**Caffeine and Exponential Decay**

grade level(s): High School subject(s): Algebra II and Chemistry

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**Problem Statement:**

I was 17 years old. It was the night before a class project was due and my friends and I had spent exactly zero hours working on the project. So we gathered our materials and started work the night before; every hour we would 'pop' a No-Doz do help us make it through the night. By time I drove us to school in the morning my hands were shaking on the steering wheel, my heart was beating irregularly, my head began to throb and I was covered in sweat. The 'all nighter' is a time honored tradition in high school and college. Pulling an 'all nighter' usually entails the consumption of mass quantities of caffeinated beverages such Mountain Dew, Coca-cola, coffee, tea and 'energy drinks'. Caffeine is a stimulant that in addition to making one feel more alert, can lead to heart palpitations, paranoia and the 'jitters'. Your team will develop a mathematical model that includes the effects of body mass to describe blood caffeine levels after the consumption of caffeinated drinks. Each team member will then apply that model to their own caffeine consumption. Each team will then examine the consumption patterns of its members, investigate recommended blood caffeine levels and make a recommendation (in the form of product label) with respect to reasonable consumer behavior. These labels will be evaluated by the class and that feedback will be used by each team to craft the final label.

**Conceptual Storyline:**

Teenagers are the target market for many of the makers of today’s “energy drinks”. Many teens have misconceptions about the effect of energy drinks and other sources of caffeine on their body. This unit will allow students to see past clever advertising to be informed consumers who apply mathematical concepts to answer practical real-world questions. “Should I drink an energy drink and what is it going to do to me?”

Prior to this unit, students should have explored exponential functions in earlier math courses. Students should also have a basic understanding of the definition of a “drug” as well as the methods used for quality online research.

This PBL will give students the opportunity to review understanding of exponential functions through hands-on activities and mathematical modeling. Students will learn about the connection between the consumption of caffeine and blood level concentrations remaining in the body as time passes. This concept can be applied generally to understand how substances break down as a first order kinetic model.

Prior work was done within the class group to establish group norms: Students developed lists of what group work “looks like” and “sounds like”. Positive reinforcement was used to add to and reinforce productive group work. Several team building activities were used to demonstrate the necessity of cooperation and perseverance in problem solvings. Consistent reinforcement was given to students to ask group members questions prior to asking the teacher questions.

**Unit Standards (NGSS, CCSS, CTE):**

HS-LS1-3 (feedback mechanisms)

Connection to unit: When the brain is active, it produces adenosine. As more adenosine builds up, you become tired. When you sleep, your body breaks down adenosine. It's a feedback mechanism in that the buildup of adenosine is part of what triggers sleep, and sleep is when adenosine breaks down. Why we get tired and need sleep is more complicated than just this one pathway (and the way that caffeine works is more complicated also), but this particular pathway is connected to caffeine. Caffeine molecules "look like" adenosine and block the receptors that would take adenosine. So caffeine prevents you from feeling tired by interrupting the adenosine-sleep feedback cycle.

HS-LS1-7 (cellular respiration)

Connection to unit: Caffeine prevents you from feeling tired and (because of how it affects dopamine levels in the brain) is a stimulant, but it does not give you energy. Energy is obtained when sugars are broken down through the process of cellular respiration (sugar is "burned" with oxygen, which produces carbon dioxide, water and releases energy).

HS-ETS1-3 (evaluating solutions)

Connection to unit: Students have to consider data, health impacts, social/cultural behavior when developing and evaluating their recommendations.

[CCSS.MATH.CONTENT.HSF.LE.B.5](http://www.corestandards.org/Math/Content/HSF/LE/B/5/)

Interpret the parameters in a linear or exponential function in terms of a context.

[CCSS.MATH.PRACTICE.MP3](http://www.corestandards.org/Math/Practice/MP3/)

Construct viable arguments and critique the reasoning of others.

[CCSS.MATH.PRACTICE.MP4](http://www.corestandards.org/Math/Practice/MP4/)

Model with mathematics.

[CCSS.MATH.PRACTICE.MP5](http://www.corestandards.org/Math/Practice/MP5/)

Use appropriate tools strategically.

CTE: Career Ready Practices

2. Attend to personal health and financial well-being.

6. Employ valid and reliable research strategies.

7. Utilize critical thinking to make sense of problems and persevere in solving them.

CCSS.ELA.PRACTICE.E6

Use technology and digital media strategically and capably.

**21st Century Skills:**

Communication, Collaboration, Critical Thinking, Information and Technology Literacy, Problem Solving

**Locally and/or Personally Relevant for Students:**

Teenagers are the target market for many of the makers of today’s “energy drinks”. Many teens have misconceptions about the effect of energy drinks and other sources of caffeine on their body. This unit will allow students to see past clever advertising to be informed consumers who apply mathematical concepts to answer practical real-world questions. “Should I drink an energy drink and what is it going to do to me?”

**Connections to career and educational pathways:**

This problem based learning unit allows students to apply exponential relationships to understand how caffeine breaks down in the body over time. There is also opportunity to apply chemistry in the examination of the effect of caffeine on the brain. The discussion throughout the unit guides students thinking about caffeine products and leads them to make a realistic recommendation to consumers for the consumption of caffeine.

**Grouping of students for instruction:**

Students should be grouped into groups of 3 (ideally) or 4 for the week. If students typically work together in groups, it is recommended that students continue in previously established groups for this week. If students do not typically work in groups, group norms need to be established. Students should be grouped heterogeneously. Special ed and ELL students may need special accommodations.

**Table of Content/Overview of Unit**

**Prior: Students keep a log of caffeine intake for 24 hours: it can be for them, a family member, or a friend.**

**Lesson 1: Review Exponential Functions: students introduced to the unit. Students explore exponential decay and growth with M&M’s.**

**Lesson 2: Caffeine: The Basics: Students learn that many medications and caffeine can be modeled with exponential decay. Students do a internet search to find a recommendation for how much caffeine should be ingested.**

**Lesson 3: Model Caffeine Intake: students use exponential decay to model the concentration of caffeine in the bloodstream over time.**

**Lesson 4: Recommendation: students synthesize their understanding of**

**Lesson 5: Evaluation**

**Lesson 0: Prior to beginning the unit**

The day 0 “lesson” was done in a 30 minute period to familiarize students with piecewise functions and to assign the caffeine intake log to students. Depending on student familiarity with piecewise functions, this may or may not be included. The way day 3 is scaffolded, students did not really need to know this material but it was nice for them to see contexts where graphs had “pieces” and they made sense.

* Caffeine and Sleep Log
* Day 0
  + The three slides used to discuss piecewise functions are from A Visual Approach to Functions, 2002, Frances Van Dyke, Key Curriculum Press.

**Lesson 1: Review Exponential Functions**

**Problem Statement:**

Your team will develop a *mathematical model* to describe blood caffeine levels after the consumption of caffeinated beverages and foods. Each team member will then apply this model to his or her own caffeine consumption. Each team will examine the consumption patterns of its members, investigate recommended blood caffeine levels and make a recommendation with respect to reasonable consumer behavior. The class will evaluate these recommendations.

Lesson one of this learning module focuses upon the italicized portions of the problem statement. Students will review exponential models and focus on the difference between growth and decay. Students will model exponential decay so that they may analyze caffeine consumption during Lesson 3.

**Learning Objectives:**

1. Students will be able to use a graphing calculator to model exponential and linear functions.
2. Students will be able to explain the constants in the exponential function
   1. “a” is the amount one begins with
   2. “b” is the number that is multiplied by each time. For exponential growth, b>1. For exponential decay, 0<b<1.

**Lesson Standards:**

[CCSS.MATH.CONTENT.HSF.LE.B.5](http://www.corestandards.org/Math/Content/HSF/LE/B/5/)

Interpret the parameters in a linear or exponential function in terms of a context.

[CCSS.MATH.PRACTICE.MP4](http://www.corestandards.org/Math/Practice/MP4/)

Model with mathematics.

[CCSS.MATH.PRACTICE.MP5](http://www.corestandards.org/Math/Practice/MP5/)

Use appropriate tools strategically.

CCSS.ELA.PRACTICE.E6

Use technology and digital media strategically and capably.

**Materials:**

* Day 1 student handout
* Day 1 review exp lesson
* M&M’s
* Graphing Calculators

**Lesson Preparation:**

* Copy day 1 student handouts.
* Put M&M’s into small cups for students. (Small dixie cups hold approximately 80 M&M’s.)

**Time Required:**

This lesson is suitable for a 50-minute class period. After giving initial instructions, the teacher will monitor and rotate through the class as student groups work together.

* Do now (5-minutes) – Review calculating percent decrease.
* Unit Overview Presentation and Learning Targets/Success Criteria (5 min)
* Activity (25+ min)
  + Students are seated in groups so they can assist each other before asking for teacher assistance.
  + Hand out M&M’s
  + Circulate to make sure students are doing calculations correctly and assist where needed with graphing calculators.
* Wrap up
  + Summarize.
  + Discuss where they have seen this before (radioactive decay, richter scale, audio scale, etc.)
  + Did you achieve “success criteria”?

**Notes, Extensions and accommodations:**

* Calculating the percent change proved to be one of the more challenging parts of the lesson so that is why it is included as a “do now” activity.
* All students need to finish pages 1-3 of this activity. Page 4 is an extension for the faster groups.
* This “lesson” should be modified based on student familiarity with using graphing calculators to model lines of best fit. As written, the lesson is a 75 min lesson if students are not familiar with graphing calculators and if they need to follow all the steps in the lesson. The focus of this lesson should be the meaning of the a and b constants, not the graphing calculator.
* Possible extension: Students could be asked to model exponential growth as well as decay. Adding exponential growth would deepen the discussion around the meaning of the coefficients “a” and “b” in the the exponential function .

**Lesson 2: Caffeine: the Basics**

**Problem Statement:**

Your team will develop a mathematical model to describe blood caffeine levels after the consumption of caffeinated beverages and foods. Each team member will then apply this model to his or her own caffeine consumption. Each team will examine the consumption patterns of its members, *investigate recommended blood caffeine levels and make a recommendation with respect to reasonable consumer behavior.* The class will evaluate these recommendations.

Lesson two of this learning module focuses upon the italicized portions of the problem statement. Students will learn more about the nature of caffeine and its physiological and psychological effects. They will learn how to evaluate the quality of references materials. Students will search for appropriate literature so that they may devise caffeine consumption recommendations during Lesson 4.

**Learning Objectives:**

1. Be able to *define* what it means for a compound to be a drug.
2. Be able to *describe* the effects that caffeine has upon the body.
3. Be able to *judge* the quality of a literature reference.

**Lesson Standards:**

HS-LS1-3 (feedback mechanisms)

Connection to unit: When the brain is active, it produces adenosine. As more adenosine builds up, you become tired. When you sleep, your body breaks down adenosine. It's a feedback mechanism in that the buildup of adenosine is part of what triggers sleep, and sleep is when adenosine breaks down. Why we get tired and need sleep is more complicated than just this one pathway (and the way that caffeine works is more complicated also), but this particular pathway is connected to caffeine. Caffeine molecules "look like" adenosine and block the receptors that would take adenosine. So caffeine prevents you from feeling tired by interrupting the adenosine-sleep feedback cycle.

HS-LS1-7 (cellular respiration)

Connection to unit: Caffeine prevents you from feeling tired and (because of how it affects dopamine levels in the brain) is a stimulant, but it does not give you energy. Energy is obtained when sugars are broken down through the process of cellular respiration (sugar is "burned" with oxygen, which produces carbon dioxide, water and releases energy).

HS-ETS1-3 (evaluating solutions)

Connection to unit: Students have to consider data, health impacts, social/cultural behavior when developing and evaluating their recommendations.

CTE: Career Ready Practices

6. Employ valid and reliable research strategies.

**Materials:**

* Caffeine Data Sheet handout (see supplementary material)
* What is Caffeine PowerPoint presentation (see supplementary material)
* Are They Reliable Power Point presentation (Quality of Reference Sources) (see supplementary material)

**Lesson Preparation:**

* Review the Caffeine PowerPoint presentation and view the ASAPScience video “Your Brain On Caffeine”. (Caffeine Power Point Lesson)
* Read the Caffeine FAQ as students may ask more detailed questions about caffeine metabolism.
* Examine the last three references given on the Caffeine Data Sheet handout. These give some details with respect to the recommended caffeine consumption levels and the webpage by Chatham may engender some interesting discussions. The three initial references are detailed peer-reviewed sources that provide deep background.

**Time Required:**

This lesson is suitable for a 50-minute class period. A suggested structure and timeline for this lesson is given below.

* Open Discussion (5-minutes) – What is a drug? Working in groups, students should devise 1-3 criteria that define a it means for a chemical to be a drug. Students report out their criteria which should include:
  + A chemical that needs to be *ingested* (eaten, drunk, inhaled, absorption or intravenous).
  + A chemical that has a *therapeutic effect* (it affects someone in a physical and/or psychological manner).
  + A chemical that is *metabolized/used* by the body (the amount of the chemical in the body decreases with time).

Close the discussion with the question: Do you consider caffeine to be a drug?

* Caffeine Data Sheet handout (6-minutes) – Distribute the Caffeine Data Sheet handout and allow five minutes for the students to read over the material. Note: the table on the back of the handout has blank rows for the students to fill in and use for Lesson 3 and Lesson 4.
* PowerPoint presentation (12-minutes) – Slides that cover the following topics:
  + What is caffeine?
    - Molecular structure and its similarity to adenosine
  + How does your body metabolize caffeine?
    - Orogastric ingestion
    - Liver and metabolites
    - Half-life in the blood stream
  + Factors that affect its metabolism
    - Age
    - Weight
    - Sex?
    - Race?
  + ASAPScience video “Your Brain On Caffeine” (3m 15s)
  + What are the immediate effects of caffeine?
    - Alertness, etc.
    - Jitters, etc.
  + What are the long-term effects of caffeine?
    - Tolerance and withdrawal
  + Sources of caffeine.
    - Imbibed and eaten
* Basic Literature Search presentation (2-minutes)
  + Different search engines (demonstrate use of Google)
  + Quality of literature sources (peer-review government (.gov) organizations (.org) commercial (.com)). Examples of each are given on the Caffeine Data Sheet handout
* Group work (10-minutes) – Students go online to find information on recommended caffeine consumption and its proper use or misuse.
* Wrap up (10-minutes) – Groups report out their findings and discuss common features or discrepancies with respect to quality of sources.
  + Offer students other examples of systems that exhibit a simple exponential decay such as radioactive decay (and its use in 14C-dating) and atmospheric pressure
* Lecture (2-minutes) – Introduce the task for Lesson 3 and what will be expected of them. If possible, they should come to class with Caffeine Consumption Log and the amount of caffeine they ingested from each of their sources.

**Notes, Extensions and accommodations:**

* The material students are asked to read today could be modified as needed for different reading levels and abilities. Specifically, English Language Learners(ELL) will find this to be very difficult text. Teachers should strongly consider modifying it and ELL students should be allowed to use electronic translators.
* Possible extensions:
  + Students could be asked to make different recommendations for adults and teens. This would deepen the science connection to explore the topics of differences between teens and adults and specifically, “Why are there different levels of recommendation for people with similar body mass?”
  + Students could be asked to look at the scientific basis (mg/kg body mass) behind the general daily recommendations. Students could calculate the recommended intake levels for people of different body masses. T
  + Students could be asked to look at the different recommendations (mg/kg body mass) between countries.

**Lesson 3: Model Caffeine Intake**

**Problem Statement:**

Your team will develop a mathematical model to describe blood caffeine levels after the consumption of caffeinated beverages and foods. *Each team member will then apply this model to his or her own caffeine consumption.* Each team will examine the consumption patterns of its members, investigate recommended blood caffeine levels and make a recommendation with respect to reasonable consumer behavior. The class will evaluate these recommendations.

Lesson three of this learning module focuses upon the italicized portions of the problem statement. Each student will use their personal caffeine intake log to model caffeine concentration in the bloodstream throughout the day.

**Learning Objectives:**

1. Students will apply what they have learned about modeling with exponential decay to model their caffeine intake.
2. Students will be able to model using piecewise functions.

**Lesson Standards:**

[CCSS.MATH.PRACTICE.MP4](http://www.corestandards.org/Math/Practice/MP4/)

Model with mathematics.

CTE: Career Ready Practices

2. Attend to personal health and financial well-being.

7. Utilize critical thinking to make sense of problems and persevere in solving them.

**Materials:**

* Day 3 handout
* Day 3 Model Caffeine Presentation
* Graph paper (whole page, axis not numbered)
* Medical Scenarios Excel File (source of slides)

**Lesson Preparation:**

* Have caffeine intake scenarios available for students who “forget” or do not do a caffeine intake log.

**Time Required:**

This lesson is suitable for a 50-minute class period. After giving initial instructions, the teacher will monitor and rotate through the class as students work. The teacher may want to have students seated in groups so students can easily obtain assistance from other students.

* “Do now”: Reviews using equation to make a table of values (5 min)
* Summarize last 2 days and learning target/success criteria (2 min)
* Present Lesson: Demonstrate how to construct tables to model piecewise functions (12 min)
  + Discuss the formula C(t) = Co(0.87)t.
    - **C(t)= Concentration at t hours**
    - **Co = Initial Concentration (mg)**
    - **T = time (hours)**
    - **b=0.87** This is based on a half-life of 5 hours. Yesterday’s video clip said the half-life of caffeine is 5 - 6 hours. Many students were very interested in where the coefficient b=0.87 came from. At this point, my students do not know how to solve for “b” but later on they will.
  + Go through whole class example. Especially focus on finding the new equation each time caffeine is consumed.
* Work time: (20 min)
  + Give students time to make their own tables and graphs.
* Wrap up: Math is used to model things in the world like medication. Today we used math to model the concentration of caffeine in the bloodstream over time. Similar models can be used to model medication concentrations in the bloodstream over time. (10 min)
  + Show slide of how long it takes a medication to come to equilibrium. Tie it to “this is why doctors sometimes tell you it will take awhile for the medication to work.”
  + Show slides of b=0.94 versus b=0.7. Discuss how we want to maintain a certain level in the bloodstream. If something decays quickly, we would want more frequent doses.
  + Did you achieve success criteria?

**Notes, Extensions and accommodations:**

* Many students were very interested in where the coefficient b=0.87 came from in the equation. The unit following this will involve solving exponential and logarithmic equations. Make sure to have students find the coefficient “b” for a half life of 5 hours, 6 hours, 10 hours, etc. and tie the coefficient back to this exploration
* Possible extension: Students could use computer spreadsheet programs and simulate different scenarios. Depending on student familiarity with writing spreadsheet equations, they could build the spreadsheet or they could use a previously created spreadsheet.

**Lesson 4: Recommendation**

**Lesson 4 – Caffeine Recommendation**

**Problem Statement:**

Your team will develop a mathematical model to describe blood caffeine levels after the consumption of caffeinated beverages and foods. Each team member will then apply this model to his or her own caffeine consumption. *Each team will examine the consumption patterns of its members, evaluate recommended blood caffeine levels and make a recommendation with respect to reasonable consumer behavior.* The class will evaluate these recommendations.

Lesson four of this learning module focuses upon the italicized portions of the problem statement. Each student group will document and discuss three unique caffeine recommendations (found online). The group will then connect their own caffeine consumption experience, data and interpretation of the data model to those recommendation. Each group will then make their own unique recommendation for healthy adolescent caffeine consumption.

**Learning Objectives:**

1. Students will apply what they have learned about the effects of caffeine as a drug on the body to make a recommendation for healthy caffeine consumption.
2. This recommendation will be turned into a concise “warning label” to be used on containers of caffeinated beverages (similar to the warning labels found on nicotine products). The label should give consumers a clear warning about the risks of caffeine usage and a recommended daily consumption limit (in mg).

**Lesson Standards:**

HS-ETS1-3 (evaluating solutions)

Connection to unit: Students have to consider data, health impacts, social/cultural behavior when developing and evaluating their recommendations.

[CCSS.MATH.PRACTICE.MP3](http://www.corestandards.org/Math/Practice/MP3/)

Construct viable arguments and critique the reasoning of others.

**Materials:**

* Day 4 handout
* Mailing label to use as a warning label
* Empty soda cans, energy drink cans, iced coffee container, etc.

**Lesson Preparation:**

This lesson builds on research about caffeine (from Lesson Day 2) and data collection/analyzation (Lesson Day 3).

**Time Required:**

This lesson is suitable for a 50-minute class period. After giving initial instructions, the teacher will monitor and rotate through the class as student groups work together.

* “Do now”: Reviews what they’ve learned about caffeine and writing equations(5 min)
* Summarize last 3 days and learning target/success criteria (5 min)
* Present Lesson: Use what you’ve learned about caffeine (day 2) and your modeling of your caffeine intake (day 3) to write a group recommendation regarding caffeine consumption.
  + Everyone presents their data source and recommendation
  + Everyone presents their data modeling
  + Group discuss and decides what their recommendation will be and the justification for it.
  + Group writes recommendation on a mailing label and affixes it to a caffeine container.
* Summary: Math is used to model things in the world like medication.
  + Did you achieve success criteria?

**Notes, Extensions and accommodations:**

* **Possible extensions:** Day 4 extensions would build on Day 2 extensions.
  + Students could be asked to investigate why there is no recommendation for caffeine levels in blood that do or do not allow sleeping.
  + Students could also be asked to make some type of presentation and use it to educate other students (for example, in a health class). Presentations could include a public service announcement, a trifold, a video, etc.
  + Students could be asked to design a mechanism/device/app/etc. that could be used to monitor or control caffeine usage. Alternatively, students could be asked to investigate the devices already out there that do this.

**Lesson 5: Evaluation**

**Problem Statement:**

Your team will develop a mathematical model to describe blood caffeine levels after the consumption of caffeinated beverages and foods. Each team member will then apply this model to his or her own caffeine consumption.Each team will examine the consumption patterns of its members, evaluate recommended blood caffeine levels and make a recommendation with respect to reasonable consumer behavior. *The class will evaluate these recommendations.*

Lesson five of this learning module focuses upon the italicized portions of the problem statement. The class will evaluate group recommendations, giving positive feedback and suggest one area for improvement.

**Learning Objectives:**

1. Construct viable arguments and critique the reasoning of others

**Lesson Standards:**

HS-ETS1-3 (evaluating solutions)

[CCSS.MATH.PRACTICE.MP3](http://www.corestandards.org/Math/Practice/MP3/)

Construct viable arguments and critique the reasoning of others.

**Materials:**

* Copies of student recommendations.
* Advertising from four energy drink companies

**Lesson Preparation:**

* This lesson is designed to be done using “clickers” (student response system). It could easily be adapted to be a gallery walk or other type of feedback activity.
* Take pictures of student recommendations and put them into the powerpoint presentation

**Time Required:**

This lesson is suitable for a 50-minute class period. After giving initial instructions, the teacher will monitor and rotate through the class as student groups work together.

* Summarize last 3 days and learning target/success criteria (5 min)
* Show student recommendations. Use clickers to have students type in one positive and one thing to be improved about each recommendation. (20 min)
* Give student groups their feedback and have them modify their recommendations. (10 min)
* Wrap up:
  + What are energy drinks good for?
  + What is bad about energy drinks?
  + Are energy drink better or or worse than coffee to ingest caffeine?
  + What quantity of energy drinks are recommended for children, teens and adults?
  + Why are there different levels of recommendation for teens and adults?
  + Is drinking or ingesting caffeine “typical” for students?
  + Is caffeine a source of energy?
  + Do students understand how caffeine decay is related to the mathematical model?
  + Can students understand the bottom of the line between the amount of the caffeine in the body system and the ability for a person to sleep?
  + Go through the advertising material from 4 different energy drink companies

**Notes, Extensions and accommodations:**

* Possible extension: This evaluation activity could be done as a gallery walk.

**Unit Assessment:**

Students will assess each other on day 5 and then modify their recommendations based on feedback from other students.

**Unit Accommodations:** As stated earlier, special ed and ELL students may need special accommodations.

**References/Resources:**

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