Diet Coke and Mentos- Geyser Optimization

Matt Nabity and Elizabeth Untiedt
Interdisciplinary Lesson
Middle School, Grade 8
Duration: One 90-minute block and one 45-minute block

Implementation: May 19-21, 2010, Falcon Bluffs Middle School, Littleton, CO
Lesson Prepared: April 26, 2010

Overview
In this lesson, students will collect data from Diet Coke and Mentos geysers and try to choose experimental settings to maximize thrust.

Purpose
Emphasis will be on building mathematical models of physical phenomena. Students will learn the power and importance of modeling, and explore graphing in three dimensions. This fun activity reinforces experimental procedure, introduces students to optimization (Elizabeth's research area), and requires students to work with uncertainty, determine best values, and explore mathematical modeling (Matt's research area).

Objectives
At the end of this lesson, students will be able to explain the concept of a maximum and an optimum. They will understand the difference between discrete and continuous models. They will understand that physical phenomena might require models with more than one independent variable, and will know that two independent variables create a response surface rather than a response curve.

Standards Met
CO State Science:
Standard 1 (Scientific Investigation Process): Benchmarks 2 (measurement/gathering data), 3 (interpreting data), 5 (identifying alternative explanations); Standard 2 (Matter and Energy): Benchmarks 3 (conservation of mass), 5 (atomic structure), 6 (compound/molecular structure); Standard 5 (Knowledge Building Process): Benchmarks 4 (predictive models)
National Science:
Standard 1 (Properties and Changes of Properties in Matter)
CO State Mathematics: Standard 4 (Geometric Concepts in Problem Solving): Benchmark 5 (Volume in 3 dimensions); Standard 5 (Measurements in Problem Solving): Benchmarks 1 and 2 (Using measurements of volume and mass; Using measurements to make comparisons)
National Mathematics:
Standard 1 (Problem Solving): Indicator 3 (build new knowledge through problem solving); Standard 4 (Mathematical Connections): Indicator 2 (apply math in contexts outside of math) and 3 (interconnection of mathematical ideas); Standard 5 (Mathematical Representation): Indicator 1 (modeling physical phenomena)

Background: Students should be able to accurately measure liquid volumes. Students should be able to accurately measure large distances. Students should be adept at recording experimental data. Students must be able to create a scatter plot in two dimensions.
References: http://www.tabblo.com/studio/stories/view/14370/
Coffeya, TS. Diet Coke and Mentos: What is really behind this physical reaction?
Am. J. Phys. 76 □6, June 2008, pp 551-7.

Lesson Vocabulary: optimum, maximum, projectile, chemical reaction, imprecision, best value, response variable, independent variable, response curve, response surface, volume,

Materials required

Per group of students (recommended group size is 4 or 5 students):

- 3 2L bottles of Diet Coke
- 3 paper clips (or comparable wire)
- 3 - 24 fruit Mentos candies
- launch pad (cardboard box that will hold bottle at a 45 degree angle, pictures included)
- safety goggles
- measuring tape
- 3 lawn flags

Preparation: Before lesson, drill a bottle cap and all the mentos through the center with a 5/32 drill bit, and prepare launch pads by cutting cardboard boxes if necessary. Lab tubs were assemble for each group with the following:

- Drilled bottle cap
- Pre-counted Mentos
- Lab worksheet
- Paper clips
- Launch pad
- Lawn flags

Safety**:** Students at launch pad will wear safety goggles. Basic lab safety procedures will be followed.

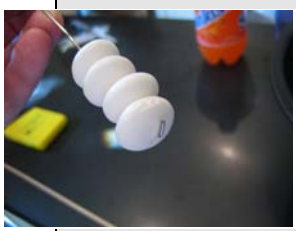
Method: 5 E's Model

Day 1

Engage: Show video of a Diet Coke/Mentos Bellagio. www.youtube.com/watch?v=znoSaHwbHYg

This part of the lesson should take 5 minutes.

Explore: Each groups combines Mentos and Diet Coke in designated amounts to carry out three experiments.



Students will carefully pour out Diet Coke so that the bottle contains the approiate volume of liquid. Bottles should ba agitated as little as possible and recapped tightly. Students will straighten out paper clips and thread on the appropriate number of Mentos to make "cartridges" for each experiment, as in the picture on the left.

Go outside. Within each group, there are (up to)two students at the launch site and (up to)two students 10-15 yars away with lawn flags, waiting to mark the point of farthest spray. One student at the launch site will thread a Mentos cartridge through a drilled cap and hold with fingers as in the picture on the right. The other student will quickly remove the Diet Coke lid so it can be replaced with the cartridge, as in the picture on the left.

The Diet Coke bottle should be placed in the launch pad, and the holding paper clip removed so that the Mentos drop into the Diet Coke, initiating the reaction.

The measuring group will flag the farthest point of spray. Afterward, they will use meter sticks to measure the *horizontal* distance travelled by the Diet Coke geyser.

Each group will have one fixed parameter and one variable parameter (assigned ahead of time by the instructors).

Class A: Groups 1-3: 2L Diet Coke; 1,3, and 5 Mentos
Group 4-6: 1.8L Diet Coke: 1,3, and 5 Mentos.

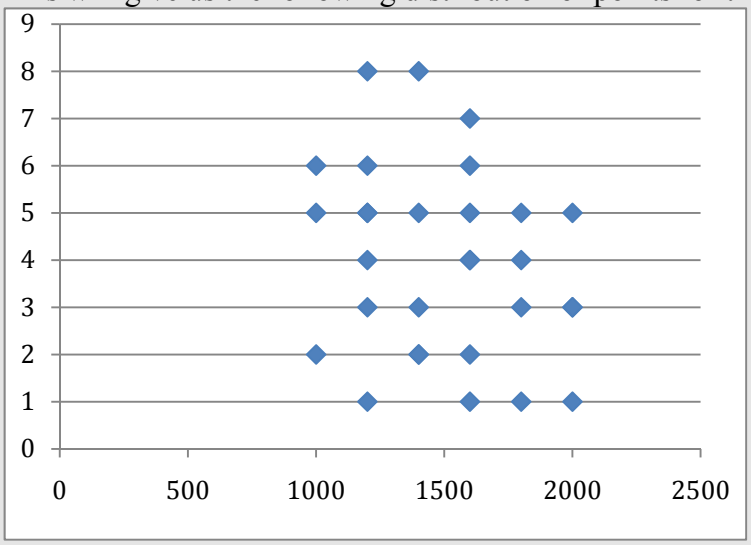
Class B: Groups 1-3: 1.6L Diet Coke; 1,4, and 7 Mentos.
Group 4-6: 1.4L Diet Coke; 2, 5, and 8 Mentos.

Class C: Groups 1-3: 1.2L Diet Coke; 1, 5, and 8 Mentos 8, 12, and 16 oz diet coke.
Group 4-6: 2 Mentos; 1, 1.4, and 1.6L Diet Coke.

Class D: Groups 1-3: 4 Mentos; 1.2L, 1.6L and 1.8L Diet Coke.
Group 4-6: 3 Mentos: 1.2, 1.4, and 2L Diet Coke.

Class E: Groups 1-3: 6 Mentos 1, 1.2, and 1.6L Diet Coke.
Group 4-6: 5 Mentos: 1, 1.2, and 1.6L Diet Coke.

This will give us the following distribution of points for the Day 2 surface plot:



This second part of the lesson should take about 50 minutes.

Explain: Return to the classroom. Each group will graph data from their individual experiment. From this 2-D model, groups will develop a hypothesis or conjecture about the underlying model for the reaction. Students will share group conclusions during a guided class discussion.

This 3rd part of the lesson should take about 30 minutes.

Day 2

Elaborate: Combine all group data to build period-specific 3-D model. f the teacher is unfamiliar with Excel, Matlab or whatever, he or she could use a 2D table much like we had on the board. Data arranged with rows/cols corresponding to mentos or volumes of diet soda. The teacher can then discuss what happens as they move from data point to data point and discuss with the class what they think will happen for
in between values. Inspect graph of the surface and make a conjecture for optimal quantities. Using the predicted optimal value, a final launch will be performed. The class prediction for optimal quantities of mentos and soda

will be launched, using the same scientific set up as during the group launches. Distance will be recorded and compared to the original data. After returning to the classroom, students will participate in a group discussion about the outcome of the final proportions. Students will participate in a guided discussion about the connection between the discrete experimental model and its continuous analog. Possible leading questions:

-Was the result an optimal value, how did it compare to the original data?

-Could there be another combination that achieves the same or is this the only possible combination?
-Why did we do the experimental/data collection portion of this activity?

-Could we have just had each group choose their own combinations?
-What would this data look like?
- Is there an underlying rule that governs the best combinations of mentos and diet soda?

Evaluate: Students will produce a paragraph explaining the water-ethanol phenomenon, with an accompanying illustration. Students will write a paragraph describing the role of uncertainty in applied math and discussing

Adaptations or differentiated learning
[Include all potential adaptations that may be useful for the classroom.]

Extensions & connections
Finite precision. Molecular Packing.

Peer review comments
[List any peer comments that aided in the preparation of this lesson]

Reflections (completed after lesson is implemented]

We were able to discuss the word optimization-root words, and what it might mean. We talked about how it could be a min or a max, and which it was in this experiment.

This lesson worked really well. If we'd had more time, we might have been able to go into more depth on the elaborate part of the lesson, with the 3D graph. Also, we could have used a better plotting tool to emphasize that the connections between data points is our goal with modeling. The scatter plot in 3D was nice, but a surface plot would have been possible with a bit more work.

The timing was great. The 90-minute block broke up nicely into three distinct parts; a materials preparation part, a data collection part with the launch, and finally a data comparison part.
[What did you learn?]
Initially, we thought this lesson was much simpler than our sphere-packing lesson, maybe almost too simple, yet the students seemed to get more out of this than the previous activity. We think this is due to the engaging nature of the experiment and the fact that we focused on one main theme or point rather than several issues relating to both our areas of research.

The point that simpler is better is something that we can carry through our professional lives. We still want to challenge people, but it seems to be more effective to challenge them one step at a time.

Activities such as this could be rescaled and still be highly impactful. Every student was engaged.

Student work in photos to be included later.