# Simple Experiments Aren't So Simple, But They Can Be Sweet!

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## Author Biography

Kimberly Shaw, Ph.D., is a Professor of Physics and the Co-Director of UTeach Columbus. She was awarded the 2015 Council for the Advancement and Support of Education Georgia Professor of the Year Award, as well as an award from the Southeastern Association for Science Teacher Education. She teaches courses in physics, as well as the Research Methods course for the UTeach program. Her focus within the field of physics education research is on determining factors that promote the success of female and minority students, and supporting improved learning outcomes and retention of all students in STEM.

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At Columbus State University, students in majors leading to teacher certification in science, math or computer science as undergraduates are a part of the UTeach Columbus (2019) program, modelled on the highly successful UTeach program created at the University of Texas. UTeach programs seek to provide streamlined programs of study that will both train secondary education majors to be effective classroom teachers with experience in active, inquiry learning, and to have a strong content background that would also qualify them for graduate programs or careers outside the classroom. Majors take the Research Methods course, which has student learning outcomes that include designing an experiment, collecting and analyzing data, creating scientific arguments, communicating research, and applying these understandings to the teaching of STEM in a secondary education setting. All of these learning outcomes provide discipline-specific windows into critical thinking skills that our graduates will use.

One unit of this course prepares our students to work on an independent research project. It begins as students are posed a research question, with the goal of touching on each of these student learning outcomes and providing practice in these techniques before larger individual projects are assigned: "How many licks does it take to get to the center of a TootsiePop®?" Students are excited to have an easy assignment, although discussion often begins with a "Can we eat the candy? Do we *have* to?" discussion. The class brainstorms in order to design the experiment and immediately confront several complications: does using an alternative method (a wet sponge) give an equal result to human saliva? Do two different people lick the same amount of candy? As a result, students quickly determine the need to define terms explicitly as a part of the overall design, and the importance of communicating those definitions clearly. This use of critical thinking allows student-developed replicable design and communication of results, both course outcomes. For example, students realize they must define the "center" and a "lick" in order to have replicable outcomes.

Discussion includes what variables are controlled, measured, and what may be confounds. Students also discuss whether the impact of how much an individual likes a flavor may have on how much candy is removed with each lick. It is also discussed that saliva and water may impact different candy flavors differently, but that question is deferred for later study. Students also discuss how many "centers" must be reached in order to have a reliable conclusion, allowing a brief introduction into sampling and statistical analysis which will be addressed more fully later in the semester. This aspect of the discussion, relying on student critical thinking skills, is important as the class determines what factors are needed for reliable and generalizable results, as well as a deeper discussion of the limitations of their conclusions.

Further brainstorming to determine the experimental design now focuses on standardizing procedures. Students discuss a standard number of licks to take before recording and taking either a sip of water, a mouth rinse, or (for those who do not wish to eat the candy) to rinse the sponge, and develop a protocol for recording data. In order to deal with potential variations in how much candy different individuals remove with each lick, each candy has its' initial mass recorded, and its' final mass. Students typically choose to determine whether or not there are individual differences by calculating the ratio of mass removed to number of licks.

At this point, students typically acknowledge that a simple question does not necessarily mean that the procedure will be simple! They have addressed questions of terminology, of sample size, of replicability of data collection and of individual variability. They have determined controls that will be implemented, and begun to think about ways to analyze the data.

During data collection, discussion diverts to classroom management issues for these future teachers. How would this project change in a classroom with younger students, or older students? How much latitude do you allow a class with good behavior, or bad behavior? Why should you not *require* people to eat the candy? What constraints might be placed on the class design of this experiment, they conclude, should be based on the context in which they are teaching. Further, the class discusses how they might constrain an experimental design rather naturally, by limitations through available materials or class rules, in order to maintain a productive classroom experiment.

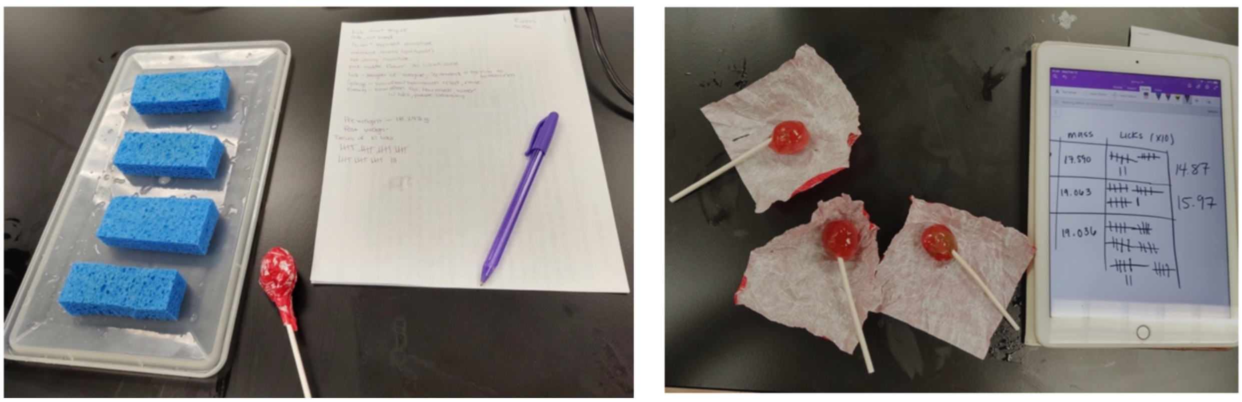

*Figure 5: Data collection setups of two students, representing several modes of data collection (licking vs. sponges)*

Students each reach the center of 2 – 3 candies, and the preliminary data (initial mass, number licks, final mass, and mode of removal) are recorded. At this point, the class reflects on prelimary results as a means of approaching the iterative nature of the experimental design process and determining which procedures are in need of further revision. For example, students often assume that the candy will be uniformly shaped, and find that there is significant variation in the thickness and symmetry of the candy from one piece to another. If the procedure is modified, the class discusses if any preliminary data can be kept and used with the data from the newer procedure.

Once students have collected their data, data analysis begins. Analysis includes whether individuals are consistent in the amount of candy they remove per lick, and how much mass on average is removed in order to reach the "center".

| Pre Mass (g) | # licks | Post Mass (g) | Difference | Method | Person | Flavor |
|---|---|---|---|---|---|---|
| 18.293 | 380 | 15.490 | 2.803 | Sponge | ES | Orange |
| 17.212 | 220 | 14.636 | 2.576 | Sponge | ES | Orange |
| 17.812 | 280 | 14.500 | 3.312 | Sponge | JS | Orange |
| 17.246 | 240 | 13.810 | 3.436 | Sponge | JS | Orange |
| 18.944 | 323 | 16.821 | 2.123 | Sponge | MG | Orange |
| 17.162 | 410 | 14.438 | 2.724 | Sponge | MG | Orange |
| 18.676 | 730 | 12.801 | 5.875 | Tongue | LW | Orange |
| 17.532 | 770 | 13.279 | 4.253 | Tongue | LW | Orange |
| 17.590 | 120 | 14.800 | 2.790 | Tongue | EC | Cherry |
| 19.063 | 160 | 15.970 | 3.093 | Tongue | EC | Cherry |
| 19.036 | 320 | 12.230 | 6.806 | Tongue | EC | Cherry |
| 17.610 | 240 | 13.770 | 3.840 | Tongue | AO | Grape |
| 17.020 | 190 | 14.160 | 2.860 | Tongue | AO | Grape |
| 19.358 | 217 | 14.826 | 4.532 | Tongue | LC | Raspberry |
| 18.817 | 182 | 14.911 | 3.906 | Tongue | LC | Raspberry |
| 17.632 | 300 | 14.145 | 3.487 | Tongue | NL | BlueBerry |
| 18.057 | 310 | 14.250 | 3.807 | Tongue | NL | BlueBerry |
| 307.060 | 5392 | 244.837 | 62.223 | Total | | |
| 18.062 | 317.1765 | 14.402 | 3.660 | Average | | |

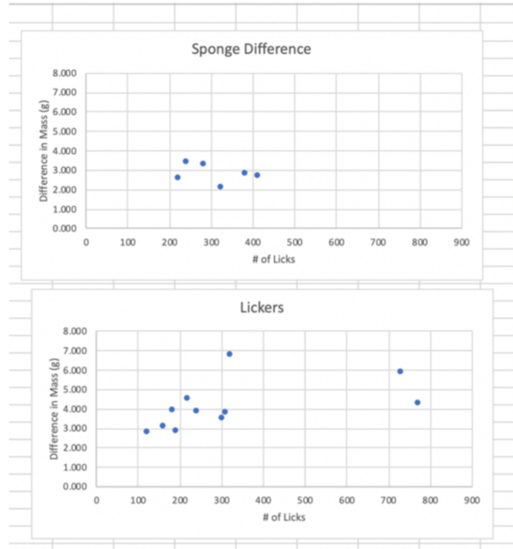


*Figure 6: Preliminary data analysis from Spring 2020, led by students.*

After analysis, the unit moves into its final phase: argumentation. In a prior class exercise, students have been introduced to the claims-evidence-reasoning model (Grooms, Enderle, Hutner, Murphy, & Sampson, 2016) of argumentation. Using this structure, each student is responsible for writing a paragraph which clearly communicates their claim about the data, cites the data as evidence, and then connects the data to the claim. Class discussion, in which several different conclusions have been reached, further allows students to provide constructive critiques and deepen their understanding of the limits of the data, and how further refining the experimental design might allow better data collection.

At the end of this unit, the class has worked together to strengthen their critical thinking skills as they apply to scientific inquiry and communication. By modelling this process of scientific inquiry from beginning to end, several course goals are achieved. First, students are able to experience the revisions that typically occur in the scientific method, more closely modelling true research. Second, students are able to design experiments, and have normalized the idea that changes to procedures are to be expected, and not a sign that they have done something wrong. Further, by working on this experiment as a class, they are all now better prepared for their individual STEM research projects, which serve as a longitudinal assessment of the learning gains for this portion of the course. And by providing practice in the steps leading to scientific argumentation, students are better prepared to write their own arguments, and to critique the arguments of others.

Students typically report having enjoyed, and learned from, this unit a great deal – although few are eager to eat any TootsiePops for the rest of the course. And while the details of this unit are specific to STEM majors, faculty from any discipline can choose a simple question that has a not-so-simple research project – to get to the sweet spot of developing critical thinking skills.

## References

UTeach Columbus. (2019, September 19). Retrieved February 24, 2020, from https://uteach.columbusstate.edu/

Grooms, J., Enderle, P., Hutner, T., Murphy, A., & Sampson, V. (2016). Argument-driven inquiry in physical science: Lab investigations for grades 6-8. Arlington, VA: NSTA Press, National Science Teachers Association.