Mentos and the Scientific Method: A Sweet Combination

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The application of active-learning and inquiry-driven pedagogies in the science, technology, engineering, and math (STEM) fields is motivated by the greater retention of information and improved student attitudes *(1–5)*. These types of learning environments provide fundamental skills (hypothesis testing, data analysis, problem solving, etc.) that can benefit the students, both science majors and nonscience majors alike.

The National Science Education Standards (NSES) report *(6)* stresses the need for incorporating more interactive pedagogies into the classroom and lab and provides a list of recommendations for science educators. In part, the NSES recommends there be less emphasis on "rigidly following curriculum, focusing on student acquisition of information and presenting scientific knowledge through lecture, text, and demonstration" and more emphasis placed on "focusing on student understanding of information and use of scientific knowledge, ideas, and inquiry processes, and guiding students in active and extended scientific inquiry". By changing these goals students can better appreciate the fulfillment and excitement that science offers and better answer questions that require scientific information and scientific ways of thinking for informed decision making *(6)*. The goals and recommendations set forth by the NSES correlate well with our mission, which as a liberal arts intensive institution, aims to (i) help our students become active, independent learners and (ii) foster creativity, critical and ethical reasoning, practical engagement, and a spirit of inquiry *(7)*. It is noted that we do not endorse the rejection of traditional curriculum and conventional teaching methods nor ignore the value of their use in the classroom. However, in an effort to diversify our teaching methods, we have begun to employ active-learning and guided-inquiry pedagogies for the reasons stated above.

In an effort to address the goals stated by the NSES, we incorporated active-learning techniques and inquiry-driven laboratory exercises into our introductory chemistry with laboratory course.[1] It is beneficial to immediately immerse the students in the process of scientific inquiry. By doing so, the students will become accustomed to the style of learning that will be used for the remainder of the semester, and they will begin to build confidence in their ability to conduct scientific inquiry. We describe an exercise, conducted during the first two weeks of class, that incorporates both active learning in the lecture and scientific inquiry in the lab. The exercise requires the students to use the scientific method to evaluate an observation of a phenomenon that has been extensively discussed on the Internet and has even been addressed on the television show *Myth Busters (8)*. The phenomenon is the explosive fountain that results when Mentos are placed in Diet Coke.

Figure 1. The fountain effect when 16 Mentos are placed in a 2-liter bottle containing Diet Coke.

Class Discussion

The exercise began by reviewing the scientific method in lecture. Since almost all students have learned about the scientific method in their high school science courses, they were called upon to help describe the different steps of the process as they were covered in the lecture. Once the scientific method was reviewed, the class was taken outside to view the Mentos–Diet Coke fountain (Figure 1). The demonstration was conducted by quickly submerging 16 mint Mentos (the Mentos had been predrilled and strung onto a thin wire) into a freshly opened 2-liter bottle of Diet Coke. The students documented all of the experimental conditions, including the approximate temperature of the Diet Coke, the approximate height of the fountain (which was estimated to be 9–10 feet), the approximate volume of the Diet Coke left in the bottle, and the appearance of the Mentos after the experiment.

As the students were going back to the classroom, many had begun discussing what might have caused the fountain to occur. When the class reconvened in the lecture hall, a more formal discussion took place as the students worked in collaborative groups (three or four students). Each group was instructed to come up with a hypothesis explaining why the fountain had occurred (5–7 minutes was spent on this process), and they were called upon by the instructor to report their hypotheses (List 1). As these were recorded on the board, it was noted by the instructor that some of the hypotheses focused on a chemical reaction and some on a physical change. This provided a framework for the ensuing discussion on experimental design.

The students went back to their groups and were given about 2–3 minutes to discuss the hypotheses and decide which one should be chosen (List 1). Following this, a brief class discussion led to the choice of a modified hypothesis that included some elements from different hypotheses. The final class hypothesis stated:

> There is a physical or chemical interaction between the Mentos coating and some component of the Diet Coke and this interaction causes CO_2 from the Diet Coke to escape violently.

It is noted that the students specifically hypothesized the Mentos coating was important because they observed that the coating was partially dissolved after the demonstration was complete.

The students then spent another 5–7 minutes in groups designing experiments to test this final hypothesis. Specific groups were again called upon to provide examples of experiments and explain how they would test the hypothesis. The discussion continued until the class was satisfied that we had a complete list of experiments (List 2). The instructor noted that the experiments had to be at a level of sophistication appropriate for our laboratory capabilities; this condition was taken into consideration as the students decided which experiments to include.[2] At this point the lecture component of the exercise was over. The required materials were purchased and the students were given a document that summarized the class hypothesis, the experiments chosen in lecture, some background information on the different states of matter and gas solubility, the difference between physical and chemical changes, and basic data analysis (see the Supplemental Material[W]).

- One of the chemicals in the Mentos coating reacts with the CO_2 in the Diet Coke.
- A chemical reaction occurred between the outer coating of the Mentos and some ingredient(s) in the Diet Coke to produce this violent reaction.
- The Diet Coke shot out of the bottle when the Mentos was added because of a reaction between the Mentos and Diet Coke caused the release of gas.
- Something in the Mentos coating caused a reaction that forced the CO_2 out of the Diet Coke solution.
- The ingredients in the Mentos coating reacted to create bubbles and build pressure, which forced the solution to shoot out of the bottle.
- The Mentos somehow forces the CO_2 out of the Diet Coke solution.
- The coating on the Mentos reacts with the phosphoric acid from the Diet Coke and causes gas to rapidly escape from the solution.

List 1. Student hypotheses.

Examine same number of Mentos in equivalent volumes of

- Diet Coke
- Caffeine-free Diet Coke (tests if caffeine is key compound)
- Regular coke (tests if any compounds found in Diet Coke, but not in Coke, are the important compounds)
- Flat Diet Coke (tests if CO_2 is key compound)
- Carbonated water (tests if CO_2 alone is capable of producing fountain effect or if other compounds in Diet Coke are needed in conjunction)
- Distilled water (tests if fountain effect is simply interaction between water and Mentos)

Run experiment with same volume of Diet Coke as above but with

- Sugar-free Mentos
- Fruity Mentos
- Mentos that have had their coating removed
- A small rock about the same size as the Mentos

List 2. Experiments to test the final class hypothesis.

Laboratory Activity

To minimize cost and waste the students used a 16-ounce beverage and one Mentos (or other corresponding material) for each experiment, as opposed to using a 2-liter beverage and 16 Mentos candies.[3] The students were also given a plastic bin, a measuring stick, and a graduated cylinder, as requested in the class experimental design process (Figure 2). This would allow the students to measure the height of the fountain and the volume of remaining beverage after the fountain.

Before starting the data collection, a prelab discussion was held. The students were asked how they could be confident that the data they were about to collect would be meaningful. They came to the conclusion that repeating the experiments would be prudent. It was decided that since there were a significant number of different experiments to be completed, each lab group would run two trials for each experiment, and then all of the lab groups would share their data. This would allow each group to do a more meaningful analysis of whether the hypothesis was confirmed or denied. Since data were going to be shared between groups, we also briefly discussed that all of the groups needed to conduct the experiments in the same fashion.[4] The students then completed the data collection and reported their results to the lab instructor (Figure 3).

Figure 2. The lab group placing one Mentos in a 16-ounce Diet Coke.

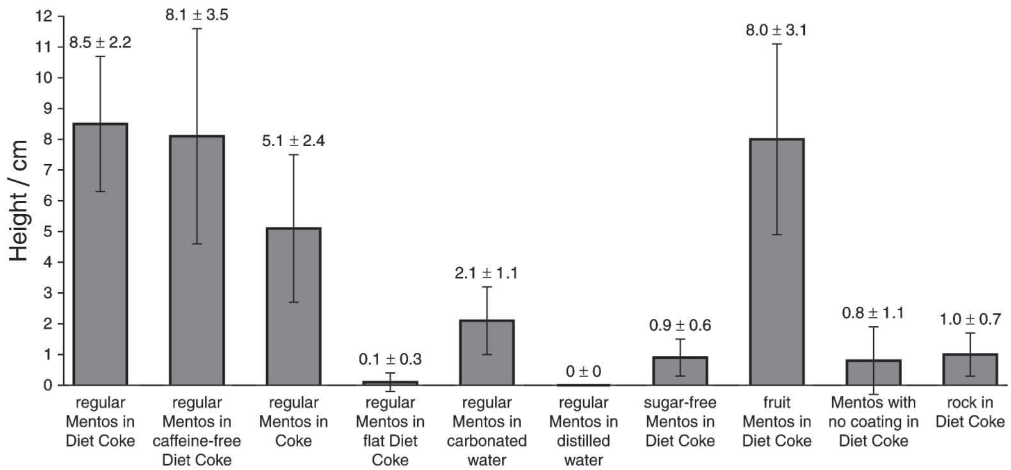

Figure 3. Class data from one lab section. Each group performed two trials; trials from all groups were used to calculate the mean and standard deviation for each experiment.

The students were then given several days to complete the report. This included copies of their lab notebook sheets, a summary of the data, example calculations (for the mean and standard deviation of the height of the fountain and for the volume of beverage remaining), an analysis explaining whether the hypothesis was confirmed or denied, and any proposed modifications to the original hypothesis. To quickly summarize, many of the students came to the conclusion that based on the data for the flat Diet Coke, the CO_2 in the beverage was necessary for this fountain effect to occur. In addition, many students also concluded that, based on the experiments with sugar-free Mentos and the Mentos with no coating, perhaps the sugar in the Mentos coating was a primary cause of the fountain. These data at least seemed to suggest that the hypothesis was not disproved outright, and it was often suggested that more experiments needed to be done to give a more specific reason for the fountain effect. A more detailed analysis (including an example of a student's data set, calculations, and conclusions) can be found in the Supplemental Material.[W]

What aspects of this lab did you like? Dislike?

- This lab made me enjoy a chem lab!
- I enjoyed being able to design the lab.
- This is the first time I have had any say in a chem lab.
- I am more involved in the experiments and the experiments are done at my discretion.
- We establish our hypothesis and try to prove it.
- It was unlike any other lab I have done.
- I liked we were using items that many people eat and drink on a normal basis.
- I enjoyed how the class got to put their input on how the experiment was conducted.

If this lab was different from your previous lab experiences, explain how.

- I felt like my partner and I were unsure of what we were doing.
- I am used to having to having a very structured lab, with a strict procedure.
- I didn't like it took so long to do the experiments.
- I did not like the number of experiments that had to be done.
- It was confusing keeping up with the data we collected.
- I think it would be interesting to have the students do the followup experiments they proposed for their revised hypothesis.

List 3. Selected responses from free-response questions in the student reflective survey.

Hazards

There are no safety hazards associated with this experiment.

Discussion

The students approached this exercise with a high level of enthusiasm and curiosity. While discussing the experimental design in lecture and collecting the data in lab, the students were engaged and at times even appeared to be in a competitive mode (for instance, boasting about who designed a better experiment was observed during the lecture discussion). This enthusiasm was confirmed based on the responses to the postlab reflection survey (List 3).

We feel this exercise was successful on many fronts. It was definitely more engaging than many of our previous lab experiments and inspired the students to independently form hypotheses and design experiments. This exercise provided a more realistic research experience, where the students were not ultimately given the "right" answer. Based on the postlab surveys, the students both recognized these facts and found value in having done these activities. This laboratory also provided the opportunity to implement activity-based learning exercises in the lecture, as the students were required to break off into collaborative group discussion when creating their hypotheses and designing their experiments. This type of learning environment effectively addresses the NSES recommendation to "guide students in active and extended scientific inquiry". Additionally, this exercise created a distinct link between the lecture and laboratory. Often times, afternoon labs become disjointed from lecture owing to the significant period of time in between these activities and because correlating curricular content between lecture and lab can become difficult. The use of lecture time to develop the laboratory activities helps solve this problem. To conclude, we feel this lecture–lab activity effectively used an inquiry-driven pedagogy to help the students become comfortable participating in the scientific process and stimulated student interest in chemistry by having them investigate an exciting, and well-known phenomenon.

Acknowledgment

We would like to acknowledge one of our students, Nevena Martinovic, for preparing Figure 3.

[W]Supplemental Material

Background information on the different states of matter and gas solubility; class data; an example of a student's data set, calculations, and conclusions; and postlab questionnaire are available in this issue of *JCE Online*.

Notes

1. This course requires three 50-minute lectures and one three-hour laboratory each week and is most often taken by non-science majors for the purpose of fulfilling the college's general education science requirement.

2. For instance, one student designed an experiment where one chemical component of the Diet Coke was removed, and then the Mentos would be placed in the beverage; the students agreed that even though this experiment would help identify the chemical components responsible for the fountain, we could not do this experiment in our laboratory!

3. It is noted that the use of 16-oz beverages and large plastic bins resulted in the need for very little cleanup. If this activity is to be done by the reader, it is recommended that a large recycling bin be placed in the lab.

4. A new, unopened, room-temperature beverage was used for each trial. The Mentos were dropped in immediately after opening the beverage and the height measurements were made from the top of the bottle opening to the peak of the fountain.

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