**Discovering extinctions in the fossil record:**

**An ACCESS Paleo lesson**

**Summary**This activity is designed to introduce students to the nature and process of science through the discovery of mass extinctions in the fossil record. Students will explore the fossil record of two major groups of organisms, brachiopods and bivalves, using the Paleobiological Database to generate and evaluate hypotheses about the differences in the diversity history of each group. By interpreting and comparing the diversity curves of each group, students will conclude that mass extinctions have occurred throughout the history of life. As they progress throughout the lab, students will keep track of each step in their scientific process to illustrate how science is a non-linear process of discovery. This self-directed, online activity is designed for students to complete on their own and is suitable for distance-learning. Alternatively, students could complete it in class working at separate computers, individually or in groups.

**Context**

*Audience*

The lesson is designed for 2-year and 4-year college students in an introductory biology or geology course.

*Skills and concepts students must have mastered*

Students should have some familiarity with the scientific method, including what a hypothesis is and how it is traditionally tested. Students should also be comfortable with basic biological concepts such as ecology, evolution, and biological diversity. A geological background is not required but may prove helpful for this lesson.

*How the activity is situated in the course*

The lesson is designed as a stand-alone activity that can be taught in conjunction with or separately from a broader discussion of the scientific process.

 **Goals and learning objectives**

*Mass Extinctions and the History of Life*

1. Students will be able to explain what mass extinctions are and how they can be identified and quantified using fossil databases and diversity curves
2. Students will understand how and why the fossil record is critical to our understanding of life on Earth
3. Students will be introduced to the concept of the geological past/deep time and paleobiology

*Nature and process of science*

1. Students will be able to explain how the real nature and process of science is different from the traditional notion of the scientific method
2. Students will be introduced to the concept of science as a non-linear, iterative process

*Scientific Skills*

1. Students will learn to assess their own work and be critical of their hypotheses, methods, and assumptions when conducting research
2. Students will gain experience analyzing and interpreting data

*Key terms*

mass extinction, extinction, diversity, fossil, hypothesis, nature and process of science

**Description of the activity**

Science is more complex than the linear "scientific method” would lead students to believe. In this activity, students will document and reflect upon their own work to understand the nature and process of scientific discovery. The activity is broken up into a series of “virtual” stations that lead students to discover the presence of mass extinctions in the fossil record. By following a similar path to how the “Big Five” mass extinctions were identified by paleontologists in the late 20th century, students will be left with a deeper understanding of the scientific process and how it differs from the more traditional “scientific method.”

The lesson has two components: An investigation of the fossil record and student reflection upon their own scientific process. Students begin the activity with an initial set of assumptions that they use to generate a hypothesis about the differences in diversity histories between two groups of marine organisms, brachiopods and bivalves. By analyzing fossil occurrence data from the Paleobiology Database, students will find that their data contradict their initial hypothesis. As they explore their initial assumptions and hypothesis using diversity data from additional groups of organisms, students will identify coordinated declines in fossil diversity throughout the history of life, ultimately discovering the presence of mass extinctions in the fossil record. Students will track each step in their scientific process using the Understanding Science application from the University of California Museum of Paleontology and will explain their process in the lab. At the end of the activity, students will be asked to reflect on their work as an example of how science is a natural process of discovery. Along the way, students are asked to write responses to open-ended questions, as well as answer multiple choice items, in a Google Form to encourage analysis and reflection.

**Materials/Procedure**

Students will need:

* a computer with internet access, which has either Google Chrome or Mozilla Firefox, to run the Understanding Science application
* a Google account to access the Google Form for this lesson
* a link to the Google Form for this lesson (which includes all student instructions and links)

Teachers may preview the Google Form for this lesson [here](https://docs.google.com/forms/d/e/1FAIpQLSestAzfXL7Fs9h9HF4G0nquSh3GdnBNOMWFl1rpK06vJbvBEA/viewform?usp=sf_link). However, NOTE THAT IF STUDENTS USE THIS URL, YOU WILL NOT HAVE ACCESS TO THEIR RESPONSES. To be provided with your *own* version of the form that will allow you to view student responses and edit questions/instructions, please email access.paleo.ucmp@gmail.com. If you wish to assess whether students completed the activities in the Understanding Science application, let students know that you will be collecting this work and instruct them to export their Understanding Science flowchart file as a Powerpoint and turn it in via email once they have completed the Google form. The export option is available through the menu icon in the Understanding Science app.

**Teaching tips**

* This lesson is designed to take 2 hours. Additional time for the questions might be required as homework depending on the pace of groups/individual students.
* Prior to the activity, explore the Paleobiology Database and Understanding Science applications to predict where your students might run into difficulty and facilitate troubleshooting.
* Throughout the lab, be mindful of student’s language. Students should avoid words such as “proven” or “disproven” as well as “correct” or “incorrect” when referring to hypotheses. For clarification, see the following section on the Understanding Science “Misconceptions about science” webpage (linked [here](https://undsci.berkeley.edu/teaching/misconceptions.php#b10)). Hypotheses should also be distinguished from predictions. For clarification, see the following section on the Understanding Science “Misconceptions about science” webpage (linked [here](https://undsci.berkeley.edu/teaching/misconceptions.php#a4)).

**Assessment**

You can use the attached answer key to assess student responses. There will be a variety of answers for questions marked as “Reflection”, but these responses should reflect student’s prior knowledge from the lab or previous course material.

**Answer Key**

Question 1 (Reflection):

1. Student responses will vary for this question but should reflect an honest assessment of their own knowledge or course material taught up to this point.
2. Student responses will vary based on their answers to Question 1a but should be consistent with their previous answer.
3. Student responses should reflect their answers to Question 1a and Question 1b.

Question 2:

1. No, there is no set starting point in the Nature and Process of Science flowchart.
2. No, there is no set ending point in the Nature and Process of Science flowchart.
3. Hypothesis testing is central to both the Nature and Process of Science flowchart and the Scientific Method.

Question 3 (Reflection):

1. Student responses should provide an honest assessment of their initial answer in 1a and compare it to the Nature and Process of Science.
2. Student responses should provide an honest assessment of their initial answer in 1a and compare it to the Nature and Process of Science.

Question 4 (Reflection):

1. Student responses will vary for this question.
2. Student responses should provide proper justification for the answer selected in Question 4a, relating their answer to why paleobiologists study the fossil record.

Question 5:

Student responses may include the following (exact wording is not necessary for credit): Overall shape of the brachiopod versus the bivalve; the folding of the brachiopod commissure and valves; the differences in symmetry between the two organisms (brachiopods have a plane of symmetry across both shells, bivalves have a plane of symmetry between the two shells).

Question 6:

Student responses should contain two parts: A statement of their prediction and a justification of why they believe this is the case. Students should receive credit for predicting that bivalves and brachiopods will either show similar or different patterns of diversity provided they include a logical explanation in their answer.

Question 7:

1. Bivalve diversity appears to consistently increase over time but is punctuated by abrupt drops in diversity. Students may also note that the diversity trajectory begins rather flat but steepens throughout geological time (indicating an increasing rate of diversification).
2. The biggest drop in bivalve diversity occurs in the Cretaceous (time bin K).

Question 8:

1. Brachiopod diversity is high and consistent for the Paleozoic, but after the Paleozoic drops abruptly and is consistently low/decrease heading to the present.
2. The biggest drop in brachiopod diversity occurs in the Permian (time bin P).

Question 9:

1. While the bivalve diversity curve starts at low values and gradually increases throughout the Phanerozoic (the geological time scale shown on the graph), brachiopod diversity is high throughout the Paleozoic and then sharply drops in the Mesozoic, remaining at lower levels of diversity through to the modern.
2. Student responses should accurately reflect their answer to Question 5: If they hypothesized that brachiopods and bivalves would have different patterns of diversity due to their ecological and physiological differences, then the overall shape of the diversity curves should support this hypothesis.
3. Both the Cretaceous and Permian drops in diversity are present in both brachiopods and bivalves.
4. Student responses should accurately reflect their answer to Question 5: If they hypothesized that brachiopods and bivalves would have different patterns of diversity due to their ecological and physiological differences, then these coordinated and sharp drops in diversity would not support this hypothesis.
5. Student responses should accurately represent their answer to Question 5. There may be a range of student answers based on their interpretation of the significance of the large extinction events noticed in brachiopods and bivalves.

Question 10:

1. “…Inspire revised assumptions.”
2. Student responses should reflect on the fact that the initial set of assumptions was relatively restricted– some other important factor is controlling the diversity of brachiopods and bivalves during the intervals when both groups show large drops in diversity.

Question 11:

1. The initial set of assumptions did not account for how the environment/environmental conditions might control the diversity.
2. “…Cause major extinctions (drops in diversity) across many groups of organisms.”

Questions 12 and 13:

Note: Student answers will vary for Question 12 and Question 13 based on the organisms they choose to investigate.

1. All three groups should be contrasted with brachiopods and bivalves: There are no real similarities between these three groups of organisms and either brachiopods or bivalves.
2. All three groups show drops in diversity at the end of the Permian (P) and Cretaceous (K):
	1. Osteichthyes: Small drop at the end of the Permian, large drop at the end of the Cretaceous.
	2. Anthozoa: Large drop at the end of the Permian, smaller drop at the end of the Cretaceous.
	3. Foraminifera: Large drop at the end of the Permian, smaller drop at the end of the Cretaceous.

Question 14:

Student answers will vary based on their answer to Question 11. If answered correctly, student responses to Question 14 should state that the observations made in Questions 12 and 13 support their hypothesis, that if environmental changes were causing these coordinated drops in diversity, they would cause extinctions across many groups of organisms.

Question 15:

Students should identify at least one of the following mass extinctions:

1. Late Ordovician (at the O­/S (Ordovician/Silurian) boundary)
2. End Devonian (at the D/C (Devonian/Carboniferous) boundary)
3. Late Triassic (at the T/J (Triassic/Jurassic) boundary)

Question 16:

Student answers might state the following:

1. Studying mass extinctions provide case studies of diversity crises on Earth.
2. Studying mass extinctions allow us to better understand the history of life.
3. Studying mass extinctions allow us to understand what kinds of events can be catastrophic for life on Earth.
4. Studying mass extinctions allows us to study how life recovers from catastrophic events on Earth.

Question 17:

a. Student responses should capture the following ideas:

1. State their selected “benefit” of studying the fossil record.
2. Follow with an explanation of how their observations led to a hypothesis that was supported by the evidence they collected.
3. Explain that further exploration of the data (asking a question) led to new observations that opposed their new hypothesis.
4. State that their new observations led to a new hypothesis/revised assumptions/opposed a hypothesis.
5. Conclude with the idea that they have added additional information to a new idea regarding the presence of mass extinctions in the fossil record.

b. The scientific method does NOT capture the complexity of the lab today because…

* 1. No experiments were formed during their scientific process.
	2. Their scientific process was exploratory and therefore naturally progressed as opposed to following a set course of action.
	3. Their scientific process involved constant revision and reflection upon their hypotheses.
	4. The steps outlined in the scientific method fail to adequately describe the steps taken throughout the activity.

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