Harnessing symbiosis to hide in plain sight

Educator guide

PAPER DETAILS

Original title: Evidence for light perception in a bioluminescent organ

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LEARNING STANDARDS ALIGNMENT

Learning Performance: Students will evaluate the evidence for the claim that the light-sensing machinery in the light organ of the Hawaiian bobtail squid was co-opted from the eye, and that the organ has evolved such that its function relies on a bacterial symbiont.

The following tables provide an overview of the learning standards covered by this article, including the A Framework for K-12 Science Education (Framework), Common Core State Standards English Language Arts-Literacy (CCSS ELA), Common Core State Standards Statistics and Probability (CCSS HSS), AP Science Practices, and Vision and Change for Undergraduate Education. Where applicable, activities and information will be marked with specific standards to which they are linked.

<table>
<tr><th colspan="3">A Framework for K-12 Science Education</th></tr>
<tr><th>Science and Engineering Practices</th><th>Disciplinary Core Ideas</th><th>Crosscutting Concepts</th></tr>
<tr>
<td>Analyzing and Interpreting Data (SEP4)
Analyze data using tools, technologies, and/or models (e.g. computational, mathematics) in order to make valid and reliable scientific claims or determine an optimal design solution.

Engaging in Argument from Evidence (SEP7)
Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments.</td>
<td>LS1.A: Structure and Function
Systems of specialized cells within organisms help them perform the essential functions of life. Feedback mechanisms maintain a living system's internal conditions within certain limits and mediate behaviors, allowing it to remain alive and functional even as external conditions change within some range. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system.

LS4.C: Adaptation
Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well-suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not.</td>
<td>Structure and Function
Investigating or designing new systems or structures requires a detailed examination of the properties of different components, and connections of components to reveal its function and/or solve a problem.

Cause and Effect
Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.</td>
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<table>
<tr><th colspan="3">Common Core State Standards English Language Arts-Literacy</th></tr>
<tr><th>Key Ideas and Details</th><th>Craft and Structure</th><th>Integration of Knowledge and Ideas</th></tr>
<tr>
<td>RST.9-10.1
Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

RST.9-10.2
Determine the central ideas or conclusions of a text; trace the text’s explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

RST.11-12.1
Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

RST.11-12.2
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.</td>
<td>RST.9-10.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.

RST.9-10.5
Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).

RST.9-10.6
Analyze the author’s purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, defining the question the author seeks to address.

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 context relevant to grades 11-12 texts and topics.

RST.11-12.5
Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas.

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.</td>
<td>RST.9-10.8
Assess the extent to which the reasoning and evidence in a text support the author’s claim or a recommendation for solving a scientific or technical problem.

RST.9-10.9
Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.

RST.11-12.8
Evaluate the hypotheses, data, analyses, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

RST.11-12.9
Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.</td>
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</table>

<table>
<tr><th colspan="2">AP Science Standards</th></tr>
<tr><th>AP Science Practices</th><th>AP Biology Content Standards</th></tr>
<tr><td>Science Practice 5 (SP5)
The student can perform data analysis and evaluation of evidence.</td><td>Essential knowledge 2.C.2 (EK2.C.2)
Organisms respond to changes in their external environment through behavioral and physiological mechanisms.

Essential knowledge 2.D.1 (EK2.D.1)
All biological systems from cells and organisms to populations, communities, and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy.

Essential knowledge 3.D.3 (EK3.D.3)
Signal transduction is the process by which a signal is converted to a cellular response. Signal transduction pathways link signal reception with cellular response.

Essential knowledge 4.A.3 (EK4.A.3)
Environmental stimuli can affect gene expression in a mature cell. Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues, and organs.</td></tr>
</table>

<table>
<tr><th colspan="2">Connections to the Nature of Science</th></tr>
<tr><th>Vision and Change for Undergraduate Biology Education
Core Competencies and Disciplinary Practices</th><th>A Framework for K-12 Science Education
Understandings About the Nature of Science</th></tr>
<tr><td>Ability to apply the process of science
Understand the process of science and how scientists construct new knowledge by formulating hypotheses and then testing them against experimental and observational data</td><td>Scientific Investigations Use a Variety of Methods
Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings. Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge.

Scientific Knowledge Is Open to Revision in Light of New Evidence
Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.</td></tr>
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ARTICLE OVERVIEW

Article summary (recommended for educator use only)

Tong *et al.* (2009) use three lines of evidence to suggest that the light organ responsible for producing bioluminescence in Hawaiian bobtail squid, *Euprymna scolopes*, is also capable of detecting both bioluminescence and environmental light. Previous work demonstrated that the light organ has anatomical similarities to the eye. This study provides molecular, physiological, and biochemical evidence that the light organ has the potential ability to perceive light and behave as an extraocular photoreceptor. The study raises the question of whether the machinery for producing the eye was duplicated or co-opted to produce the light organ and can therefore be considered an example of evolutionary tinkering.

Importance of this research

Previous research on the mechanisms that allow squid to control the amount of bioluminescence needed for counterillumination have focused on the eyes and on extraocular photoreceptors that are located on the surface of the squid, away from the light organ. However, no work had been undertaken to explore the possible role of the light organ itself in perceiving bacteriogenic or exogenous light. Previous work on *E. scolopes* focused on the symbiosis with *Vibrio fischeri*, the bacterium responsible for producing bioluminescence, and the ability of the light organ to control this bioluminescence. Future research will focus on similarities and differences in structure and function between the light organ and the eye. This research represents an example of evolutionary co-option, also called “tinkering.”

Experimental methods

- Expressed Sequence Tags and Reverse-Transcriptase Polymerase Chain Reaction for transcriptome analysis
- Electroretinography
- Immunocytochemistry and confocal microscopy

Conclusions

- The light organ appears to have genes to produce both of the two major classes of photoreceptors: ciliary and rhabdomeric.
- The eyes respond with typical depolarization found in rhabdomeric photoreceptors. The light organ, however, responds with depolarization typical of ciliary photoreceptors, even though no c-opsin (ciliary opsin) was detected. This suggests that the light organ has the physiological potential to sense and respond to light.
- Proteins associated with the eye, rhodopsin, arrestin, and rhodopsin kinase were found in tissues of the light organ, suggesting that the light organ has the molecular machinery to respond to light.

ACTIVITIES FOR INTERACTIVE ENGAGEMENT

Learning Performance: Students will evaluate the evidence for the claim that the light-sensing machinery in the light organ of the Hawaiian bobtail squid was co-opted from the eye, and that the organ has evolved such that its function relies on a bacterial symbiont.

Writing an abstract Students write a new abstract for the article at a grade-appropriate reading level.	**RST.9-10.2** **RST.11-12.2** **Nature of Science**
Locating this study in the larger field Students use the annotated list of references to explain how this research builds on the published work of at least one other independent group of scientists. Students will evaluate whether data from this research supports or contradicts previous conclusions, and reflect on the statement that scientific knowledge is a "community effort."	**RST.9-10.8** **RST.11-12.8** **Nature of Science**
Science in the news Students explore news stories in the Related Resources tab and evaluate the stories for tone, accuracy, missing information, etc. They may then write their own news stories on the article.	**RST.9-10.5** **RST.11-12.5** **RST.9-10.6** **RST.11-12.6** **RST.9-10.8** **RST.11-12.8** **Nature of Science**
Results and conclusions Students diagram each of the experiments presented in the study (divided up by figure, if appropriate). They then consider the results depicted in each figure, and how these results support the conclusions of the study.	**SEP7** **SP5**
The next steps Students design a follow-on experiment to this study that either addresses flaws or unanswered questions in the research at hand, or builds on it to explore a new question.	**Nature of Science**

DISCUSSION QUESTIONS

1. The authors of this study found that the light organ has the same proteins that are involved in sensing light in the eye. What are the possible reasons for this? What are the implications? Why would the same proteins be present in the light organ, instead of a different kind of protein that does the same job?	**SEP4** **LS1.A** **LS4.C** **Structure and Function** **SP5** **EK3.D.3** **EK4.A.3**
2. Why did the authors use two different methods to determine that opsin, rhodopsin kinase, and arrestin are present in the light organ? What are the benefits and drawbacks of each kind of analysis?	**SEP7** **Cause and Effect**
3. What are some of the potential uses of bioluminescence in Hawaiian bobtail squid and other organisms?	**LS1.A** **LS4.C** **Structure and Function** **EK2.C.2**
4. What are some other examples of mutualisms besides *Vibrio* and *Euprymna*? Among mutualisms, commensalisms, and parasitisms, which is the most beneficial kind of relationship?	**SEP4** **LS4.C** **EK2.C.2** **EK2.D.1**
5. Why is it important for *Euprymna* to be able to control the population of *Vibrio* in its light organ? Why does *Euprymna* need to be able to "sanction" cheaters? What are some of the reasons that this system might have evolved this way?	**SEP7** **LS1.A** **LS4.C** **Structure and Function** **SP5** **EK2.D.1**
6. What is the significance of the light organ being able to sense light?	**LS1.A** **LS4.C** **Cause and Effect** **EK2.C.2** **EK2.D.1**
7. Why does evolutionary tinkering happen? Using examples from other systems where this kind of co-option has occurred, discuss the pros and cons of such a phenomenon.	**LS4.C** **Structure and Function** **Cause and Effect** **EK3.E.2**