Teacher Resource for:

Uniform ripening Encodes a Golden 2-like Transcription Factor Regulating Tomato Fruit Chloroplast Development..

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GENERAL USE OF Science in the Classroom

Student Learning Goals:
“One fundamental goal for K-12 science education is a scientifically literate person who can understand the nature of scientific knowledge.”

The U.S. National Academy of Sciences defines science as: “Any new finding requires independent testing before it is accepted as scientific knowledge; a scientist is therefore required to honestly and openly report results so that they can readily be repeated, challenged, and built upon by other scientists. Proceeding in this way over centuries, the community effort that we call science has developed an increasingly accurate understanding of how the world works. To do so, it has had to reject all dogmatic claims based on authority, insisting instead that there be reproducible evidence for any scientific claim.”

An important student learning goal, central to any understanding of “the nature of scientific knowledge,” is to give each student an appreciation of how science is done.

This includes knowing why:
• Scientists must be independent thinkers, who are free to dissent from what the majority believes.
• Science can deal only with issues for which testable evidence can be obtained.
• All scientific understandings are built on previous work.
• It is to be expected that one scientist’s conclusions will sometimes contradict the conclusions of other scientists.
• Science is a never-ending venture, as the results from one study always lead to more questions to investigate.

1 A Framework for K-12 Science Education, National Research Council, 2012
Using This Resource

**Learning Lens:**

The Learning Lens tool can be found on the right sidebar of each resource and is the source of annotations. Click on the headings to highlight portions of the text of the corresponding research article. A subsequent click on the highlighted text will produce a text box containing more information about that particular piece of text. Below is an example of the Glossary function of the Learning Lens.

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**ABSTRACT**

White-Nose Syndrome (WNS) is an emerging disease affecting hibernating bats. Mortality and precipitous population declines in winter *hibernacula*. First described in 2016 in New York State spreading rapidly across eastern North America and currently affects seven species of bats (1). A regional population collapse and is predicted to lead to regional extinction of the little brown myotis (*myotis lucifugus*), previously one of the most common bat species in North America. Novel diseases can have serious impacts on native wildlife populations which in turn can have substantial impacts on ecosystem integrity.

**REPORT**

Emerging infectious diseases are increasingly recognized as direct and indirect agents of extinction of free-ranging wildlife (1–4). Introductions of disease into naïve wildlife populations have led to serious declines or local extinctions of different species in the past few decades, including amphibians from chytridiomycosis (5, 6), rabbits from myxomatosis in the United Kingdom (7), Tasmanian devils from infectious cancer (8), and birds in North America from West Nile virus (9). Here we demonstrate that White-Nose Syndrome (WNS), an emerging infectious disease, is causing unprecedented mortality among hibernating bats in eastern North America and has caused a population collapse that is threatening regional extinction of the little brown myotis (*myotis lucifugus*), a once widespread and common bat species.

VNS is associated with a newly described psychrophilic fungus, *Geomyces destructans* that grows on exposed tissues of hibernating bats, apparently causing premature arousals, aberrant behavior, and premature loss of critical fat reserves (9, 10) (Fig. 1). The origin of WNS and its putative pathogen, *G. destructans*, is uncertain (9). A plausible hypothesis for the origin of this disease in North America is introduction via human trade or travel from Europe, based on recent evidence that *G. destructans* has been observed on at least one hibernating bat species in Europe (11). Anthropogenic spread of invasive pathogens in wildlife and domestic animal populations, so-called pathogen pollution, poses substantial threats to biodiversity and ecosystem integrity and is of major concern in conservation efforts (1, 2).

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An example of the resource with the Glossary, Previous Work, Author’s Experiments, News and Policy Links, and References and Notes tools turned on. The Glossary tool is in use.
Learning Notes:

Learning Notes accompany each figure and are designed to help students deconstruct the methods and data analysis contained within each figure.

Fig. 1. Spatial distribution of head scales. (A) Head scales in most snakes (here, a corn snake) are polygons (two upper panels) with stereotyped spatial distribution (two lower panels); left (yellow) and right (red) scale edges overlap when reflected across the sagittal plane (blue). (B) Polygonal head scales in crocodiles have a largely random spatial distribution without symmetrical correspondence between left and right. (C) Head scales from different individuals have different distributions of scales’ sizes and localizations (blue and red edges from top and bottom crocodiles, respectively).

Method: 3D geometry and color-texture reconstruction

The authors took 120 color pictures of each animal to create detailed, three-dimensional models of reptile heads. Watch this video in which the authors further explain their modeling methods:

http://www.sciencemag.org/content/suppl/2012/11/29/science.1226265.DC1/1...
References:

The Reference section of each resource is annotated with a short statement about how or why each reference relates to the current research study.

17. Lewejohann et al., Environmental bias effects of housing conditions, laboratory environment and experiment on behavioral tests. Genes Brain Behav. 5, 64 (2006).
Thought Questions

Thought Questions are located above the Learning Lens in the right sidebar of each resource. These questions were written to be universal and applicable to any primary research paper. Thought questions do not have a single answer, or a correct answer for that matter, and can be used to stimulate discussion among students.
Suggestions for Classroom Use:

In addition to the thought questions discussed above, other resources are provided for use in the classroom. These can be found toward the end of the teacher guides associated with each specific article and include:

1. Discussion questions specific to the article, related to the standards, and/or associated with the figures.

2. Activities tied to the articles.

Some ways to use the Science in the Classroom articles:

1. Assign to student groups to read and discuss during class.

2. Assign small sections of the article to student groups to read and discuss during class, with the expectation that they will present or use jigsaw to teach the entire class what is in their part of the article.

3. Assign to individual students to complete during class or as homework.

4. Assign reading as an extra credit project.

Some ideas for interactive student engagement after reading the article:

1. Students write answers to discussion questions (for example, those linked to the standards or those linked to the diagrams).

2. Go over the abstract, as well as information about the purpose and structure of an abstract, and have students write their own abstracts for the articles in language that could be understood by their peers.

3. Have students edit the article, or parts of the article, to a simpler reading level.

4. Have students, alone or in small groups, use the annotated list of references to explain how the scientists who wrote this article built on the published work of at least one independent group of scientists in making their discoveries. In the process, did they produce data that supports the findings of the earlier publication that they have cited in the text? In what way does this article support the statement that scientific knowledge is built up as a “community effort”?
5. Use the article and discussion questions linked to the standards and the diagrams for a teacher-led classroom discussion. The discussion can focus on the nature of science and scientific research, as well as on the science in the article itself.

6. Have students give a classroom presentation about the article, parts of the article, or their answers to discussion questions.


ARTICLE-SPECIFIC MATERIALS

Connections to the nature of science from the article

A useful schematic for thinking about both the nature of science and the process of science is to frame discussion around the How Science Works Flowchart on the Understanding Science website. This schematic divides science into four interacting categories of Exploration and Discovery, Testing Ideas, Community Analysis and Feedback, and Benefits and Outcomes. A useful activity for students could be to map Burrows’s and Sutton’s research onto the Flowchart, as Understanding Science models with Walter Alvarez and the discovery of the meteor impact that led to the extinction of dinosaurs.

- **Exploration and Discovery**
  Dr. Powell and colleagues set out to identify the gene that is responsible for affecting uniform ripening at the expense of a flavorful tomato. Working with a number of other researchers, including Dr. James Giovannoni, a professor at Cornell University working on fruit ripening, the investigators were able to identify the gene that controls fruit flavor, GLK2. Interestingly, GLK2 has a closely related sister gene called GLK1, which is known to be involved with chloroplast development and maturation. Using this information and the discovery that GLK2, but not GLK1, is expressed in the fruits, the researchers were able to identify the molecular mechanism behind generating a flavorful tomato.

- **Testing Ideas**
  The authors tested the idea that GLK2 is involved with tomato flavor by generating transgenic plants where GLK2 is expressed in plants that are known not to have a functional copy. What was found is that expressing GLK2 in mutant plants restores the phenotype in the immature fruits and overexpressing GLK2 results in very dark green fruits. In addition, sugar and starch contents in the fruits are higher in the transgenic plants. This strongly suggests that GLK2 is controlling sugar content.

- **Community Analysis and Feedback**
  The authors submitted this paper to Science, which accepted the paper after peer review recommended it for publication. The work has influenced the community of scientific experts (scientists who study insects, biomechanics, and functional morphology, for example), but it has also impacted the broader community of people
interested in scientific research, as demonstrated by the number of news outlets reporting on the research.

- **Benefits and Outcomes**
  In the language of the How Science Works Flowchart, the benefits of this research are to “satisfy curiosity” and “build knowledge,” but also to “develop technology,” perhaps nanotechnologies that employ gears with asymmetrical teeth that can only rotate in one direction.

*The importance of this scientific research*

- To identify the mechanism for why certain phenomena are observed

*The actual science involved*

- Breeding tomato plants
- Assessing phenotypes of immature fruits
- Generating transgenic plants
- Mapping the location of the gene of interest in order to identify it
- Characterizing gene expression of the gene of interest
- Using microscopy to assess chloroplast development
- Measuring sugar and starch content in immature and mature fruits
Connect to Learning Standards:


  Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms."


  Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved."

  http://www.corestandards.org/ELA-Literacy/RST/11-12/

- Connects to Next Generation Science Standard Practice 1:

  Asking questions (for science) and defining problems (for engineering)

- Connects to Next Generation Science Standard Practice 4:

  Analyzing and interpreting data

  http://www.nap.edu/openbook.php?record_id=13165&page=42
Summary of the Article for the Teacher:

It is recommended that this not be used by students in place of reading the article.

General Overview:

When shopping for tomatoes, people often look for a uniform scarlet hue. Plant breeders have selected for plants that have uniform light green fruit that will develop the characteristic red hue uniformly as it ripens. However, once these green tomatoes turn the perfect red they tend to lack the sweetness and flavor of those more imperfect tomatoes grown in the garden at home, and researchers have now identified the genetic reason behind this. The responsible gene is Golden 2-like (GLK) 2. When GLK2 is expressed, there is an increase in the fruit’s photosynthetic capacity, resulting in higher sugar content and a favorable fruit. Unfortunately, in uniformly colored tomatoes, GLK2 is inactivated. Should tomato lovers start sacrificing beauty for taste?

Topics Covered:

- Gene expression
- Gene duplication
- Photosynthesis
- Organelle development

Methods used in the Research:

- Genetic mapping
- Transgenic (genetically engineered) plants
- Quantitative RT-PCR
- Transmission electron microscopy

Conclusions:

The gene involved with increasing sugar and starch content by promoting chloroplast development and maturation in mature tomatoes negatively impacts the hue of the tomato. Loss of function of this gene results in uniform ripening, though also a tasteless fruit.
Areas of Further Study:

- Incorporating and testing these artificial muscles into development of prosthetics, Selection of a desired trait resulted in loss of other desired traits. Is there a way to manipulate crops to retain all desired traits?

- What impact will breeding methods have on our food supply?
Resources for Interactive Engagement:

Discussion Questions

1. Why would plant breeders have been interested in selecting plants that make tomatoes that ripen uniformly? What is the advantage to having fruit that looks a certain way?

A: Ask students to think about what they imagine tomatoes to look like. Now ask them if they would buy a tomato that didn’t fit what they expected (green/orange patches, wasn’t perfectly round, etc.).

2. Photosynthesis is a process of generating sugars and starches, which all living organisms require for life. Usually we think of photosynthesis happening solely in leaves. Why would it be advantageous to have photosynthesis occurring in developing fruits?

A: Tomatoes are an annual plant, meaning they only live for 1 year. Usually they generate fruit during the height of the growing season, when there is lots of sunlight and optimal access to water and nutrients from the soil. Because of this, it is advantageous for the plant to use all potential tissues to perform photosynthesis in order to accumulate sugar and starch. In addition, generating a better tasting fruit will make it more appealing to herbivores, which are key for seed dispersal.

3. In this paper, the researchers talk about another GLK, GLK1, which is not expressed in fruits. Why would there be two similar copies of a gene in an organism (Gene duplication)? How would this play a role in evolution?

A: Gene duplication is a driving force behind evolution, allowing for expansion of molecular activities. Gene duplication can allow for sub-specialization of a sister gene, allow the product to perform new activities the other traditionally does not perform. Quoting Susumu Ohno, duplication creates redundancy and redundancy fuels innovation. As GLK1 is not normally expressed in fruits, the duplication event allowed for GLK2 to be expressed in fruits. This allows for a tastier fruit, which is important for seed dispersal.

4. One of the last experiments was overexpressing GLK2 in the fruit, resulting in a dark green, immature tomato that has increased concentrations of glucose, fructose, and starch. One thought is that plant breeders could select for plants that generate these fruits instead, in order to resolve the issue with uniform ripening and conserving taste. Why would it be or not be advantageous to have breeders select for plants that make uniform dark green fruits?
A: Benefit: Potentially allow for uniform ripening and conservation of taste.  
Potential problem: May be reason that there is a distribution of color.  
Overexpression of GLK2 could alter the taste of the fruit, making it also undesirable.  
May impact shipping of fruit, causing them to ripen too fast.