Teacher Resource for:

Direct Imaging of Covalent Bond Structure in Single-Molecule Chemical Reactions

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.

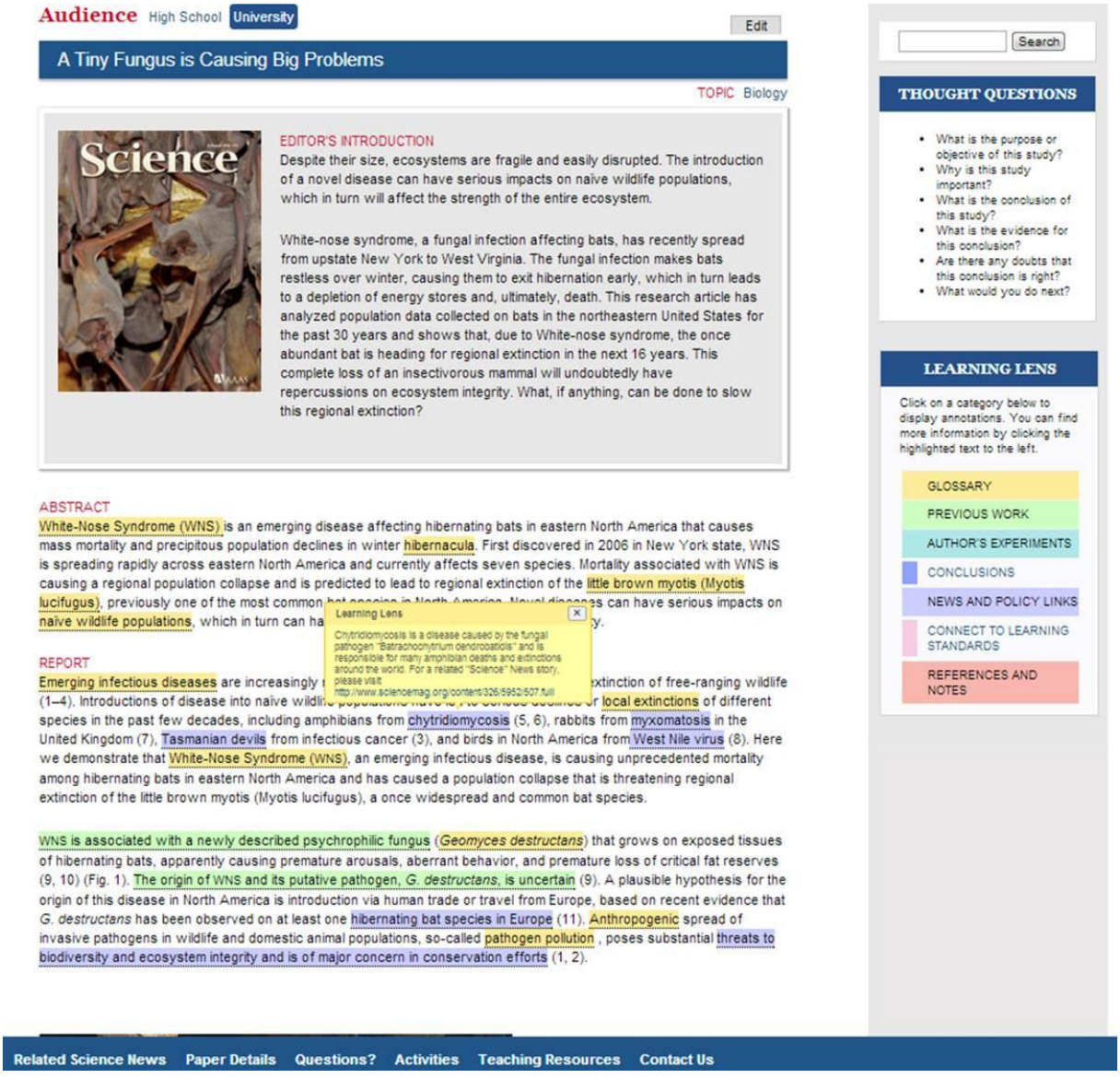
This includes knowing why:

- 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 do scientists need to see molecules?
- Why are there so many different techniques to see molecules?

The importance of this scientific research

- This technique allows scientists to see flat molecules at the atomic level. This research looks into the possibility of seeing molecules, the atoms, react in real time. Will give insight into how chemical reactions occur.

The actual science involved

- Microscopy: AFM, STM
- Computational chemistry
- Reaction mechanisms and rates
- Activation energy
- Exothermic reactions

Connect to Learning Standards:

English Language Arts:

http://www.corestandards.org/ELA-Literacy/RST/11-12/#CCSS.ELA-Literacy.RST.11-12.4

Learning Std CCSS.ELA-LITERACY.RST.11-12.4:
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical contexts.

Learning Std CCSS.ELA-LITERACY.RST.11-12.6
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.

AP Chemistry Essential Knowledge

http://media.collegeboard.com/digitalServices/pdf/ap/IN120085263_ChemistryCED_Effective_Fall_2013_lkd.pdf

Learning Objective for EK 4.A.1 (page 50):
The student is able to design and/or interpret the results of an experiment regarding the factors (i.e., termperature, concentration, surface area) that may influence the rate of a reaction. [See SP 4.2, 5.1].

Learning Objective for EK 3.C.2: LO 3.11 (page 47).
The student is able to interpret observations regarding macroscopic energy changes associated with a reaction or process to generate a relevant symbolic and/or graphical representation of the energy changes [See SP 1.5, 4.4].

Learning Objective for EK 4.B.3: LO 4.6 (page 53).
The student is able to use representations of the energy profile for an elementary reaction (from the reactants, through the transition state, to the products) to make qualitative predictions regarding the relative temperature dependence of the reaction rate (see SP 1.4, 6.4).

Learning Objective for EK 5.C.2: LO 5.8 (page 63).
The student is able to draw qualitative and quantitative connections between the reaction enthalpy and the energies involved in the breaking and formation of chemical bonds. [See SP 2.3, 7.1, 7.2].

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:

How exactly do chemicals react? How do molecules break and form new bonds? How do we know what the products of chemical reactions look like? In this study, the organic hydrocarbon, phenylene-1,2-ethynylene (C26H14) is visualized at the atomic level with non-contact atomic force microscopy (nc-AFM). The reactant, phenylene-1,2-ethynylene (C26H14), was placed on a solid silver surface and heated, causing the products to form. The scientists saw a few products being formed from the reactant and they were able to distinguish the structure and bond order of these products using nc-AFM. To determine how exactly these three products were formed, computational chemistry was used to examine how the reactant was converted to the products.

Why this Research is Important:

This technique allows scientists to see flat molecules at the atomic level. This research looks into the possibility of seeing molecules, the atoms, react in real time. Will give insight into how chemical reactions occur.

Methods used in the Research:

- atomic force microscopy to view the molecules
- computational chemistry to determine reaction rates and how the chemicals react
- organic chemistry to create the molecules

Conclusions:

The results show that the researchers were able to view the products of the chemical reaction with nc-AFM. Using computational chemistry, they were able to determine how the chemical reaction occurs to form the different products from the reactant.

Areas of Further Study:

This study is limited by the fact that the molecules were flat and only contained hydrogen and carbon. To increase the versatility of this technique, being able to develop a method that allows molecules with a variety of shapes and atoms will be needed.

Resources for Interactive Engagement:

Discussion Questions

1. Why did the reactant needed to be heated over 90ºC?
2. Why was the reactant placed on a surface of silver?
3. Why did multiple products form from this reaction?
4. What are the limitations of this new technique?
5. What is the research question the scientists wanted to answer?
6. What would happen if the same reactant [phenylene-1,2-ethynylene (C26H14)] was put into solution rather than being on the solid silver surface? Would the same products form?

Activities connecting to the data shown in the Article

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