Teacher Resource for:

Crocodile Head Scales Are Not Developmental Units But Emerge from Physical Cracking

Using This Teacher Resource

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GENERAL USE OF Science in the Classroom

Student Learning Goals:

Current views of science education emphasize that “one fundamental goal for K-12 science education is a scientifically literate person who can understand the nature of scientific knowledge.” (From *A Framework for K-12 Science Education*, National Research Council, 2012).

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.”

A very 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.

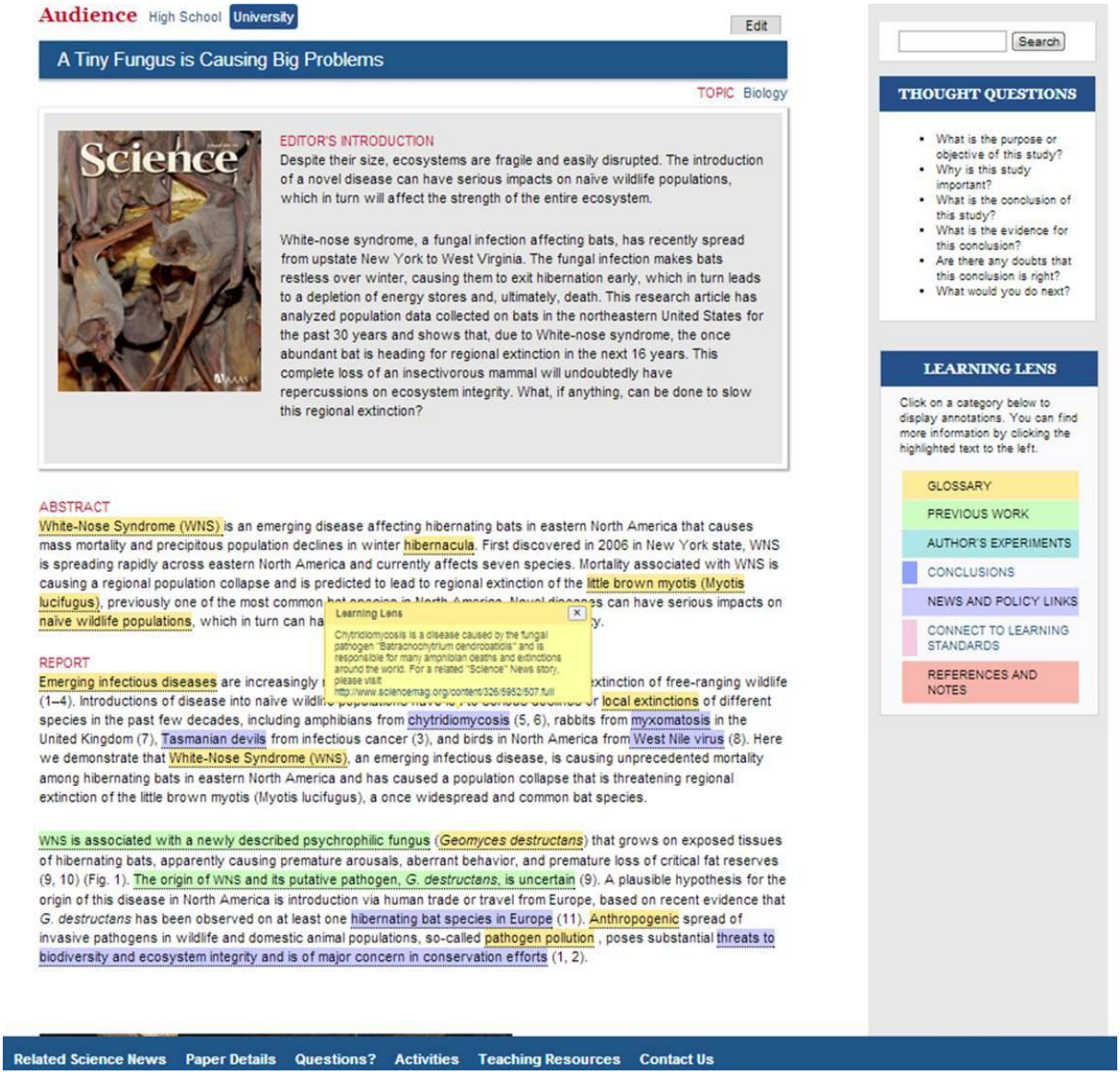
This includes knowing why:

- 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.

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. Clicking on any of the headings will result in corresponding text of the research article being highlighted. A second 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 in use.



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.

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.

Suggestions for Classroom Use:

Four alternative ways to use the SitC reading, questions, and activities:

1. Assign to small groups to complete during class

2. Assign different sections of the article to small groups to complete during class. Use class presentations or jigsaw to teach the entire class what is in the article.

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

4. Assign as an extra credit project.

Interactive student engagement ideas for use after reading the article:

1. Have 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 best understood by their peers.

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

4. Have students, working 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

Student Learning Goals:

Connections to the nature of science from the article

- Why can it be valuable to investigate nonmodel organisms? See also Milinkovitch & Tzika Escaping the Mouse Trap; the Selection of New Evo-Devo Model Species. Journal of Experimental Zoology (Mol. Dev. Evol.) 308B: 337–346 (2007)
- How can physics provide insight into biology? See also the movie https://www.youtube.com/watch?v=76kJYRkcsUA

The importance of this scientific research

- Understanding processes controlling development
- Realizing the importance of physical parameters and processes in development (physics of biology)

The actual science involved

- Imaging and 3D modeling
- Mathematical analysis of biological patterns
- Comparative morphology
- Comparative developmental biology (evolutionary developmental biology)

Connect to Learning Standards:

This resource connects to three sets of learning standards:

1. **The AP Bio Standards**

http://media.collegeboard.com/digitalServices/pdf/ap/2012advances/AP-Biology_CED_Fall2012.pdf

Essential Knowledge 1.B.1:*Organisms may share conserved core processes and features that evolved and are widely distributed among organisms today* (page 14).

Essential Knowledge 2.E.1: *Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms* (page 42).

2. **The Science and Engineering Practices contained in the Next Generation Science Standards**

http://www.nap.edu/openbook.php?record_id=13165&page=41

- Practice 2: *Developing and using models*
- Practice 5: *Using mathematics and computational thinking*

3. **AAAS Project 2061**

http://assessment.aaas.org/topics/CE#/

- Cells in multicellular organisms repeatedly divide to make more cells for growth and repair.

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:
One of a crocodile's most characteristic traits is its thick, scaly skin. Although similar in appearance to elaborately patterned skin of other reptiles such as snakes, the scales on crocodile heads form irregular shapes. How are these scales formed? High-resolution imaging and 3D modeling "cracked" the code behind this developmental process.

Topics covered:
- developmental biology
- spatial modeling
- mechanical stress
- labeling of mRNA and proteins

Why this Research is Important:
The field of development biology has extensively investigated the genetic control of development of complex features. How do physical processes regulate development?

Methods used in the Research:
- High-resolution imaging and 3D modeling
- Cell staining and microscopy
- Gene expression measurement
- Use of reporter protein and immune-fluorescent imaging

Conclusions:
The authors reveal that a physical process, cracking due to mechanical stress, rather than a genetic program, controls development of crocodile head scales.

Areas of Further Study:
- How does genetic regulation interact with the physical cracking controlling crocodile head scale development?
- How do cell sense and react to mechanical stress?
- What other developmental programs do physical processes control?

Resources from Dr. Milinkovitch's website:

http://www.lanevol.org/LANE/Evo-Devo.html
http://www.lanevol.org/LANE/croccrack.html
http://www.lanevol.org/LANE/crocisos.html

Other resources:

Check the slideshow from *Science*:
http://www.sciencemag.org/site/multimedia/slideshows/1226265/index.html

Check the PodCast from *Science*:
http://www.sciencemag.org/content/338/6111/1233.2.full

Check Sarah C. P. Williams' article in *Science*NOW:
http://news.sciencemag.org/plants-animals/2012/11/crocs-chaotic-cracked-cranial-covering?ref=hp

Check the slideshow from BBC Nature:
http://www.bbc.co.uk/nature/20523854

Resources for Interactive Engagement:

1. Discussion Questions Associated with the Standards

The AP Biology Standards

Essential Knowledge 1.B.1:Organisms may share conserved core processes and features that evolved and are widely distributed among organisms today (page 14).

- Can you relate the development described in this study to human development? To bird development?

Essential Knowledge 2.E.1: Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms (page 42).

- Can you name some places in this research where timing was essential?
- What could have happened if this timing was off?

The Science and Engineering Practices that appear in the Next Generation Science Standards

Practice 2: Developing and using models

- Does the model the authors built work like they had envisioned?
- What can we learn from this model?
- If this models works, what is the next step?
- Why are researchers using a crocodile as a model for their experiments?

Practice 5: Using mathematics and computational thinking

- Could this study have been done without math?
- Can you name other parts of Biology that can benefit from including math?

AAAS Project 2061

Cells in multicellular organisms repeatedly divide to make more cells for growth and repair.

- What would happen in this study if cell growth became unregulated?

2. Activities connecting to the data shown in the Article

The Activities are linked to in the tool bar along the bottom of each resource. Activities linked to this particular resource contain raw data from the authors that the students will be able to work with directly.

http://scienceintheclassroom.org/research-papers/116/activities