OVERVIEW

How Science Works is a flexible tool that allows students to observe and map the often-nonlinear processes of scientific investigations. This Click & Learn can be used to analyze text or film-based resources, as well as student-driven inquiry projects. This document suggests a possible implementation strategy including reflection, sharing, and engaging with science media, to complement BioInteractive’s Scientists at Work videos. An example of a product created by this Click & Learn for The Effects of Fungicides on Bumble Bee Colonies video is available from the "Downloads" box on the How Science Works resource page. This strategy can be easily adapted for any of BioInteractive’s other films that include transcripts.

KEY CONCEPTS

- Testing ideas is at the heart of the process of science, but many other activities and events, such as identifying a societal need, sharing ideas, and getting feedback from colleagues, also contribute to scientific progress.
- Science is a human endeavor that relies on individual researchers and the larger scientific community. Science both is shaped by and shapes the broader community in which it is embedded.
- Because the process of science is shaped by people and events, it often takes a more winding path than is typically portrayed in journal articles or most science media.

STUDENT LEARNING TARGETS

- Reflect on one’s own understanding of the process of science.
- Appreciate the richness of people and events that impact scientific discovery and the resulting nonlinearity of the process of science.
- Using an example, analyze the chronology of a discovery and identify the steps in the scientists’ process.
- Practice communication skills.
- Reflect on how one’s own understanding of the process of science has changed as a result of doing the activity.

CURRICULUM CONNECTIONS

<table>
<thead>
<tr>
<th>Standards</th>
<th>Curriculum Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGSS (2013)</td>
<td>SEP1, SEP2, SEP3, SEP4, SEP6, SEP7, SEP8</td>
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<tr>
<td>AP Bio (2015)</td>
<td>SP1, SP3, SP6</td>
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<tr>
<td>IB Env Systems and Societies (2017)</td>
<td>1.2</td>
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<tr>
<td>Common Core (2010)</td>
<td>ELA.RST.9-12.3, ELA.WHST.9-12.2</td>
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<tr>
<td>Vision and Change (2009)</td>
<td>DP1, DP4, DP5, DP6</td>
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</tbody>
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KEY TERMS

experimental design, how science works, process of science, scientific discovery, scientific method

TIME REQUIRED

One 90-minute class session or a 50-minute session with the online Click & Learn completed as homework

SUGGESTED AUDIENCE

- Middle School: Scientific method and practices
- High School: Experimental design
- College-level: Freshman science course introducing the process of science
PRIOR KNOWLEDGE
Students will likely be familiar with concepts related to the nature and process of science, such as collecting and analyzing data. This activity builds on this knowledge to provide a fuller description of how science works.

MATERIALS
- whiteboards or sheets of paper for student diagramming
- copies of the Scientists at Work transcript for each student or group (available from the "Downloads" box on the BioInteractive pages of many videos)
- color-coded cards of the science activities and practices from the How Science Works flowchart, which are provided at the end of this document (optional; the cards can be provided as a list or shown via whole class projection if preferred)
- colored pencils or highlighters for each student or group (colors should match those of the activities cards: red/pink, green, blue, and purple)
- computers and an internet connection so students can access the Click & Learn

SUGGESTED PROCEDURE
1. Ask students to diagram their understanding of the process of science on a sheet of paper or whiteboard. They can work as individuals or in pairs.
2. Have students present their diagrams to another student (or group). They can then add elements to their work inspired by what they learned from their colleagues.
3. Provide students with the science activities cards, which they should use to revise or elaborate on their diagrams. Indicate that the colors refer to different domains of the scientific endeavor (red/pink for Exploration & Discovery, green for Testing Ideas, blue for Benefits & Outcomes, and purple for Community Analysis & Feedback).
   - Alternative to cards: Write or project the activities on a whiteboard and discuss where they may fit on student diagrams.
4. Show a Scientists at Work video from the BioInteractive website. Explain that the video is about scientists investigating a question. While the video is playing, students should listen for words that are similar to those on the activities cards.
   - Alternative to cards: Write or project the activities on a whiteboard. While watching the Scientists at Work video, students place a check mark next to activities heard or seen in the video.
5. Distribute a copy of the video transcript to each student or pair of students, along with colored pencils or highlighters that correspond to the domains in the How Science Works Click & Learn (again, red/pink for Exploration & Discovery, green for Testing Ideas, blue for Benefits & Outcomes, and purple for Community Analysis & Feedback).
6. Ask students to use the corresponding colors to underline activities from each domain in the video transcript. Students should find that all four domains are represented, although probably not equally. Students may identify or categorize activities differently from their peers.
7. Explain that, although science is typically taught as the scientific method/experimental design only, many more activities are involved in scientific discovery. These activities relate to how ideas for research come about, how they are evaluated by scientists, and how the results influence society. The steps feed into one another in an often-nonlinear fashion. Understanding the full richness of the scientific process is the goal of today’s activity.
8. Introduce the How Science Works Click & Learn that the students will use to document the process of science.
   a. Explain that the Click & Learn allows us to be “Monday morning quarterbacks.” That is, we can use hindsight to analyze the activities that scientists used to investigate a topic.
b. After the introduction in the Click & Learn, students will see an interactive version of the *How Science Works* flowchart with text bubbles containing descriptions of activities that are part of the nature and process of science. Students can click on each bubble to create a sequence that matches the process of science in the video they are analyzing. As they build the sequence, each step is added to a list on the left side of the screen. In this list are text boxes where students can explain what happened during each of the scientists’ activities. The list can be reordered by clicking and dragging on individual items. When their analysis is done, students can export their work as a PowerPoint.

c. The Click & Learn offers two versions of the *How Science Works* flowchart that can be used depending on the students’ background. The *Standard* framework is recommended for students in high school and college, while the *Simplified* framework is recommended for students in middle school. Note that the *Simplified* model has fewer components and more accessible language, but the *Standard* model offers details that are more descriptive of the processes explored in BioInteractive videos.

d. Students can work through the Click & Learn individually, in groups, or with the whole class. In the last option, the teacher goes through the activity in front of the class, provides examples at each step, answers questions, and checks for understanding.

9. Have students use the Click & Learn to map the process of science depicted in the video.

   a. Students may review the introduction at their own pace or skip it to start building their own customized flow chart.
   
   b. Students should use their color-coded *Scientists at Work* transcript to decide which science activities, and in what sequence, to include in their map of the scientific process.
   
   c. Using the transcript, students should write a detailed description of each activity in the pop-up panels in the list on the left side of the screen. Each panel provides space for typing text and adding attachments. (Click the down arrow in the top-right corner of the panel to expand it.)
   
   d. Students can save their work to a local computer or Google Drive via the menu (icon with three horizontal bars) in the top-right corner of the Click & Learn. The files can be reopened from this same menu for additional revision.
   
   e. Students should use the menu to export their completed analysis as a PowerPoint, which can then be projected or printed.

10. Have students evaluate and reflect on their learning.

   a. By comparing the models from different PowerPoints, students can discuss why they might not have exactly the same results.

   b. Have students write reflections on the importance of the different domains and their interconnectedness. Appropriate prompts may vary depending on the video selected, but suggested prompts include:

      - Which science activities seemed most helpful in pushing the investigation forward?
      - Which activities surprised you?
      - Describe the importance of testing to the process of science. How is this reflected in the *How Science Works* diagram?
      - Can you imagine a scientific investigation that doesn’t involve testing ideas?
      - Will investigations always start in the *Exploration & Discovery* domain? Why or why not?
      - What is the importance of community in scientific research?
      - Did the video include any examples of how scientific research influences society or how scientific research is influenced by societal needs and culture? If so, describe them.
OPTIONAL EXTENSIONS

Students can use the *How Science Works* Click & Learn to think about the variation in how the scientific process proceeds. The Click & Learn can help students document a story about a scientific discovery, explain why researchers came to pursue their question(s) of interest, and what happened as a result of their findings. These crucial steps are often omitted from stories of science but are captured in the *How Science Works* framework.

Many learning activities, some of which are suggested below, could be supported by this Click & Learn using procedures similar to the one described above.

- Students designing and conducting their own research project can use the Click & Learn to document their process of discovery or reflect upon their process at the end of their study. They can use the resulting PowerPoint to present their work to the class.
- Students can dissect a scientific discovery described in a newspaper article, a chapter in a popular science book, or a popular science article (e.g., from *Scientific American*).
- Students can analyze or review a scientific case study taught in class (for example, those obtained from the National Center for Case Study Teaching in Science collection or the "Science in Action" stories from the Understanding Science website).
- Students writing their own scientific case study can use the Click & Learn to guide their thinking. Students would begin by researching a scientific discovery and logging their findings in the Click & Learn. They could then write their case study by using the Click & Learn to select the steps used during the investigation.
- College students can analyze the contents of a scientific paper, observing that most of the steps in the paper are probably from the Testing Ideas domain. The class can discuss why this is the case, and what is gained or lost by omitting steps from the other domains.

AUTHORS
Kim Parfitt, Central High School, Cheyenne, WY; Annie Prud'homme-Genereux, PhD, TELUS World of Science - Edmonton, AB
Reviewed and edited by Mark Nielsen, PhD, HHMI; Esther Shyu, PhD, HHMI; Anastasia Thanukos, PhD, UCMP; Jessica Bean, PhD, UCMP
<table>
<thead>
<tr>
<th>Cards for Standard framework:</th>
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<tbody>
<tr>
<td>Curiosity</td>
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<tr>
<td>Practical problem</td>
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<tr>
<td>Exploring the literature</td>
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<tr>
<td>Making observations</td>
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<tr>
<td>Personal motivation</td>
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<tr>
<td>Finding inspiration</td>
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<tr>
<td>Sharing data and ideas</td>
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<tr>
<td>New technology</td>
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<tr>
<td>Asking questions</td>
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<tr>
<td>New observation or idea</td>
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<tr>
<td>Serendipity</td>
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Cards for *Simplified* framework:

<table>
<thead>
<tr>
<th></th>
<th>Coming up with an explanation</th>
<th>Learn more</th>
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<tbody>
<tr>
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<td>Gathering data</td>
<td>Answer questions</td>
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<tr>
<td>Making observations</td>
<td>Interpreting observations</td>
<td>Satisfy curiosity</td>
</tr>
<tr>
<td>Sharing data and ideas</td>
<td>Revising what I thought after more observations</td>
<td>Solve everyday problems</td>
</tr>
<tr>
<td>Reading about scientific discoveries</td>
<td>Repeating the investigation</td>
<td>Coming up with new questions/ideas</td>
</tr>
<tr>
<td>Asking questions</td>
<td>Feedback and peer review</td>
<td>Listening to classmates</td>
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<tr>
<td>New observation or idea</td>
<td>Pure chance</td>
<td>Discussion with classmates</td>
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