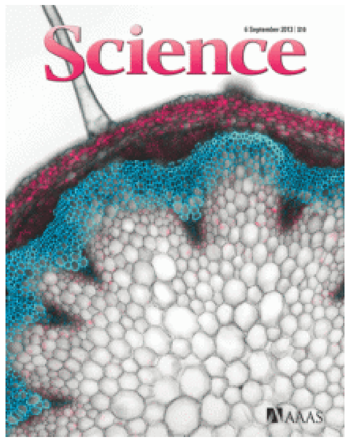
## Teacher Resource for:

## Radio Jets Clearing the Way Through a Galaxy: Watching Feedback in Action.




## Table of Contents:

# 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."[1]

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:

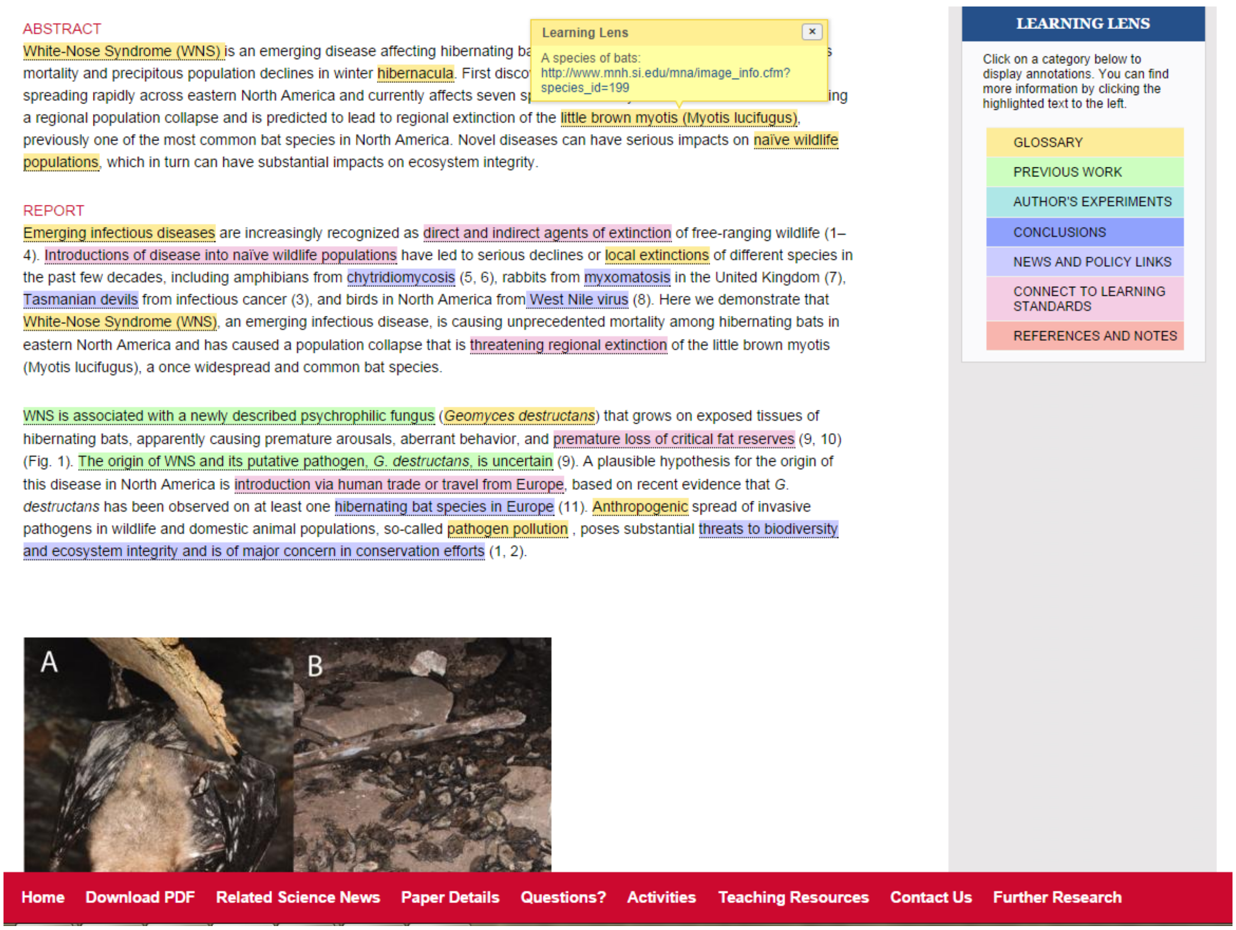
- Scientists must be independent thinkers, who are free to dissent from what the majority believes.
- Science can deal only with issues for which testable evidence can be obtained.
- All scientific understandings are built on previous work
- It is to be expected that one scientist's conclusions will 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.




*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.

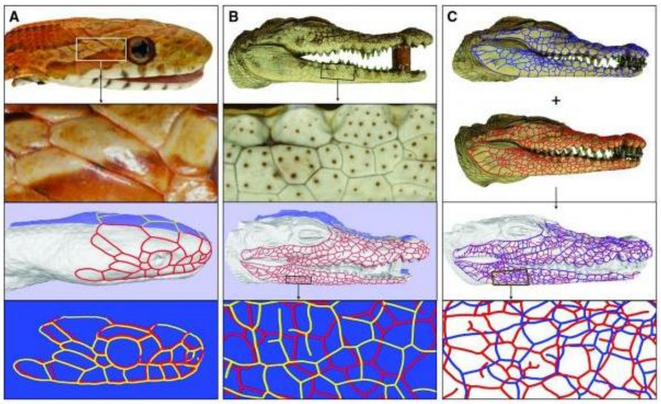



**Fig. 1. Spatial distribution of head scales. (A) Head scales in most snakes (here, a corn snake) are polygons (two upper panels) with stereotyped spatial distribution (two lower panels): left (yellow) and right (red) scale edges overlap when reflected across the sagittal plane (blue). (B) Polygonal 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 | Panel A | Panel B | Panel C

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...

**LEARNING LENS**

Click on a category below to display annotations. You can find more information by clicking the highlighted text to the left.

- GLOSSARY
- PREVIOUS WORK
- AUTHOR'S EXPERIMENTS
- CONCLUSIONS
- NEWS AND POLICY LINKS
- CONNECT TO LEARNING STANDARDS
- REFERENCES AND NOTES

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# 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.


6. L. Lewejohann, B. Zipser, N. Sachser, "Personality" in laboratory mice used for biomedical research: A way of understanding variability? Dev. Psychobiol. 53, 624 (2011).
7. G. Kempermann, The neurogenic reserve hypothesis: What is adult hippocampal neurogenesis good for? Trends Neurosci. 31, 163 (2008).
8. Lewejohann et al., Behavioral phenotyping of a murine model of Alzheimer's disease in a seminaturalistic environment using RFID tracking. Behav. Res. Methods 41, 850 (2009).
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16. C. Crabbe, D. Wahlsten, B. C. Dudek, Genetics of mouse behavior: Interactions with laboratory environment. Science 284, 1670 (1999).
17. Lewejohann et al., Environmental bias? Effects of housing conditions, laboratory environment and experimenter on behavioral tests. Genes Brain Behav. 5, 64 (2006).
18. D. W. Bailey, How pure are inbred strains of mice? Immunol. Today 3, 210 (1982).
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26. D. P. Wolferet al., Laboratory animal welfare: Cage enrichment and mouse behaviour. Nature 432, 821 (2004).
27. K. Lewin, Dynamic Theory of Personality (McGraw-Hill, New York, 1935).
28. K. L. Jang, R. R. McCrae, A. Angleitner, R. Riemann, W. J. Livesley, Heritability of facet-level traits in a cross-cultural twin


**Learning Lens**

This paper showed that while both physical activity, like running, and living in an enriched environment can result in the generation of new hippocampal neurons in mice, a combination of the two activities leads to even greater rates of neurogenesis.

**LEARNING LENS**

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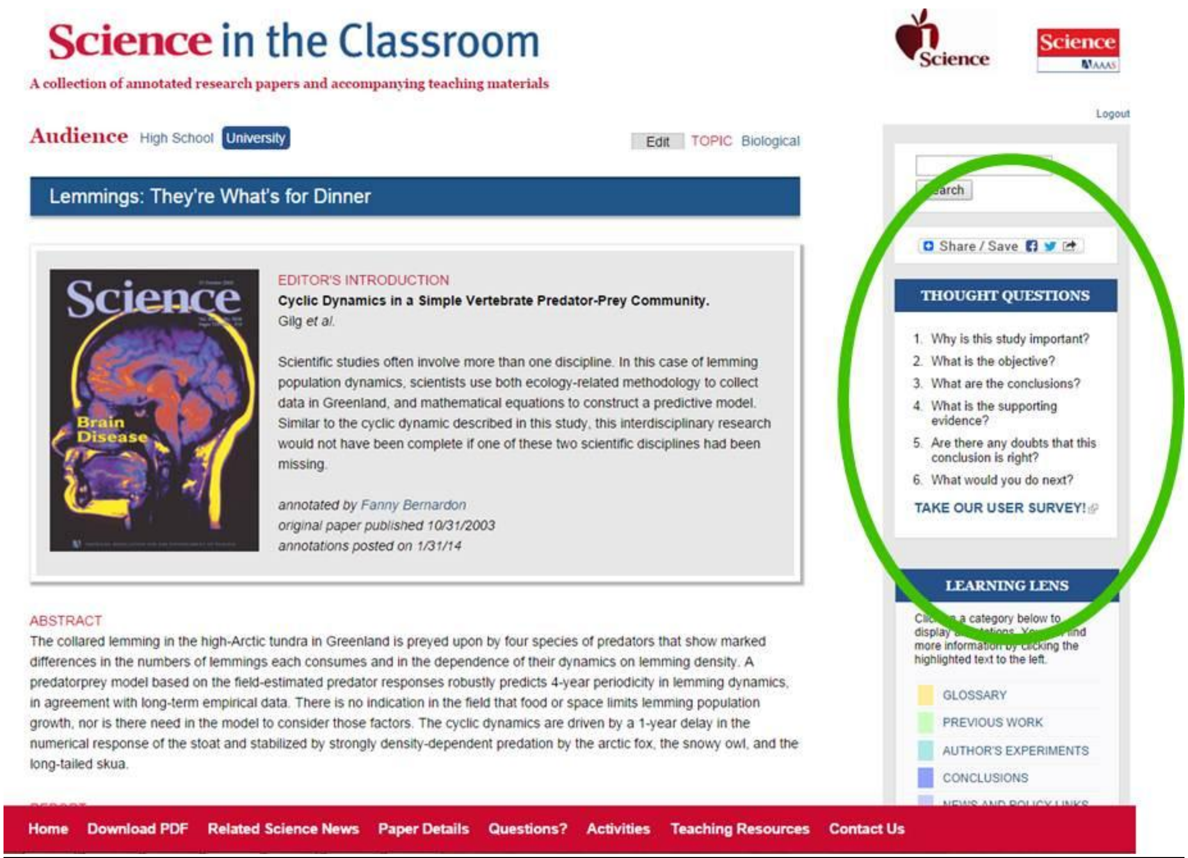
- REFERENCES AND NOTES

## 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

## Student Learning Goals:

*Connections to the nature of science from the article*

- How is it different to "do an experiment" when studying galaxies versus other types of science that can be performed on a benchtop?
- What big questions can be answered by studying the universe?
- What impacts might technology used in observations of the universe have on other aspects of our society?

*The importance of this scientific research*

- Since one cannot do experiments on test galaxies to see how they evolve, it is essential to use telescopes to look at distant objects and deduce their evolutionary paths from these observations. Fortunately, the universe is vast so it is likely that snapshots of galaxies at different evolutionary stages are visible. All galaxies have a black hole at their center and a correlation between the mass of this black hole and the mass of the overall galaxy had been observed, but the connection between these two masses was unclear. This work suggests one possible mechanism for coupling of the mass of a galaxy and its central black hole using state-of-the-art high-resolution observations.

*The actual science involved*

- A large, multinational radio interferometer was used to image gas flowing out from the galaxy 4C12.50, which is at a distance of roughly 1.5 billion light years from earth. These observations were then compared to radio emissions, which reveal that the gas is being pushed out of the galaxy by radio emissions coming from the central black hole.

## **Connect to Learning Standards:**

AP Physics:

http://media.collegeboard.com/digitalServices/pdf/ap/ap-physics-1-2-course-and-exam-description.pdf

- Essential Knowledge 3.C.1: gravitational force (page 49)
- Essential Knowledge 6.F.1: types of electromagnetic radiation are characterized by their wavelengths (page 106)
- Essential Knowledge 6.A.1 kinematics (page 42)
- Essential Knowledge 1.A.4: discrete energy state transitions lead to spectra (page 19)
- Essential Knowledge 1.E.1: matter has a property called density (page 27)
- Essential Knowledge 1.C.2: gravitational Mass (page 23)

## 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:

Supermassive black holes exist at the center of galaxies, often weighing more than one billion times as much as the sun. What forces could connect the mass of a galaxy to the mass of its central black hole? One possibility is the light emitted from the disc of material being drawn towards the black hole. This active galactic nucleus shoots jets of light away from the black hole out through the surrounding galaxy. These jets of light can interact with material in the host galaxy as they pass by and eject this material from the galaxy. In this way, the mass of the black hole influences the brightness of the jet, which then shoots more material out of the galaxy, providing a compelling explanation for how the mass of a galaxy could be coupled to the mass of its central black hole.

### Why this Research is Important:

Since one cannot do experiments on test galaxies to see how they evolve, it is essential to use telescopes to look at distant objects and deduce their evolutionary paths from these observations. Fortunately, the universe is vast so it is likely that snapshots of galaxies at different evolutionary stages are visible. All galaxies have a black hole at their center and a correlation between the mass of this black hole and the mass of the overall galaxy had been observed, but the connection between these two masses was unclear. This work suggests one possible mechanism for coupling of the mass of a galaxy and its central black hole using state-of-the-art high-resolution observations.

### Methods used in the Research:

- Radio interferometry
- computer analysis

### Conclusions:

Hydrogen gas is being pushed out of the galaxy 4C12.50 by radio emissions from its central black hole, influencing the rate of star formation in the galaxy and providing an explanation for the correlation between the mass of a galaxy and the mass of its central black hole.

## Areas of Further Study:

- Locate similar objects and image them
- conduct additional computer simulations to connect these observations to theory
- explore multiple stages of interactions between the central black hole and outflowing matter.

# Resources for Interactive Engagement:

## 1. Discussion Questions

What other forces contribute to the evolution of galaxies besides radio jets?

What other methods could be used to study the forces governing galaxy evolution?

What implications does the huge size of the universe have in terms of observation of cosmological objects?