Teacher Resource for:

Enhanced Remote Earthquake Triggering at Fluid-Injection Sites in the Midwestern United States

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.

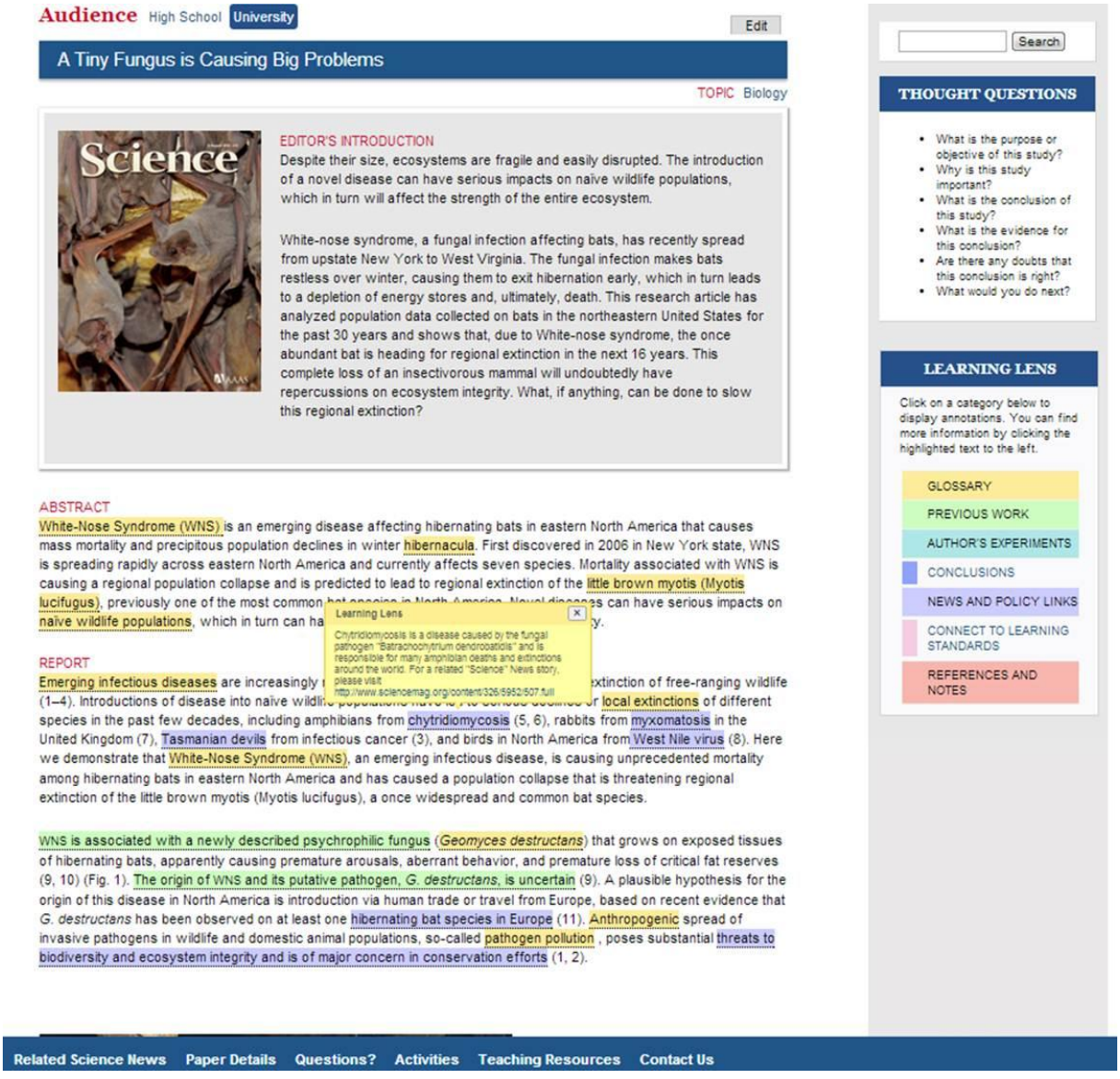
This includes knowing why:

- 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
    - How does human activity influence earthquake frequency?
    - What can we learn from this data?

- The importance of this scientific research
    - To better understand the consequences of natural gas development (and similar technologies).

- The actual science involved
    - seismic measurements
    - investigation of dynamic triggering
    - analysis of Advances National Seismic System (ANSS) data
    - statistical analysis

Connect to Learning Standards:

This resource connects to four sets of learning standards:

Discussion Questions related to these standards are found in Resources for Interactive Engagement

1. The AP Environmental Standards

http://apcentral.collegeboard.com/apc/public/repository/ap-environmental-science-course-description.pdf

- Earth Systems and Resources
    - Earth Science Concepts (Geologic time scale; plate tectonics, earthquakes and volcanism; seasons; solar intensity and latitude) (page 6)

- Population
    - Human Population
        - Impacts of population growth (Hunger; disease; economic effects; resource use; habitat destruction). Found on page 7.

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 1: *Asking questions.*

- Practice 2: *Developing and using models.*

3. The Common Core English and Language Arts Standards

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

- RST.11-12.7: *Integrate and evaluate multiple sources of information presented in diverse formats and media in order to address a question or solve a problem.*

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 predictable feature of earthquakes is that they are completely unpredictable. Or are they? Scientists are beginning to collect data indicating that a range of human activity, including hydraulic fracturing, can induce earthquakes. How is this data analyzed? What can we learn from this data, and will it allow us to predict, or even prevent, future earthquakes?

Topics covered:
- seismic measurements
- investigation of dynamic triggering
- analysis of Advances National Seismic System (ANSS) data
- statistical analysis
- environmental impacts

Why this Research is Important:
Hydraulic fracking is a major environmental concern in the United States. How do scientists collect data on how this practice affects the environment? How are these data properly analyzed? What can this data tell us about the environmental impact of emerging technologies? What else can we learn from how the earth reacts to these new stresses?

Methods used in the Research:
- seismic analysis
- statistical analysis

Conclusions:
The authors argue that the presence of naturally triggered earthquakes (by seismic waves) at fluid injection sites shows that the faults in the region have been weakened and brought close to failure by the infiltration of fluid.

Areas of Further Study:
How can scientists use this new information to refine current natural gas extraction?

Resources for Interactive Engagement:

1. Discussion Questions Associated with the Standards

The AP Environmental Standards

Earth Systems and Resources
Earth Science Concepts (Geologic time scale; plate tectonics, earthquakes and volcanism; seasons; solar intensity and latitude) (page 6)

- How are plate techtonics related to earthquakes?
- As stress on the earth increases (through drilling, for example), how will plate tectonics be influenced?
- How will resulting earthquakes be influenced?
- Do you think this stress on the earth is worth recovering natural gas for?

Population
Human Population
Impacts of population growth (Hunger; disease; economic effects; resource use; habitat destruction). (page 7)

- As human population increases, what happens to the energy demands of the earth?
- How will this influence both plate tectonics and earthquakes?

The Science and Engineering Practices contained in the Next Generation Science Standards

Practice 1: Asking questions.

- How is asking questions an important part of scientific research?
- What are some other “big questions” in geology? Select one of your “big questions” and narrow it down to a question that could be investigated.

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?

The Common Core English and Language Arts Standards

RST.11-12.7: Integrate and evaluate multiple sources of information presented in diverse formats and media in order to address a question or solve a problem.

- Why did the authors investigate earthquake data at more than one location?
- How are these locations similar?
- How do these locations differ?
- How do the scientists integrate data from different locations together?

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.