Asking Scientific Questions

OVERVIEW

This activity allows students to formulate and analyze scientific questions. The activity begins with students observing different organisms or phenomena and developing questions based on their observations. They then sort their questions into those that can and cannot be answered using the methods of science. Students practice writing scientific questions, designing experiments to address scientific questions, developing questions that involve cause and effect, and understanding the importance of cause-and-effect questions in scientific research.

The goals of this activity are for students to better understand the structure of scientific questions and to practice constructing their own questions. Students also analyze the titles of published scientific reports to discern how practicing scientists communicate cause and effect. Several possible extension activities, which can make use of BioInteractive's Data Points and Science in the Classroom resources, are provided for continuing the investigation and research of phenomena.

The resource includes PowerPoint slides to guide Parts 2 and 3 of the activity and is accompanied by this video example from a college classroom that models implementation. Additional information related to pedagogy and implementation can be found on this resource's webpage, including suggested audience, estimated time, and curriculum connections.

KEY CONCEPTS

Posing, refining, and evaluating testable scientific questions about natural phenomena and investigating answers through experimentation, research, and information gathering are key aspects of the processes of science.

STUDENT LEARNING TARGETS

- Compare and contrast questions that can be analyzed using the methods of science and those that are outside of science.
- Develop novel, testable scientific questions that are inspired by student observations and interests.
- Explain the importance of cause-and-effect research in the processes of science.
- Analyze titles of scientific papers to identify the goals of the research study and, when appropriate, causes and effects in the study.
- Identify, evaluate, and predict the scientific questions that drove research based on data or figures from the scientific literature.

PRIOR KNOWLEDGE

This foundational activity is meant to be used at the beginning of a course to help students develop their skills in scientific questioning. No prerequisite knowledge is required, but the skills students practice in the activity should be reinforced throughout any course.

MATERIALS

- "Student Handout" (recommended for each student to have their own copy)
- "Characteristics of Questions" Venn diagram (can project or make copies)
- "Journal Article Titles" handout (recommended for each student or student group to have their own copy; decide which set of titles you would like to use and make copies of that set)
- (optional) "Scientific Figure Example" handout (can project or make copies)

BACKGROUND

Asking scientific questions, especially questions related to cause and effect, is a valuable and exciting aspect of actually "doing" science. Students at all levels should engage in asking scientific questions as a way of following up on their curiosity or urge to solve a problem. These science practices are explicitly called out in science teaching standards throughout K–12 and the undergraduate curriculum and are often a major focus for graduate students in science. Students should be able to ask questions from their observations, or from examining models and scientific claims. They should also be able to challenge the claims made in an argument and to determine relationships between dependent and independent variables, or between causes and effects.

Scientists ask many different types of questions for many different purposes. Six common types of studies are hypothesis-driven research, measuring specific values, measuring functions or relationships, constructing models, making observations and identifying patterns, and improving a product or process, including developing new scientific tools. The types of studies align well with the crosscutting concepts of the NGSS, especially patterns, cause and effect, and systems and system models. Though many types of studies are used in science, scientists put a high degree of emphasis on asking scientific questions to determine cause and effect because the search for causes has led to some of the most important insights offered by science. Most scientific arguments are closely tied to scientific investigations of cause and effect. Additionally, confusing cause-and-effect relationships with phenomena that are merely correlated has led to many unproductive claims, wasting time and energy.

The NGSS suggest that "In grades 9–12, students understand that empirical evidence is required to differentiate between cause and correlation and to make claims about specific causes and effects. They suggest cause-and-effect relationships to explain and predict behaviors in complex natural and designed systems. They also propose causal relationships by examining what is known about smaller-scale mechanisms within the system. They recognize changes in systems may have various causes that may not have equal effects." (National Research Council 2013, Appendix G).

TEACHING TIPS

- The "Student Handout" for this activity has three parts. Part 1 can be completed in about 30 minutes if students complete Step 6 for homework, or 45 minutes if all of Part 1 is completed in class. Parts 2 and 3 can be completed in about 30 minutes.
- An accompanying PowerPoint slide deck can be downloaded from this resource's webpage. You can use these slides to help guide Parts 2 and 3 of this activity.
- This video example from a college classroom models implementation of Parts 2 and 3 of this activity.

PROCEDURE

The numbered parts and steps shown below correspond with those shown in the "Student Handout."

PART 1: Scientific Questions

1. Provide the phenomenon or phenomena you want students to observe. The "Student Handout" uses organisms as an example and recommends that students observe the organisms for at least 5 to 10 minutes and record at least 10 observations. You could also ask students to make detailed sketches of what they observe in order to help them make more careful observations.

    - This activity works well with live organisms, especially organisms that students may be able to use in follow-up experiments, such as crickets, grasshoppers, termites, pill bugs, fruit flies, or even microscopic organisms such as *Daphnia* or various protozoa (such as *Paramecium*).

        - If using live organisms in class, the activity works best if they can be put in containers. It is ideal to provide enough separate containers for groups of three or four to each have their own.

   - In each container, try to create an environment that mimics the organisms' natural settings (terraria for insects, aquaria for fish, etc.). Make sure the organisms have many things in the containers with which they can interact, such as plants, shelter, and each other.

- Alternatively, you may want to gather pond water for students to observe, or, if appropriate for your school environment and policies, allow students to go outside and make their observations.

- If you do not have access to organisms, consider using the BioInteractive activity *Scientific Inquiry and Data Analysis Using WildCam Gorongosa*, in which students make observations from trail camera data, develop and investigate a scientifically testable research question using trail camera data that they download from the WildCam Lab, and analyze results. After completing that activity, consider having students continue with Part 2 of this activity.

2. Ask students to write down as many questions as they can about the phenomena (e.g., organisms) within five minutes. If your students are not experienced in asking questions, it may help to provide them with sentence stems such as "I wonder if…?", "Could it be…?", "What would happen if…?", or "Does ___ cause ___?" Encourage students to express their creativity.
3. Ask students to circle the questions they wrote that they think could be addressed using the methods of science. They should then write the criteria they used to decide whether a question was scientific.
   - Consider having students exchange their ideas in small groups and try to come to a consensus on what makes a question scientific.
   - Lead a class discussion with the goal of developing a list of criteria that must be fulfilled in order to make a question scientific. You may want to start to organize students' ideas into groups based on the criteria under the "Scientific Questions" side of the "Characteristics of Questions" Venn diagram. For example, ideas similar to "questions must be testable" could be one group, "answers rely on evidence from natural phenomena" a second group, and "repeatability" a third group.
4. After listing students' ideas, project or give out a copy of the "Characteristics of Questions" Venn diagram, which compares and contrasts scientific questions with questions outside of science.
   - Ask students if they would like to add any ideas to the diagram. Then ask students to compare their answers to the criteria on the handout. You may want to emphasize that science is limited to explanations based on observations from the natural world. This does not mean that some scientists do not believe in the supernatural or are not religious; it simply means that explanations based on the supernatural are not acceptable within the "rules" or limitations of science.
   - To reinforce important concepts from the nature of science, you may also want to highlight that the answers to scientific questions can later be rejected with new evidence, and that answers are shared in the scientific community.
   - It is important to highlight that questions that are not scientific may still be very meaningful and valuable. However, the focus in science class is mostly on questions that can be addressed using the methods of science.
5. If necessary, have students revise their questions to make them scientific and comparative. You may want to briefly discuss the value of comparative questions in science, as discussed before Step 5 in the "Student Handout."
6. Ask students to write an outline or sketch of an experimental design they would employ to answer the research question they wrote in Step 5. The outline should include the independent and dependent variables (though these specific terms may not be used as they have not been introduced in the activity yet), as well as variables they will attempt to control.

- To save time in the classroom, consider having students do this step for homework.

PART 2: Cause and Effect

Before Step 7:

- Decide if you will use the accompanying PowerPoint slides (can be downloaded from this resource's webpage) to help guide Parts 2 and 3 of the activity.
- Lead students in a class discussion about the definition of science. After students share their ideas, reflect back on the "Characteristics of Questions" Venn diagram in Part 1 and highlight that the goal of science is to explain natural phenomena.
- Share a definition of science, "Experimental, hypothesis-driven investigation of phenomena to elucidate (1) patterns in nature and (2) the processes governing the formation, maintenance, and changing of those patterns." Then pivot the discussion to cause and effect by asking students to read the introductory paragraph above Step 7 in the "Student Handout."

7. After students read the paragraph above Step 7, which is about the value of experiments that elucidate causes and effects, ask them to generate as many synonyms as they can for each term.
   - Lead a short class discussion in which you list student-generated ideas for cause and effect synonyms. After listing student ideas, you may want to list other synonyms, as summarized in the table below. Highlight the terms "dependent variable" and "independent variable" and how these terms are used when designing an experiment. The middle column ("Verbs") will be added in Step 8.

Table 1. Terms related to cause, effect, and verbs that link cause and effect.

Synonyms for Cause	Verbs	Synonyms for Effect
independent variable	drives	dependent variable
x	generates	y
driver	causes	responding variable
generator	regulates	$f(x)$
process	controls	pattern
agent	increases	
force	decreases	
factor	suppresses	
actor		
source		
basis		

8. Ask students to add verbs that link cause and effect to the table they started in the previous step. In a class discussion, highlight how the verbs demonstrate directions or types of change.
9. Assign groups of students a local organism and give them the challenge of coming up with a research question with cause, effect, and a verb. The organisms used in the PowerPoint slides are shark, grouper, seagrass, brain coral, crab, and plankton, but you may want to replace these organisms with ones that will be more relevant to your students.
10. Ask students to describe what would happen to their experiment if they switched the order of the cause, effect, or verb in their experimental question. Emphasize how reordering could completely change the way the experiment was designed or the interpretation that would result.
    - For example, if the original question is "How does solution temperature affect the rate of a chemical reaction?", a reordered question could read "How does the rate of a chemical reaction affect the solution temperature?" The reordered question would result in a very different experiment.

PART 3: Practice Analyzing Questions

11. Choose a set of titles for students to examine from the "Journal Article Titles" handout. Either make copies of the handout or plan for a way to display the titles and have students copy them.
    - The titles in the handout are organized according to different subdisciplines in biology. The latter half of the handout also includes simplified titles.
    - If you choose the title "Protein measurement with the Folin phenol reagent," you may want to mention to students that this is by far the most cited paper in all of science, having been cited over 300,000 times.
    - As explained in the "Student Handout," students will need to identify the type of research described by the title. If the title is describing a cause-and-effect relationship, they highlight the potential causal agent(s) in yellow (or underline once) and highlight the effect(s) in green (or underline twice).
12. Direct students to a scientific figure or other data source and ask them to identify the testable, comparative question that drove the research. Potential options are described below.
    - The "Scientific Figure Example" handout provides an example of figures from a published scientific paper, accompanied by a caption. You can either project the handout or give each group of students a copy. A question that is consistent with these figures is "Do freshwater benthic stickleback fish differ in the amount of time they spend in schools compared to marine stickleback fish?" (The figures in this handout come from BioInteractive Data Point "Schooling Behavior of Stickleback Fish from Different Habitats"; visit the link for more background on the research and a short video showing the experiment in action.)
    - BioInteractive's other Data Points provide a variety of figures, each with a caption and background information. You may want to show students only the figure and the caption and not include the background information, which may give away the scientists' question.
    - Alternatively, you could have students view the data or read the methods or results section from a Science in the Classroom paper.
13. Have students reflect on the role of creativity in science, especially in asking questions. Many students view science classes as a source of information, rather than seeing a process in which they can creatively ask and answer questions about nature.
14. Have students identify questions in science that they find interesting or inspiring. You may want to collect the questions students write here, then repeat this step at the end of your course to see if their interests have shifted.

ANSWER KEY

Answers for Step 11 of the "Student Handout" are shown below, for both the full and simplified titles. "Causes" are highlighted yellow and underlined once; "effects" are highlighted green and underlined twice.

Ecology	Type of Research
1. *Simplified title*: Impact of food and predation on the rise and fall of population sizes of snowshoe hares *Full title*: Impact of food and predation on the snowshoe hare cycle	a
2. *Simplified title*: Two species competing for a limited resource cannot coexist *Full title*: The competitive exclusion principle	c
3. *Simplified title*: How competition from other species and other factors affect where a barnacle species lives *Full title*: The influence of interspecific competition and other factors on the distribution of the barnacle *Chthamalus stellatus*	a

4. *Simplified title*: The interaction of drought and habitat explain patterns of where and when saguaro cactus plants grow *Full title*: The interaction of drought and habitat explain space–time patterns of establishment in saguaro (*Carnegiea gigantea*)	a
5. *Simplified title*: Development of a new method for assessing the amount of disturbance in salt march ecosystems *Full title*: Development of a multimetric index for integrated assessment of salt marsh ecosystem condition	d
6. *Simplified title*: The make-up of the microbial community in the leaves of pitcher plants is affected more by the types of predators than the number of predator species *Full title*: Predator identity more than predator richness structures aquatic microbial assemblages in *Sarracenia purpurea* leaves	a
Molecular and Cell Biology	
1. *Simplified title*: Changes to molecules chemically attached to a gene can cause a change in the shape of a flower *Full title*: An epigenetic mutation responsible for natural variation in floral symmetry	a
2. *Simplified title*: A model for the structure of DNA *Full title*: A structure for deoxyribose nucleic acid	c
3. *Simplified title*: The amount of protein in a solution can be measured using a special chemical *Full title*: Protein measurement with the Folin phenol reagent	d
4. *Simplified title*: A protein that controls the transportation and fate of other cellular proteins also releases a chemical signal to regulate the amount of brown fat and sensitivity to insulin *Full title*: Membrane trafficking protein cdp138 regulates fat browning and insulin sensitivity through controlling catecholamine release	a
5. *Simplified title*: A specific group of enzymes control cellular stress and signals that affect cells' ability to track time *Full title*: ASK family kinases mediate cellular stress and redox signaling to circadian clock	a
6. *Simplified title*: A map showing the location and amount of a specific group of proteins helps reveal the structure of chromosomes during mitosis. *Full title*: A quantitative map of human condensins provides new insights into mitotic chromosome architecture	b
Evolution	
1. *Simplified title*: Living with predators does not cause the evolution of larger brains in a species of small fish *Full title*: Exposure to predators does not lead to the evolution of larger brains in experimental populations of three-spine stickleback	a
2. *Simplified title*: The process of natural selection and the formation of new varieties and species *Full title*: On the tendency of species to form varieties; and on the perpetuation of varieties and species by natural means of selection	c

3. *Simplified title*: Large-brained frogs mature later and live longer *Full title*: same as the simplified title	b
4. *Simplified title*: Differences among coral species and adaptation to climate are caused by changes in many genes *Full title*: Polygenic evolution drives species divergence and climate adaptation in corals	a
5. *Simplified title*: A measurement of the rate of new heritable mutations in eggs and sperm in African green monkeys *Full title*: Direct estimate of the spontaneous germ line mutation rate in African green monkeys	b
6. *Simplified title*: A mathematical model to explain the relationship between species size and the number of different types of cells it has *Full title*: A theoretical approach to the size-complexity rule	c
Anatomy and Physiology	
1. *Simplified title*: A reduced ability to make arteries open wider when oxygen is low reduces oxygen to the brain and outer parts of the body in men with high blood pressure *Full title*: Reduced arterial vasodilatation in response to hypoxia impairs cerebral and peripheral oxygen delivery in hypertensive men	a
2. *Simplified title*: Description of the anatomy of an artery for the thyroid and how it relates to a nerve for the voice box (larynx) *Full title*: Observations on the superior thyroid artery and its relationship with the external laryngeal nerve	b
3. *Simplified title*: A model for how the heart changes its structure in athletes that have high blood pressure in their arteries *Full title*: Athletic heart remodeling in athletes with arterial hypertension	c
4. *Simplified title*: The effect of a female sex hormone on daily cycles of body temperature and activity in female rats *Full title*: Effect of systemic estradiol administration on circadian body temperature and activity rhythms in female rats	a
5. *Simplified title*: The Great Recession worsened blood pressure and blood glucose levels in American adults *Full title*: same as the simplified title	a
6. *Simplified title*: The shape of the nasal cavity is affected by physical and geometric limits *Full title*: Physical and geometric constraints shape the labyrinth-like nasal cavity	a
Genetics	
1. *Simplified title*: Two new genetic mutations that are associated with reduced brain size in infants interrupt the connection between an enzyme and a protein that helps connect nerves *Full title*: Two microcephaly-associated novel missense mutations in CASK specifically disrupt the CASK–neurexin interaction	a
2. *Simplified title*: Patterns in DNA describe the history of the ancestors of people living in the Himalayas *Full title*: Reconstructing the demographic history of the Himalayan and adjoining populations	b

3. *Simplified title*: The loss of chemical changes to DNA that occurs in sections of chromosomes that are copied later than others can be used to tell how many times a group of cells has divided *Full title*: DNA methylation loss in late-replicating domains is linked to mitotic cell division	b
4. *Simplified title*: Low levels of a protein associated with cell growth causes inflammatory bowel disease and abnormal brain function *Full title*: Human TGF-β1 deficiency causes severe inflammatory bowel disease and encephalopathy	a
5. *Simplified title*: Patterns in long segments of DNA around the gene associated with sickle cell disease show that the mutation occurred once in human history about 7,300 years ago *Full title*: Whole-genome-sequence-based haplotypes reveal single origin of the sickle allele during the Holocene wet phase	b
6. *Simplified title*: Mutations to a gene that stop the production of a protein found in the middle of the flagellum in sperm cause sperm to have many defects that result in infertility in both mice and humans *Full title*: Absence of CFAP69 causes male infertility due to multiple morphological abnormalities of the flagella in human and mouse	a

REFERENCES

Ecology	Author/Journal/Year
1. Impact of food and predation on the snowshoe hare cycle	Krebs et al., *Science*, 1995
2. The competitive exclusion principle	Hardin, *Science*, 1960
3. The influence of interspecific competition and other factors on the distribution of the barnacle *Chthamalus stellatus*	Connell, *Ecology*, 1961
4. The interaction of drought and habitat explain space–time patterns of establishment in saguaro (*Carnegiea gigantea*)	Winkler et al., *Ecology*, 2017
5. Development of a multimetric index for integrated assessment of salt marsh ecosystem condition	Nagel et al., *Estuaries and Coasts*, 2017
6. Predator identity more than predator richness structures aquatic microbial assemblages in *Sarracenia purpurea* leaves	Canter et al., *Ecology*, 2018
Molecular and Cell Biology	
1. An epigenetic mutation responsible for natural variation in floral symmetry	Cubas et al., *Nature*, 1999
2. A structure for deoxyribose nucleic acid	Crick and Watson, *Nature*, 1953
3. Protein measurement with the Folin phenol reagent	Lowry et al., *Journal of Biological Chemistry*, 1951
4. Membrane trafficking protein cdp138 regulates fat browning and insulin sensitivity through controlling catecholamine release	Zhou et al., *Molecular and Cellular Biology*, 2018
5. ASK family kinases mediate cellular stress and redox signaling to circadian clock	Imamura et al., *Proceedings of the National Academy of Sciences*, 2018
A quantitative map of human condensins provides new insights into mitotic chromosome architecture	Walther et al., *Journal of Cell Biology*, 2018
Evolution	
1. Exposure to predators does not lead to the evolution of larger brains in experimental populations of threespine stickleback	Samuk, *Evolution*, 2018
2. On the tendency of species to form varieties; and on the perpetuation of varieties and species by natural means of selection	Darwin and Wallace, *Zoological Journal of the Linnean Society*, 1859

3. Large-brained frogs mature later and live longer	Yu et al., *Evolution*, 2018
4. Polygenic evolution drives species divergence and climate adaptation in corals	Rose et al., *Evolution*, 2017
5. Direct estimate of the spontaneous germ line mutation rate in African green monkeys	Pfeifer, *Evolution*, 2017
6. A theoretical approach to the size-complexity rule	Amado et al., *Evolution*, 2017
Anatomy and Physiology	
1. Reduced arterial vasodilatation in response to hypoxia impairs cerebral and peripheral oxygen delivery in hypertensive men	Fernandes et al., *Journal of Physiology*, 2018
2. Observations on the superior thyroid artery and its relationship with the external laryngeal nerve	Alzahrani et al., *Anatomy & Physiology*, 2018
3. Athletic heart remodeling in athletes with arterial hypertension	Smolensky, *Human Physiology*, 2018
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2. Reconstructing the demographic history of the Himalayan and adjoining populations	Tamang et al., *Human Genetics*, 2018
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6. Absence of CFAP69 causes male infertility due to multiple morphological abnormalities of the flagella in human and mouse	Dong et al., *American Journal of Human Genetics*, 2018

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