Popping Popcorn Kernels: Expanding Relevance with Linear Thinking

W

Jordan L. Fantini, Michael M. Fuson, and Thomas A. Evans*
Department of Chemistry and Biochemistry, Denison University, Granville, OH 43023; **evans@denison.edu*

Popcorn is a popular snack food that has been applied instructionally with remarkable creativity *(1).* Much of this creativity has been inspired by a 1984 *ChemMatters* article that included a detailed popping mechanism and description of the popcorn flakes that form *(2).* A 1972 article in this *Journal (3),* "A 'Relevant' First Experiment for Freshman Chemistry", described the advantages of popping individual popcorn kernels as an introduction to laboratory methods and numerical analysis. Our experiment retains characteristics of this 'relevant' experiment but asks students to relate the popping behavior of their kernels to the popping mechanism as it is currently understood. Kernel behavior is characterized in graphs of mass and volume data, a digital picture of the popcorn flakes formed (Figure 1), and the density of these flakes. The density of materials is a common laboratory topic early in an introductory chemistry sequence *(4).* Other popcorn-related articles in this *Journal* have described the use of popcorn for teaching error analysis *(5),* offered strategies for using popcorn as the context for a discussion of the scientific method *(6),* and explored the physical chemistry of foam formation *(7).* In addition, the popping process has been used for introducing thermodynamic principles *(8).*

The structure of a popcorn kernel (Figure 2) is important to its behavior. The pericarp forms the tough outer surface of the kernel and serves as a moisture barrier. A region of starch granules, the hard endosperm, is the largest feature inside the pericarp. The soft endosperm contains starch and most of the water in the kernel, which popcorn processors carefully control to 13–14%. The heated kernel forms a solid foam that is produced when the pericarp bursts in response to the vapor pressure of superheated water. This information and other aspects of the popping mechanism *(2, 9)* are conveyed to students with the help of a computer animation *(10).*

As the kernel is heated, water vapor infiltrates the hard endosperm, which softens and becomes gelatinous above 150 °C. The pericarp bursts explosively when the gelatinous starch reaches a temperature of 180–190 °C. Vapor pressure expands a tiny hole in each starch granule, creating a cell of the foam. Evaporation of the superheated water cools the foam to produce the familiar solid flake. Very little water was in the vapor phase immediately before the kernel burst.

Students test two hypotheses and a corollary developed from the description of the seed and its transformation:

(i) Flake and kernel masses are directly proportional.

(ii) Flake volume and kernel mass are directly proportional.

(iii) The corollary, the density of the flakes is a constant.

Individual kernels are weighed before and after popping. A digital photograph of the flakes (Figure 1) is obtained. The volume of each flake is determined by sand displacement *(11)* measured in a graduated cylinder and flake densities are calculated. Manually prepared graphs are examined for linear relationships to test the two hypotheses. Flake densities are examined to test the corollary. The digital photograph of popcorn flakes is the context for students reporting their understanding of the popping process as it is represented in the behavior of individual kernels. If spreadsheet functions are performed in addition to manual graphing, more time beyond a three-hour laboratory period is required.

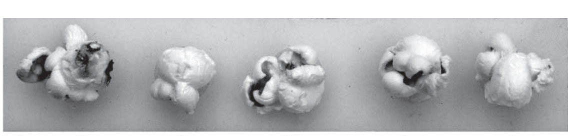
Experimental Procedures

Quantitative Popping

Our popping procedures are adapted from Macomber's original article *(3).* A sample holder is used to keep track of individual samples. Kernels are popped in an Erlenmeyer flask over a Bunsen burner. Five kernels and the flakes they form are weighed individually on an analytical balance and a digital photograph of the set of five flakes is obtained.

Determining Flake Volume and Density

Flake volume is determined by sand displacement. Sea sand (20–25 mL) is added to a 50- or 100-mL graduated cylinder and the volume of sand is measured to the nearest 0.1 mL. Some of the sand is poured quantitatively into a beaker and a flake is placed in the graduated cylinder. The sand



Sample	1	2	3	4	5
Density/ (g/mL)	0.12	0.16	0.12	0.14	0.11

Figure 1. Set of flakes with the calculated density displayed below each flake.

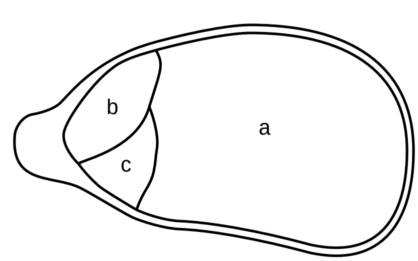


Figure 2. Diagram of the kernel structure inside the hull (pericarp): (a) hard (vitreous) endosperm, (b) germ, and (c) soft (floury) endosperm.

is returned to the graduated cylinder and the graduated cylinder is tapped gently to achieve a level surface and complete packing of the sand around the flake. The volume of sand plus flake is recorded to the nearest 0.1 mL. This procedure is repeated for all five flakes.

Hazards

Heated glass can shatter or cause burns. The popcorn flakes in the lab must not be consumed.

Results and Discussion

Popping Kernels and Graphing the Data

Sample data and spreadsheet analyses from one student are shown in Table 1. Uncertainty in flake volume measurement is estimated as ± 0.1 mL, based on triplicate measurements of individual flakes. Nearly all student results exhibit pronounced variation in density, for example, samples 2 and 4 in Figure 1 and Table 1. We have detected no correlation between flake density and mass lost. Graphs generated from the data in Table 1 are shown in Figure 3. A strong linear correlation of flake mass versus kernel mass is consistently observed. However, because of variation in flake density, students frequently observe weak or no correlation of flake volume versus kernel mass.

In generating the data and creating the graphs students encounter principles and techniques that they have applied before but perhaps not mastered. Confidence in lighting a Bunsen burner is just one example of a technique in this experiment where the range of student abilities is easily identified. Since graphing is performed during the lab, more able students often offer assistance to those who are less confident. The contrasting correlations that most students obtain help to emphasize that not every data set describes a linear relationship.

Relating Behavior to the Popping Mechanism, Hypothesis Testing

The popping mechanism is straightforward. By using the mechanism to give meaning to their results, students apply a central strategy of chemists: explaining observable phenomena in terms of processes that are hidden. The strong linear correlation in graphs of flake mass versus kernel mass confirms the first hypothesis. Popping is an example of physical change in which mass loss is accounted for by water loss. Heavier kernels have more water to lose.

A weaker linear correlation, or no correlation, in graphs of flake volume versus kernel mass appears to disconfirm the second hypothesis and the corollary. Heavier kernels do not necessarily yield larger flakes. Flake density is not a constant. Comparing samples 2 and 3 and samples 4 and 5, kernel mass differences of 3% are associated with flake volume differences of ca. 30%. Low volume, high density flakes, such as 2 and 4, result from reduced expansion. Uneven heating, a damaged hull or low water content are among the possible explanations for reduced expansion. Average flake volumes obtained by hot air popping of individual kernels *(11)* are higher than students obtain with our method, although students must sometimes explain how a "giant" flake formed. Lower expansion and mass loss significantly less than the 13–14% initial water content suggest that heating a kernel in an Erlenmeyer flask over an open flame is not optimal for popping kernels. Although a recent study confirms the dependence of expansion volume on both moisture content and popping method *(12)* a test of the second hypothesis and corollary as described here has not been reported.

Spreadsheet Activities

Spreadsheet applications are illustrated in Table 1 and Figure 3. We have also used popping kernels as the context for a spreadsheet exercise designed to find the linear form of the relationship between temperature and the vapor pressure of water *(13)*.

Table 1. One Student's Data from Popping Kernels

Sample	Kernel Mass/g	Flake Mass/g	Flake Vol/ mL	Flake Density/ (g/mL)	Mass Lost (%)
1	0.1391	0.1212	1.0	0.12	12.9
2	0.1258	0.1148	0.7	0.16	8.7
3	0.1295	0.1167	1.0	0.12	9.9
4	0.1721	0.1557	1.1	0.14	9.5
5	0.1771	0.1603	1.5	0.11	9.5
Ave	0.15	0.13	1.1	0.13	10.1
SD	0.02	0.02	0.3	0.03	1.6

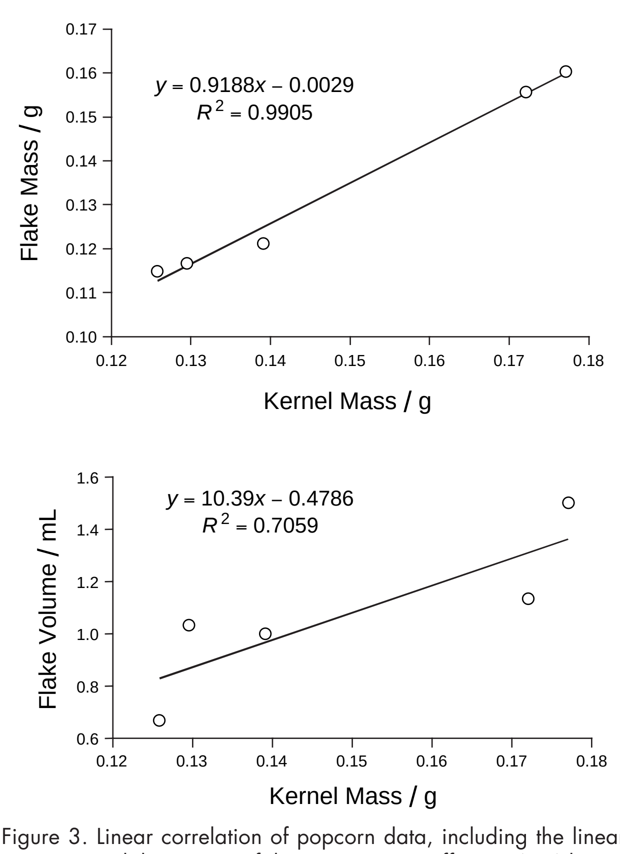


Figure 3. Linear correlation of popcorn data, including the linear equation and the square of the regression coefficient: (top) kernel mass vs flake mass and (bottom) kernel mass vs flake volume.

Conclusion

Data from popping individual popcorn kernels are useful for developing students' graphing skills and understanding of hypothesis testing. In addition, access to individual flake volumes and their variation directs student attention to the popping mechanism. Students use quantitative measurement and mechanism to develop an understanding of change and its relationship to the identity and structure of the materials involved. Popcorn experiments will continue to evolve in response to changes in instructional priorities and resources. New discoveries reported in the popcorn literature, for example, a kinetic model for kernel popping *(14)* or structural changes in the pericarp during popping *(15),* will create new instructional opportunities. We are confident that many ways will be found to expand the relevance of popcorn to the teaching and learning of chemistry.

[W]Supplemental Material

Instructions for students, notes for instructors, and the animation of popcorn popping are available in this issue of *JCE Online*.

Acknowledgments

Several generations of Denison students and faculty have contributed to the development and success of our instructional attention to popcorn. We particularly thank Marissa Sherman (class of 2007) and Ryan Gingo (class of 2008) for their assistance in preparing this report. Ken Ziegler (retired), Department of Agronomy, Iowa State University, Ames, IA offered important advice on an early draft. Trent Edmunds, Denison University Instructional Technology, developed the computer animation of a kernel popping.

Literature Cited

1. (a) Popcorn Board Home Page. *http://popcorn.org*. (b) Education World. *http://www.education-world.com/a_lesson/lesson/lesson324.shtml*. (c) Popcorn Home Page. *http://webtech.kennesaw.edu/jcheek3/popcorn.htm*. (d) An Educator's Reference Desk Lesson Plan. *http://www.eduref.org/Virtual/Lessons/Interdisciplinary/INT0015.html*. (e) Project Labs. *http://www.rohmhaas.com/company/plabs.dir/htmldocs/Interdiciplinary.html*. (f) SIDS Instructional Resources. *http://www.shermanisd.net/Instruction/Technology_Integration/popcorn.htm*. (g) Popcorn–Cooking with Phase Changes. *http://kicp-yerkes.uchicago.edu/2003-winter/pdf/ywi2003-**popcorn**.pdf* (all accessed Dec 2005).
2. Sibley, L. K. *ChemMatters*. *http://www.chemistry.org/portal/a/c/s/1/acsdisplay.html?DOC=vc2%5C1rp%5Crp1_popcorn.html* (accessed Dec 2005).
3. Macomber, R. S. *J. Chem. Educ*. **1972,** *49,* 714–715.
4. Henderson, S. K.; Fenn, C. A.; Domijan, J. D. *J. Chem. Educ.* **1998,** *75,* 1122–1123.
5. Kimbrough, D. R.; Meglen, R. R. *J. Chem. Educ*. **1994,** *71,* 519–520.
6. Sauls, F. C. *J. Chem. Educ*. **1991,** *68,* 415–416.
7. Hansen, L. D.; McCarlie, V. W. *J. Chem. Educ*. **2004,** *81,* 1581–1584.
8. Hunt, R. G. *Phys. Teach.* **1991,** *29,* 230–235.
9. (a) Ziegler, K. E. Popcorn. In *Corn: Chemistry and Technology,* White, P. J., Johnson, L. A., Eds.; American Association of Cereal Chemists: St. Paul, MN, 2003; Chapter 22. (b) Parker, M. L.; Grant, A.; Rigby, N. M.; Belton, P. S.; Taylor, J. R. N. *J. Cereal Sc*. **1999,** *30,* 209–216. (c) Schwartzberg, H. G.; Wu, J. P. C.; Nussinovitch, A.; Mugerwa, J. *J. Food Eng*. **1995,** *25,* 329–372. (d) Hoseney, R. C.; Zelenak, K.; Abdelrahman, A. *J. Cereal Sci*. **1983,** *1,* 43–52.
10. Trent Edmunds. Denison University Information Technology. *http://www.denison.edu/chem/animations2006.html* (accessed Dec 2005).
11. Tian, Y.; Buriak, P.; Eckhoff, S. R. *Cereal Chem*. **2001,** *78,* 578–582.
12. Gökmen, S. *J. Food Eng*. **2004,** *65,* 357–362.
13. Kildahl, N.; Varco-Shea, T. *Explorations in Chemistry;* Wiley: New York, 1996; pp 209–232.
14. Byrd J. E.; Perona M. J. *Cereal Chem*. **2005,** *82,* 53–59.
15. Tandjung, A. S.; Janaswamy, S.; Chandrasekaran, R.; Aboubacar, A.; Hamaker, B. R. *Biomacromolecules* **2005,** *6,* 1654–1660.

This article has a related *JCE* Classroom Activity:
"Popcorn—What's in the Bag?" by Marissa B. Sherman and Thomas A. Evans
See pages 416A–416B in this issue.

***JCE* Classroom Activities**

Find all 79 Activities at *JCE Online*
http://www.JCE.DivCHED.org/HS/classAct/ClassAct.html