Teacher Protocol: Math and Plant Biology Video Game

The Biology of Drought Defense in Plant Cells

The purpose of this activity is to integrate concepts in plant and mathematical biology for high school students through video gaming. The game allows players to help a plant cell fight drought by controlling the ratio of proteins and hormones that send signals to the DNA to defend the cell and capture energy using photosynthesis. Scientists study drought to develop better farming practices, more resilient crops, and to create strategies to help ecosystems survive. Engaging with mathematical models via technological tools helps increase student interest and confidence, while learning more about plants increases student interest in plant biology and awareness of the roles plants play in our environment. To assess if students improve their attitudes towards math, the Attitudes Towards Mathematics Inventory (ATMI) survey will be administered as pre- and post-test. To assess if students improve their awareness about plants, the Plant Awareness Disparity Index (PAD-I) survey will be administered as a pre- and post-test.

You can find the game at: https://rdale.itch.io/plants
The password is: plantGame

Goals

1. Improve students' attitudes towards math
2. Improve mathematical knowledge through contextualizing mathematical concepts
3. Increase awareness of plants
4. Increase students' knowledge of plant drought resistance
5. Examine changes in students' attitudes towards math and plant awareness

The concepts that this activity will cover:

- Connect DNA and proteins to cellular functions
- Understand that cells use proteins to send messages/signals about events
- Understand that concentration of proteins is important for the cell to transmit messages/signals

- Consider how biological feedback loops impact balancing concentration of proteins
- Engage in mathematical and systems thinking about the balance between energy cost to make proteins, and the cost of not responding to environmental signals
- Connect environmental signals to small-scale responses in individual cells
- Observe the impact of randomness (diffusion) on the ability of the cell to send messages

Next Generation Science Standards	
Performance Expectations	**Disciplinary Core Ideas**
Life Sciences	
LS1 From Molecules to Organisms: Structures and Processes	
LS1-5. Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.	LS1.C: Organization for Matter and Energy Flow in Organisms
LS1-3. Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.	LS1.A: Structure and Function
LS3 Heredity: Inheritance and Variation of Traits	
LS3-1. Ask questions to clarify relationships about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.	LS3.A: Inheritance of Traits
PS1 Matter and its Interactions	
PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.	PS1.B: Chemical Reactions
PS1-5. 5. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.	ETS1.C: Optimizing the Design Solution
Mathematics	

MP2. Reason abstractly and quantitatively.	
MP.3. Construct viable arguments and critique the reasoning of others.	
MP4. Model with mathematics.	

What do students should know before starting the activity:

- DNA is in the nucleus
- DNA is the blueprint for proteins
- Proteins are made from amino acids
- Cells use proteins and hormones to send messages to the DNA and other cells
- Chloroplasts perform photosynthesis in plants, which captures energy from sunlight
- (optional) salt creates drought stress through osmosis
- Scientists often use salt to create drought stress in plants

Introduction

How does our brain know when we are thirsty? Our bodies send messages to our brains using proteins. Our brains then tell us it is time to drink water – and the thirstier we are, the more water we need. How would this happen in plants if they do not have brains?

All organisms use delicate balances of proteins to send and receive signals. The amount and type of protein is important to successfully send these signals – otherwise, you may think you are thirsty when you aren't. Responding to signals costs energy, and cells want to be as efficient as possible. Our bodies use lots of proteins to tell us that we are hungry, thirsty, happy, and tired. If you are hungry and forget to eat, your body will make you feel tired so you will spend less energy. This also happens when plants run out of water.

In the plant cell, when the plant feels thirsty (called 'drought'), the protein ABA is produced. When the plant cell is flooded with this protein, the cell can begin to respond to the danger. Plants need water to transform energy from light (photosynthesis). If a plant doesn't reduce photosynthesis, it will use up all its water reserves.

Unlike us, plants can't simply get up to grab a cup of water. The plant needs to let the DNA know that drought is occurring. The DNA can make other proteins that save water. ABA does this by finding the protein PP2C. When PP2C and ABA hit each other,

SNRK2 is released and travels to the DNA. The number of signals from SNRK2 that the DNA receives tells the DNA how severe the drought is. The better the signal, the better the DNA can respond, and the plant can survive drought and continue to grow.

Details about the game

In this game, students play as a plant cell defending itself from drought. Drought is represented by salt particles. When scientists want to study drought's effects on individual cells, they use salty solutions. This is because salt can draw water out of cells by osmosis.

Students control the number and type of proteins in the cell. Students learn how the proteins work together to send messages to the DNA. Proteins move through the cell randomly. Successfully sending messages to the DNA rewards students with 'amino acid' points that they can spend on making more proteins.

Students can also build chloroplasts to save energy – but the drought must be controlled in order to accomplish this, as photosynthesis requires water. Finally, students can adjust the 'stickiness' of protein interactions, which changes the difficulty to successfully send signals in the cell.

Project Steps

1. Administer the pre-surveys any day before you start the activity:
    - pre-test of the Attitudes Towards Mathematics Inventory (ATMI)

      https://survey.iad1.qualtrics.com/jfe/form/SV_3rzfaWKHhne2X1Y
    - pre-test of Plant Awareness Disparity Index (PAD-I)

      https://survey.iad1.qualtrics.com/jfe/form/SV_1EXukaAyiebOKmG
2. Introduce the concepts of plant drought to students
3. Explain how to download the game from the app store, or navigate to the website
4. Review with students the instructions (tutorial) on how to play the game
5. Play the game
6. Ask students to answer the questions
7. Administer the post-surveys after the students finish the activity:

- post-test of the Attitudes Towards Mathematics Inventory (ATMI)

  https://survey.iad1.qualtrics.com/jfe/form/SV_6ihlf7Dguugy95c

- post-test of the Plant Awareness Disparity Index (PAD-I)

  https://survey.iad1.qualtrics.com/jfe/form/SV_3qtF3pnmxnbZsTI

Time

30-45 minutes – explain background, check instructions, play the game, and answer questions. It takes about 5-10 minutes to complete the game.

Materials

An android device or a computer with a browser

After play questions:

- How much energy were you able to collect?
- What protein did you build the most of: ABA, ABPF, or PP2C/SNRK2? The least?
- What happened when you reduced the binding rate? Increased it?
- What happened to the chloroplasts if the salt particles hit them?

CONTACT INFORMATION

Technical & scientific adviser

Dr. Renee Dale

Postdoctoral Fellow

Donald Danforth Plant Science Center

rdale@danforthcenter.org

Project manager

Dr. Sandra Arango-Caro

Education Researcher

Education Research and Outreach Laboratory

Donald Danforth Plant Science Center

Sarango-caro@danforthcenter.org

Director of Education

Dr. Kristine Callis-Duehl

Education Research and Outreach Laboratory

Donald Danforth Plant Science Center

KCallis-Duehl@danforthcenter.org