a culinary arts classroom or other approved food preparation area; as the science lab should not be used for food preparation, nor should students taste or consume lab-produced products.

Master roasting and brewing competition

Now that students have performed the process of turning the green beans into a cup of coffee, they begin to work on their process of roasting, grinding, and brewing their best cup of coffee. Green coffee beans can be obtained online or from local suppliers (who often donate beans or give a deep discount for this educational endeavor). I try to have beans from each of the four main growing regions of the world (Africa, Central America, South America, and Asia).

Students have learned about the growing regions and do a little more research into the varieties available, and can usually find roasting and brewing suggestions for the beans they choose for their master roast. Because there are so many variables in the processes necessary for taking the green beans to a cup of coffee, students can all choose the same variety or all of them can choose different ones. They will each get a different product in the end.

I give my students one day to work out the details of their master roast and brew for the competition (testing the roast, the grind, and the extraction process using their senses and chemical tests; pH, color, turbidity, etc.). I then assemble a panel of judges ready for them on day 2. (I have many coffee-drinking administrators, teachers, and local community members volunteering to be on the tasting panel of judges.) We do a blind tasting and judges use an evaluation rubric to judge each contest entry.

Students write a description of their roasting, grinding, and brewing techniques and a justification for their choices that is read to the judges as they sample each group's entry. This argument from evidence asks students to really think about the scientific choices they make. A trophy is awarded to the master roasting team, and it is displayed in the classroom with team member's names for all to see. Students complete the lab packet (see "On the web") that includes their roasting, cupping, and brewing notes and justification for each choice they made in their master roast for competition.

Safety note: We prepare and brew the coffee in a culinary arts room or appropriate food preparation location, as food and lab safety best practices dictate that the lab not involve food prep or eating.

Extension activity

Students, individually or in groups, read one of three to four scientific journal articles on adolescent consumption of caffeine and prepare a poster session–style presentation on their findings. Students present a claim, evidence, and reasoning to support the view that they choose to take on the topic of adolescent consumption of caffeine. Students then present their work to the group and field questions by the observers to explain their conclusions or the conclusions of the paper they have reviewed. ■

ACKNOWLEDGMENTS

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ON THE WEB

Black Coffee: The Irresistible Bean (three-part video series about coffee from PBS): *www.youtube.com/watch?v=TTDy-L0NKIg*

Espresso, Café Latte, Cappuccino...A Complex Brew (teachers guide): *www.acs.org/content/dam/acsorg/education/resources/highschool/chemmatters/teacherguide/chemmatters-tg-april2017-coffee.docx*

Lab packet: *www.nsta.org/highschool/connections.aspx*

The UC Davis Coffee Lab for undergraduate coffee science teaching and research: *https://coffeecenter.ucdavis.edu*

Website dedicated to the chemistry of coffee: *www.coffeechemistry.com*

Video by PBS Learning Media about the Science behind a cup of coffee: *https://oeta.pbslearningmedia.org/resource/0c1c1d56-2209-4049-b505-e69c867cf420/brewing-the-perfect-cup)*

Video by the American Chemical Society and PBS about the science of coffee: *www.youtube.com/watch?v=xANGsTqxdUw*

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Tom Cubbage (*tom_cubbage@gfps.k12.mt.us*) is a science teacher at C.M. Russell High School, Great Falls, Montana, and is Director, NSTA Division XV.