

# Introductory Unit

*“Nothing shocks me. I’m a scientist.”*  
– Harrison Ford (as Indiana Jones)

This unit of the *Facilitator’s Guide* introduces the *Physics for the 21st Century* course and key themes related to how science is practiced, or the nature of science. In this unit, participants will explore a variety of activities related to the following nature of science themes: *Measurement & Observation*; *Evidence*; *Models*; *Logic & Implications*; and *Coherence & Consistency*. We also examine broader questions, such as: Why study physics? Why study current topics in physics research? Why are these topics useful for teachers and their students?

## ***What Will Participants Learn?***

Participants will be able to:

1. Describe two major nature of science themes that will be present in this course and argue why they are important.
2. Discuss the relationship of the nature of science to a few topics in this unit.
3. Argue why modern physics topics are useful in the high school science classroom.

## ***What’s in the Introductory Unit?***

**Text:** The *Introduction to the Online Text* provides an overview of the rationale behind a course on modern physics, the content in each chapter, and how the content relates to common themes throughout this course. The text begins with several examples of reductionism—breaking down complex systems into simpler units (Chapters 1–3) through identification of subatomic particles and their interactions. Physicists also use experimentation and observation to determine how phenomena can be explained through general principles (Chapters 4–7), with sometimes surprising applications. We may gain insight into complex systems, with many interacting parts, by looking at the interactions of many pieces to see the creation of a more complex whole (Chapters 8–9). The theme of *Evidence*, or how we know what we know, helps to pinpoint our interpretation of experimentation (Chapters 10–11).

**Video:** There is no video accompanying the *Introduction to the Online Text*.

**Interactive Lab:** There is no interactive lab accompanying the *Introduction to the Online Text*.

**Activities:**

- The Hook: What We See Isn't What We Get (10 minutes)
- Activity 1: Why Teach Physics? (20 minutes)
- Activity 2: The Shape of Things—*Measurement & Observation* (20 minutes)
- Activity 3: How Do We Know? *Evidence* (20 minutes)
- Activity 4: The Farmer and the Seeds—*Models* (30 minutes)
- Activity 5: Turning Gears—*Logic & Implications* (10 minutes)
- Activity 6: Rules of the Game—*Coherence & Consistency* (10 minutes)
- Back to the Classroom (30 minutes)

All other units in this course focus on one aspect of the nature of science in the discussion of a particular physics topic. This introductory unit introduces participants to all nature of science themes in the course, but does not have a particular theme itself.

## Exploring the Unit

### *The Hook: What We See Isn't What We Get*

Time: 10 Minutes.

Purpose: To introduce the role that perception plays in understanding the natural world—and why our observations should always be carefully examined.<sup>1</sup>

Materials:

- Three copies of a full-page human face from a magazine cover or a digital image.

Before the Session: Create two versions of a face using the “Vanna” activity at <http://www.exploratorium.edu/snacks/vanna/index.html>. You may scan this image and use it with a digital projector, or use the cropping tool in digital image editing software.

#### *To Do and To Notice*

Display the image that has its eyes and mouth reversed, but upside-down. Tell participants that in this course, we'll be exploring some unfamiliar things. Casually ask them, “What do you notice?” (*Hint:* Don't display the image for more than 10 seconds.) Display the same image right side up. Now what do they see? Participants will usually want you to switch between the two images a few times.

Ask participants for suggested reasons why they may not have noticed something strange about the upside-down face; whereas when it was turned right side up, it looked grotesque.

#### *What's Going On?*

We are used to seeing faces in a particular way. Our brains don't process the pieces of a face as individual parts, but rather see the face as a whole. Thus, when the face is upside-down, the gestalt processing of the entire face is disrupted. We don't notice that there is something strange—or if we do, it doesn't look as strange as it does right side up.

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<sup>1</sup> Inspired by the Exploratorium's Snack, “Vanna,” at <http://www.exploratorium.edu/snacks/vanna/>.

Observation is an important part of the scientific process. Yet our perception has inherent flaws, which can lead us to make errors in what we report. Our eyes are not cameras. In this course, we will explore some of the curious things about nature that scientists have discovered by measuring things that are out of the realm of our ability to perceive.

### ***Going Further***

You may also wish to use the auditory illusion “Find the Highest Note” at [http://www.exploratorium.edu/exhibits/highest\\_note/ex.about.fr.html](http://www.exploratorium.edu/exhibits/highest_note/ex.about.fr.html). (Scroll over the key to play the sound. This can be slow to load—be patient or use the noninteractive version at <http://asa.aip.org/demo27.html>). Be sure to play the continuous version at <http://asa.aip.org/demo27.html> as well—it’s striking. Ask participants, “What do you notice? What’s going on?” Each key is actually a collective of notes spaced by an octave. The volume of the different notes in the chords changes as you go around the keyboard, creating the illusion of a never-ending staircase of sound.<sup>2</sup>

## ***Activity 1: Why Teach Physics?***

Time: 20 Minutes.

Purpose: To share past experiences and discuss how participants approach the nature of science in the classroom.

Materials:

- *Nature of Science Themes* handout from the online resource: *Facilitator’s Guide High Resolution Graphics*
- Icons of nature of science themes from the online resource: *Facilitator’s Guide High Resolution Graphics* (optional)

### ***To Do and To Notice***

Ask participants to take a few minutes to write down their answers to the question, “Why teach physics?”<sup>3</sup> What do they want to help their students learn? Then, ask participants to discuss the issue in groups of three to four. Write their responses on the board and look for ways to organize the different reasons that are presented.

Then, facilitate a Think–Pair–Share on the following questions. (See: *Hints for Facilitators and Independent Learners* for a description of Think–Pair–Share activities.)

1. What do your students think science is?
2. What do you think science is?
3. What activities in your classroom demonstrate what science is, or the nature of science?

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<sup>2</sup> More on this activity here:

[http://www.exo.net/~pauld/summer\\_institute/summer\\_day1perception/find\\_the\\_highest\\_note.html](http://www.exo.net/~pauld/summer_institute/summer_day1perception/find_the_highest_note.html).

<sup>3</sup> “Why Teach Physics?” and the accompanying discussion are provided by Dewey Dykstra, *Piaget Beyond “Piaget” Workshop*, Boise, ID (2009).

List the nature of science themes from this unit on the board. (See: *What's Going On?* below.) A handout-ready copy is available in the online resource: *Facilitator's Guide High Resolution Graphics*.

Ask participants to list the content areas of this course on the board: *The Basic Building Blocks of Matter; The Fundamental Interactions; Gravity; String Theory and Extra Dimensions; The Quantum World; Macroscopic Quantum Mechanics; Manipulating Light; Emergent Behavior in Quantum Matter; Biophysics; Dark Matter; and Dark Energy*. Why teach these topics in the classroom?

### ***What's Going On?***

We have many valid reasons for teaching physics. Highlight participant responses that are related to the process of doing science, or scientific inquiry, such as the scientific method, the process of discovery, or the role of logic. Explain that we often struggle to help students see science as a dynamic process for exploring, understanding, and modeling the natural world, rather than a collection of facts.

The research and ideas that make up this course represent areas of physics that are still under active exploration. They demonstrate how science is a process of exploring the natural world through observation and model building, and then more observation to confirm, reject, or modify those models. These themes help support the science standards on the nature of science—the scientific community's views about the natural world and how we can study it.

Teaching 21st century physics in the high school classroom can have many advantages. It can spark student interest and motivation, and can help the teacher and students learn about the frontiers of physics. Showing that physics is an ever-changing field of unanswered questions serves to present physics as an exciting career choice. Students may not recognize that the fundamental ideas in physics (such as conservation of energy) are tools used in the frontiers of research to answer fundamental questions about the universe. Each unit in this course contains a list of connections to the science standards and benchmarks. In addition, the frontiers of research provide a platform for discussing the nature of the scientific enterprise and investigation.

List the following themes on the board, and indicate that these will be explored in today's session.<sup>4</sup> (These themes are also available in the online resource: *Facilitator's Guide High Resolution Graphics*.) The table below shows how each theme is distributed throughout the units.

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<sup>4</sup> These themes are borrowed heavily from E.F. Redish and D. Hammer, *Am. J. Phys.*, 77, 629–642 (2009), and are supplemented by F.J. Rutherford and A. Ahlgren, *Science for All Americans*, Oxford University Press (1991).

## Nature of Science Themes

	Measurement & Observation	Evidence	Models	Logic & Implications	Coherence & Consistency
<b>Unit 1:</b> The Basic Building Blocks of Matter	✓				
<b>Unit 2:</b> The Fundamental Interactions			✓		
<b>Unit 3:</b> Gravity				✓	
<b>Unit 4:</b> String Theory and Extra Dimensions		✓			
<b>Unit 5:</b> The Quantum World	✓				
<b>Unit 6:</b> Macroscopic Quantum Mechanics			✓		
<b>Unit 7:</b> Manipulating Light					✓
<b>Unit 8:</b> Emergent Behavior in Quantum Matter			✓		
<b>Unit 9:</b> Biophysics					✓
<b>Unit 10:</b> Dark Matter		✓			
<b>Unit 11:</b> Dark Energy				✓	
<b>Review</b>					✓

1. **Measurement & Observation: What Do We See?** Because we cannot always trust our direct perception, we must confirm our observations via measurement. Thus, much, if not all, scientific evidence relies on indirect measurement. A variety of tools allow scientists to probe aspects of the natural world that are beyond our human capacity to perceive.
2. **Models: What Do We Think?** Scientists create models, or hypotheses and theories, to make sense of their observations. Hence, a model is a scientific account of nature. A good model is testable and suggests evidence that would support or refute it. When experimental observations do not match the existing model, scientists may change their ideas about nature.
3. **Evidence: How Do We Know?** How do we know what we know? The data collected through measurement and observation are the raw materials from which we weave our stories, or explanations, about the world. Evidence consists of these data, processed through the logical framework of a model, that support our hypotheses. Are the data consistent with the predictions of the model? If so, then the data can be used as evidence in support of the model.

4. **Logic & Implications: What Does It Mean?** Science is founded on the principles of logical reasoning and arguments. Can we accept the implication of a new scientific idea or model of the natural world? Sometimes, the logical implications of an observation or model will cause scientists to reject previously accepted principles.
5. **Coherence & Consistency: How Does It Hook Together?** Science is not a set of independent facts and formulas, as often viewed by students. Rather, scientific findings are accepted as true because they hold together with other ideas and findings. Conflicts between results or between experiment and theory reduce scientists' confidence in either the experiment or the theory.

## Activity 2: The Shape of Things— Measurement & Observation



Time: 20 Minutes.

Purpose: To highlight the role of indirect measurement in science.

Materials:

- Pie plate
- Wooden “mystery shapes” to hide under pie plate
- Marble(s)
- Ramp (such as a plastic ruler with a groove)
- Pen or marker
- Containment fence (e.g., a hula-hoop)

Before the Session: Attach the wooden mystery shape to the inside of the pie plate so that it's hidden from view when the pie plate is turned over, and there is space for the marble to roll under the lip of the pie plate. Make a ramp out of a piece of PVC pipe or other object, such as a plastic ruler with a groove in it. Place a containment fence, such as a hula-hoop or a section of garden hose, around the apparatus. For a large class, you may want to build multiple setups with similar or different unknown mystery shapes, depending on how much structure you need to provide.



Materials for *The Shape of Things*<sup>5</sup>

<sup>5</sup> Image and activity used with permission from Thomas Jefferson National Accelerator Facility Office of Education. <http://education.jlab.org/beamsactivity/6thgrade/shapeofthings/overview.html>.

**To Do and To Notice**

Bring the class close to the setup or use a document camera to demonstrate the design. Participants may not look under the pie plate, and may only roll marbles under it to figure out what's there.

1. What is the shape of the object?
2. Where is the object located?

Facilitate discussion during the activity about how to determine the answer to these questions. When participants make a statement (e.g., "It must be toward the center"), ask them, "How do you know that?" Help them to make their reasoning explicit (e.g., that the angle of incidence of the marble is equal to the angle at which it hits the object). (*Hint: One method of data collection is to place a piece of paper on top of the pie plate so that participants may draw lines showing where the marble entered and exited from the pie plate. These lines represent inferred paths of travel, as we cannot directly observe the marble's trajectory.*)

Once participants have fully explored the activity, facilitate a class discussion using the ideas provided below:

1. How did you determine the shape and location of the object?
2. If you only shoot marbles from one side of the pie plate, which mystery objects would look the same?
3. How is this similar to Rutherford's gold foil experiment?
4. What other kinds of phenomena are not directly observable and thus need special equipment to measure?
5. How do you imagine that *Measurement & Observation* relates to other topics covered in *Physics for the 21st Century*, or to other topics you've taught?

Facilitate a Think–Pair–Share. How can you use this in your classroom?

**What's Going On?**

Once participants have fully explored the activity, facilitate a class discussion using the ideas provided below. If possible, do so while standing beside one example, or use a document camera so students can see a visual reference during the discussion.

1. **How did you determine the shape and location of the object?** We inferred it indirectly by observing the resultant motion of the marbles. Discuss the assumptions that go into this result (e.g., the marble that exits is the same marble that entered; marbles bounce off solid objects; the angle of reflection equals the angle of incidence).
2. **If I'm only shooting marbles from one side of the pie plate, which mystery objects would look the same?** Discuss that some solutions are not unique—it's difficult and sometimes impossible to discern a triangle from a circle if you're just probing it from one direction. Experiments have limitations in what we can deduce from them.
3. **How is this similar to Rutherford's gold foil experiment?** The marbles are analogous to alpha particles; the unseen space under the pie plate is analogous to the gold foil (or a cross-section of it); and the mystery object is the nucleus.

- The fact that the alpha particles ricocheted off something indicated that there was something large and dense in the atom (i.e., the nucleus).
4. **What other kinds of phenomena are not directly observable and thus need special equipment to measure?** Some examples include electric and magnetic fields, changes over time, and many astronomical observations.
  5. **How do you imagine that *Measurement & Observation* relates to other topics covered in *Physics for the 21st Century*, or to other topics you've taught?** For example, particle physics (the subject of Unit 1), astronomy (the subject of Units 10 and 11), or other areas where the type of knowledge in a field is strongly related to the measurement techniques available.
  6. **How can you use this activity in your classroom?** For example, students may not use the term “infer.” This would be a good activity to help them expand their science vocabulary. Inform participants that lab sheets and related activities can be downloaded from the activity website, at <http://education.jlab.org/beamsactivity/6thgrade/shapeofthings/index.html>.

Take-home message: We cannot always trust our direct perception and must confirm our observations via measurement. In addition, we cannot directly perceive many of the phenomena studied in physics. Therefore, much, if not all, scientific evidence relies on indirect measurement with sophisticated tools. A variety of tools allow scientists to probe aspects of the natural world that are beyond our human capacity to perceive. We will use the following icon to signal when *Measurement & Observation* is a key theme of a particular unit in this course.



### ***Activity 3: How Do We Know? Evidence***

Time: 20 Minutes.

Purpose: To explore the idea of evidence, or “How do we know what we know?” through a series of clicker questions. Since this is the first clicker question of the course, explain to participants the concept of peer discussion, as described in *Hints for Facilitators and Independent Learners* (page 13).

Materials:

- “What Can We Learn from a Tooth?”  
[http://www.exploratorium.edu/webcasts/explotv\\_player.php?id=00001107&type=flv](http://www.exploratorium.edu/webcasts/explotv_player.php?id=00001107&type=flv)

- Optional: “Why Did the Neanderthals Disappear?”  
[http://www.exploratorium.edu/webcasts/explotv\\_player.php?id=00001084&type=flv](http://www.exploratorium.edu/webcasts/explotv_player.php?id=00001084&type=flv)

### **To Do and To Notice**

Clicker/Discussion Questions: How do we know that something exists? <sup>6</sup>

- 1. Do you think we can be reasonably certain of the existence of something we can't see? Is that scientific?**
  - A. Yes, we can have evidence even if we can't see it.
  - B. If we never see it, we can't be sure.
- 2. Have you ever seen an atom?**
  - A. Yes
  - B. No
- 3. How sure are you that atoms exist?**
  - A. Not very sure
  - B. Somewhat sure
  - C. Very sure
  - D. Certain



Watch the video on “What Can We Learn from a Tooth?” from the Exploratorium’s Evidence project<sup>7</sup> (2 minutes). What types of claims could be supported by evidence from teeth? You may also wish to show “Why Did the Neanderthals Disappear?” (2 minutes) to demonstrate the types of theories generated by anthropologists.

Discuss the answers to the clicker questions and reactions to the video as a group, focusing on *Evidence*. How do you imagine that *Evidence* relates to other topics covered in *Physics for the 21st Century*, or to other topics you’ve taught?

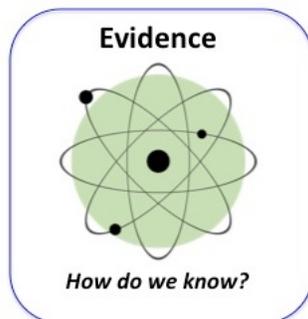
### **What’s Going On?**

In order to assess any scientific claim, it’s important to ask, “How do you know?” Much evidence comes from observation and measurement, and takes the form of numbers. How these numbers were collected (e.g., the number of measurements and the experimental conditions) is an important part of evaluating evidence. Many claims rely on rather meager evidence, such as certain theories about the nature of early species that rely on a single fossil. Others, such as the existence of the atom, rely on multiple lines of evidence and many different kinds of measurements. In this course, for example, multiple lines of evidence point toward the existence of atoms and quarks (Unit 1), the quantum nature of matter and light (Unit 5), or dark matter and energy (Units 10 and 11).

<sup>6</sup> Questions developed by Dr. Douglas Duncan at the University of Colorado at Boulder.

<sup>7</sup> See all videos from the Exploratorium’s website Evidence here: <http://tinyurl.com/yze6plx> and the full Evidence site at <http://www.exploratorium.edu/evidence/>.

Take-home message: Evidence consists of data and its interpretation. More compelling evidence rests on well-founded assumptions, accurate data, and good sampling techniques. A good skeptic should be in the habit of asking, “How do we know?” We will use the following icon to signal when *Evidence* is a key theme of a particular unit in this course.



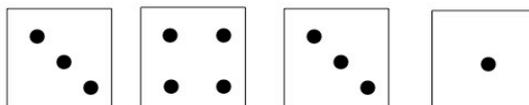
## ***Activity 4: The Farmer and the Seeds—Models***

Time: 30 Minutes.

Purpose<sup>8</sup>: To create models of how different types of seeds sprout in order to recognize that models are based on observations, new observations can throw doubt on existing models, and one can never have final proof that a model is correct.

### ***To Do and To Notice***

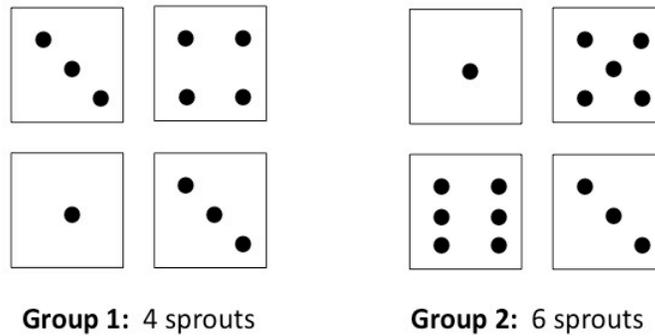
A farmer has some strange seeds. Each seed is a square with dots on it, as shown below (images available in the online resource: *Facilitator’s Guide High Resolution Graphics*).



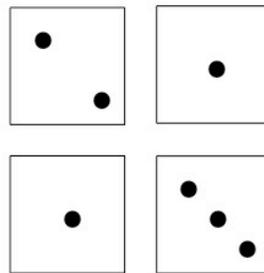
**Four different kinds of seeds**

He wants to know how many sprouts he will get, depending on what seeds he sows. On two of his plots, he sows the seeds as shown below, getting four and six sprouts in each, respectively. Tell participants, “On your own, come up with a scheme that would predict how many sprouts are generated depending on the dot patterns showing on the seeds.” After they have generated their own ideas, ask them to share their scheme with one or two people sitting near them. They don’t have to reach consensus.

<sup>8</sup> Credit: D. Dykstra, *Piaget Beyond “Piaget” Workshop*, Dewey Dykstra, Boise, ID (2009). See that text for an alternative example exploring an anthropologist’s examination of markings made by an ancient culture (attributed to Andy Johnson).



Now, the farmer plants another plot of seeds and gets the following result:



**Group 3:** \_\_\_\_\_

Ask participants, “What prediction does your scheme give for this seed grouping?” Once they’ve made their predictions, tell them that it yields seven sprouts. Does this change their model?

Facilitate a discussion.

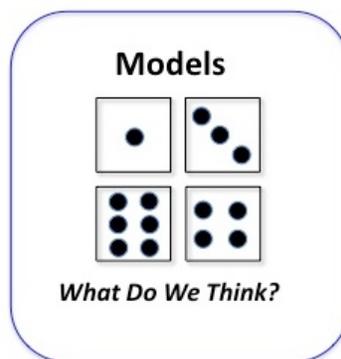
1. Where did each of our schemes come from?
2. How should we use the results of the comparison between predictions and the results from the third seed planting?
3. If we have found a scheme that has worked for several different seed plots so far, how do we know that it will work on the next one?
4. How do we know if we have figured out all the possible schemes? How do we know that our scheme is really the answer?
5. Why does this activity matter?
6. How do you imagine that *Models* relates to other topics covered in *Physics for the 21st Century*, or to other topics you’ve taught?
7. How do we teach that scientific models are not reflections of reality, yet give students the sense that science is trustworthy since it’s very predictive?

### ***What’s Going On?***

Scientists make up theories to explain the data that they see. As learners, we also construct our own understanding. We can’t always look inside a seed (or atom) to see how it works, so we use observations (both direct and indirect) as evidence for our models, theories, and hypotheses. In this way, scientific models are human constructions used to form an account of nature based on the result of evidence and observations. Models are judged, in part, by their power to predict the outcome of experimentation. Even though we can’t know the absolute “truth,” we can create models that have fantastic powers to explain and predict.

1. **Where did each of our schemes come from?** We made decisions about what elements of observations to use and how to use them. They came from us—they were not “out there” waiting to be discovered (as many students think about scientific “facts”).
2. **How should we use the results** of the comparison between predictions and the results from the third seed planting? We should modify our model.
3. **If we have found a scheme that has worked** for several different seed plots so far, how do we know that it will work on the next one? Answer: We don’t!
4. **How do we know if we have figured out all the possible schemes?** How do we know that our scheme is really the answer? Answer: We don’t!
5. **Why does this activity matter?** It can be a useful way for students to understand the nature of scientific models and questions. Note the similarity between this and the previous clicker questions on the atom. The existence of the atom, and its structure, is a model, but one which has good evidence. This also has deep implications for how our students learn, and how we will learn in this course—we cannot teach a set of facts, but we can help students make sense of ideas by constructing their own mental models and explanations.
6. **How do you imagine that *Models* relates to other topics covered in this course, *Physics for the 21st Century*, or to other topics you’ve taught?** Most of our ideas in physics are models, even if we don’t realize it, such as the model of the atom (which has changed over the centuries). Particle physics (Unit 1) and quantum theory (Unit 5) shed light on our model of the atom, while gravity (Unit 3) and string theory (Unit 4) discuss our models of spacetime itself.

Take-home message: Models are human constructions, rather than an accurate picture of nature. Because models can have predictive power, they are useful in creating explanations of the natural world. We will use the following icon to signal when *Models* are a key theme of a particular unit in this course.



## Activity 5: Turning Gears—Logic & Implications

Time: 10 Minutes.

Purpose: To examine a chain of gears in order to talk about the analogy that one idea leads to implications in a logical chain. These ideas can then be extended to talk about scientific models using a parabolic reflector.

Materials:

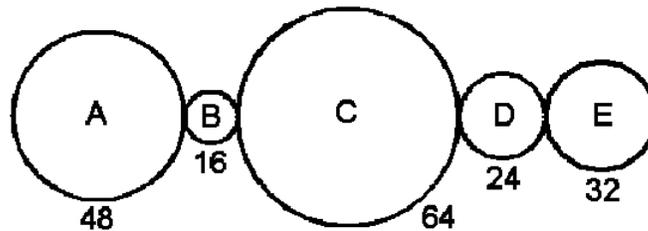
- Mirage toy<sup>9</sup> (optional)

### To Do and To Notice

Clicker/Discussion Question: Turning of Gears.<sup>10</sup>

Given five gears, each with a different number of teeth, as shown below: **If Gear A is turned 10 times clockwise, how many times does Gear E turn, and in what direction?**

- A. 15 turns counterclockwise
- B. 10 turns counterclockwise
- C. 15 turns clockwise
- D. 10 turns clockwise
- E. Something else



Discuss the question as a class. How does this relate to science in general, and to topics and ideas in physics and this course in particular?

Sometimes, new theories lead to predictions that, though surprising, are true. Can you think of some? New theories sometimes lead to predictions that cause scientists to throw out the theories. Can you think of any theories like these?

### What's Going On?

The best answer is (C). Ten clockwise turns of Gear A causes every subsequent gear to ratchet through 480 teeth; 480 divided by 32 is 15. Odd gears turn clockwise, and even gears turn counter-clockwise; so Gear E turns clockwise.

When the gears turn, we assume that the gears follow certain simple rules, like the teeth don't slip, and it rotates through all teeth in a full turn. These assumptions, and logical arguments, can tell us how Gear E behaves in response. This is an analogy for the roles

<sup>9</sup> For example, <http://www.arborsci.com/detail.aspx?ID=210>.

<sup>10</sup> Question and image courtesy of E.F. Redish and D. Hammer, *Am. J. Phys.*, 77, 629–642 (2009).

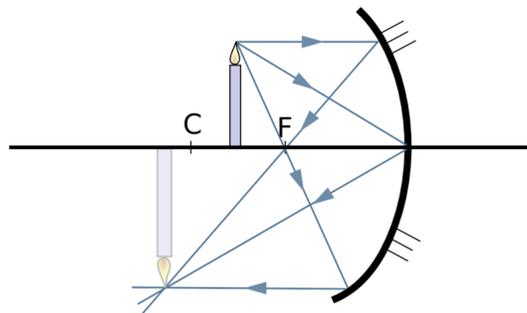
that logic and implications play in the scientific enterprise. Given certain ideas (such as, the world is made of atoms), what are its implications? Can we accept those implications? Einstein's theory of relativity, for example (Unit 3), led to the prediction that light would bend around an object—a surprising prediction, which turned out to be true. Quantum theory (Unit 5) predicted that matter acts like waves, creating interference patterns, which also turned out to be true.

### ***Going Further***

Ask participants to help you create a list of the principles of light that relate to how we see an object, such as “some objects give off light” or “light scatters in all directions when it hits an object.” Below is an example of such a list:

- Light travels in straight lines through empty space.
- Light bounces off smooth surfaces at an angle of reflection equal to an angle of incidence.
- We only see something when light coming directly from it enters our eyes.
- Our eyes identify a point as being on an object when rays traced back converge at that point.

Use these principles to come up with a prediction of what will happen when an object is placed near a spherical mirror. Below is a ray diagram that participants may draw.

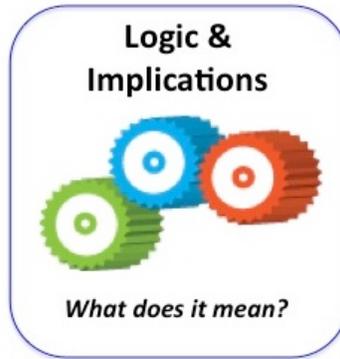


**An image formed by a spherical mirror<sup>11</sup>**  
(Available in the online resource: *Facilitator's Guide High Resolution Graphics*)

Using the Mirage toy, demonstrate that this indeed is what happens. We see a surprising result—an image that appears to float in midair. The implications of our assumptions and our model lead to predictions, which can be verified experimentally. Discuss in terms of the ideas of logic and implications.

**Take-home message:** Following the implications of our ideas and assumptions is an important part of science. When scientists have a new idea or theory, they look to see what its implications are. Sometimes, these implications cause them to reject the theory, or sometimes they predict new phenomena. We will use the following icon to signal when *Logic & Implications* is a key theme of a particular unit in this course.

<sup>11</sup> Concave mirror producing image when the object is between the curvature's center and the focus. Source © Wikimedia Commons, License: CC ShareAlike 3.0. Author: Marcelo Reis, 27 November 2004. [http://commons.wikimedia.org/wiki/File:Concavo\\_3.png](http://commons.wikimedia.org/wiki/File:Concavo_3.png).



## ***Activity 6: Rules of the Game— Coherence & Consistency***

Time: 10 Minutes.

Purpose: To discuss and explore how physical theories must be consistent across the discipline as a whole.

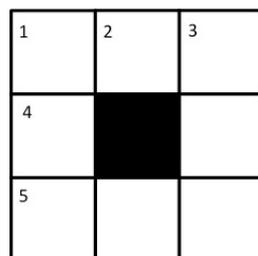
Materials:

- Image of puzzle and solution from online resource: *Facilitator's Guide High Resolution Graphics*

### ***To Do and To Notice***

Ask participants to complete the following crossword puzzle in pairs. Ask them to consider these questions:

1. Are you sure of your answers? Are there any answers you're unsure of? Why?
2. Can anyone find a second solution to the puzzle?
3. What if the clue for 3-Down was "Tit for \_\_\_"?
4. How does this relate to physics topics you've taught?



ACROSS

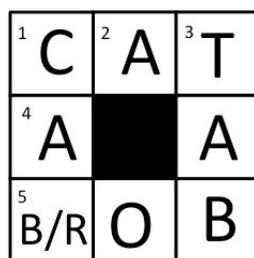
1. Common household pet
5. Nickname for "Robert"

DOWN

1. A mode of transportation
3. Pull this to open a can

**What's Going On?**

Here is the completed puzzle:



## ACROSS

1. Common household pet
5. Nickname for "Robert"

## DOWN

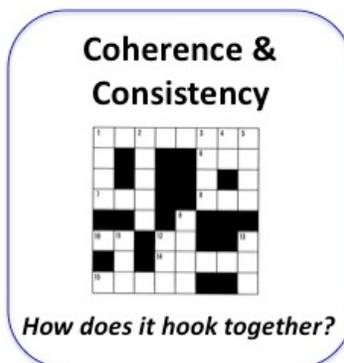
1. A mode of transportation
3. Pull this to open a can

There are some ambiguities in the puzzle, which may or may not be resolved by consistency with the rest of the puzzle:

- **1-Across** could be CAT or DOG. Consistency with 1-Down and 3-Down requires that it be CAT.
- **5-Across** could be BOB or ROB. Either answer is consistent with 1-Across.
- **1-Down** could be CAB or CAR. Because 5-Across could begin with "R" or "B," the data ends up being insufficient to distinguish between these two possibilities.
- **3-Down** should be TAB from the clue. What if the clue were "Tit for \_\_\_"? This would be incompatible with the evidence from other clues, suggesting that one of the clues is wrong, analogous to incorrect measurements in science.

As in all games, this crossword puzzle has a set of rules. The clues are used to solve the puzzle, but some of the clues lead to ambiguous answers. Those ambiguities are resolved by requiring the letters of one word to be consistent with the overlapping letters from other words. When the letters of one word aren't consistent with the rest of the puzzle, this leads to frustration. Similarly, in science there may be multiple theories that are consistent with the data, leading scientists to seek more clues. Because physics is a well-established science, it has a high degree of consistency. Students, however, often see physics as a set of independent facts and formulas—or disconnected words that are not part of a larger puzzle. Many students will make ad-hoc guesses as explanations for new phenomena, rather than using larger principles and ideas that are accepted by the physics community to make meaning of the new observation.

**Take-home message:** Science seeks consistency in its theories, in order for the principles to be as broad as possible. Physicists come to accept ideas and findings as true because they hold together with other ideas and findings as a coherent framework. We will use the following icon to signal when *Coherence & Consistency* is a key theme of a particular unit in this course.



# Back to the Classroom

Time: 30 Minutes.

Purpose: To explore the *National Science Digital Library Science Literacy Maps* as a tool for investigating science standards and benchmarks, and discover how participants might use them in their own teaching.

Materials:

- A computer with Internet access for each group of two to three participants

## ***To Do and To Notice***

Ask participants to navigate to <http://strandmaps.nsdlib.org>. Give them the following tasks in small groups, and then facilitate a large group discussion about what they find.

1. Explore the Science Literacy Map to find the concept related to the basic structure of the atom.
2. What concepts are connected to this topic? What do students need to know to understand this concept, and what does knowledge of this topic allow them to understand?
3. What else can you find out from the Science Literacy Map?
4. How might you use this information to help teach the nature of the atom, in conjunction with the *Shape of Things* activity? (*Note:* Make sure that participants discuss how to use students' prior knowledge about the topic in teaching that topic.)
5. Explore the Science Literacy Map to find the nature of science concept that discusses how predictions are compared to observations to test a scientific model. What other topics are connected to this concept?
6. How would you use this information to help teach the nature of science, in conjunction with the *Shape of Things* or *The Farmer and the Seeds* activities?

## ***What's Going On?***

The Science Literacy Maps are a rich area for exploration of scientific concepts and how they relate to one another, and to find classroom resources for addressing these topics.

To find the science content on the basic structure of the atom, they must navigate to "The Physical Setting" > "Atoms and Molecules" and locate the concept "Atoms are made of a positive nucleus surrounded by negative electrons." Participants should notice the arrows leading toward and from that concept, and that vertical height is related to higher-level concepts. Clicking on the concept will bring up related benchmarks, standards, and resources. Clicking on "Show Student Misconceptions" will show a related list of misconceptions.

## **Classroom Resources**

"**The Shape of Things**" classroom activity from the Thomas Jefferson National Accelerator Facility Office of Science Education.

<http://education.jlab.org/beamsactivity/6thgrade/shapeofthings/overview.html>.

**“The Rutherford roller” classroom activity** from the Exploratorium’s Eric Muller. A variation on “The Shape of Things.” <http://www.exo.net/~emuller/activities/index.html>.

**“The ghost particle” classroom activity** from PBS’s *The Elegant Universe* allows students to make inferences about an object they can’t see. [http://www.pbs.org/wgbh/nova/teachers/activities/3306\\_neutrino.html](http://www.pbs.org/wgbh/nova/teachers/activities/3306_neutrino.html).

**Educational activities on perception** at the Exploratorium’s fabulous Snack Page <http://www.exploratorium.edu/snacks/iconperception.html> and a day’s worth of activities on perception as it relates to the question of “What is Science?” at [http://www.exo.net/~pauld/summer\\_institute/summer\\_day1perception/day1\\_perception.html](http://www.exo.net/~pauld/summer_institute/summer_day1perception/day1_perception.html).

**Evidence: How Do We Know What We Know?** An interactive and thought-provoking website on evidence and the nature of science from the Exploratorium, including a case study in human origins, a visual diagram of the scientific process, and the ability to map your own beliefs. <http://www.exploratorium.edu/evidence/>.

**Black Box Activity.** An excellent alternative to the *Farmer and the Seeds* activity that demonstrates the nature of models and their explanatory power. Contained in a teacher’s guide from the Perimeter Institute. [http://www.perimeterinstitute.ca/Perimeter\\_Explorations/Quantum\\_Reality/The\\_Challenge\\_of\\_Quantum\\_Reality/](http://www.perimeterinstitute.ca/Perimeter_Explorations/Quantum_Reality/The_Challenge_of_Quantum_Reality/).

**Science for All Americans** by the AAAS Project 2061. Readable and lucid recommendations on what constitutes scientific literacy, including the nature of science themes. Online at <http://www.project2061.org/publications/sfaa/online/sfaatoc.htm>.

**The Science Media Group Digital Library** has videos on a variety of topics, including the scientific method and nature of science. This video library may be searched by Strand Map, Benchmarks, and other criteria. <http://www.hsdvl.org/>. See for example:

- A Private Universe (20 minutes) <http://www.learner.org/resources/series28.html>
- A Private Universe Project in Science, Program 3: Physics: Hands-On/Minds-On Learning (90 minutes) <http://www.learner.org/resources/series29.html>
- Minds of Our Own, Program 1: Can We Believe Our Eyes? (60 minutes) <http://www.learner.org/resources/series26.html>
- The Science of Teaching Science, Program 2: Eliciting Students’ Prior Knowledge (90 minutes) <http://www.learner.org/resources/series90.html>

## Between Sessions

### FACILITATOR

You may wish to share the *Classroom Resources* section of the next unit with participants for their homework.

You may wish to share the learning goals of the next unit from *What Will Participants Learn?* with participants in preparation for the next session.

Divide participants into four groups for a jigsaw activity during the next session. The participants in each group have the responsibility of becoming “experts” on one of the

fundamental forces—gravity, electricity and magnetism, the weak force, or the strong force. They will work together as a group to determine the fundamental aspects of their force, and teach the class about that force.

## PARTICIPANTS

**Text:** If you haven't already done so, read the *Introduction to the Online Text*. Also read Unit 1: *The Basic Building Blocks of Matter*.

While reading Unit 1, you may choose to organize your reading by using the following table and bring it in to class, prepared to discuss. You will not necessarily have entries for all cells of the table—simply use this as a tool to organize your understanding of the topics presented in the chapter. In the next session, you will use this table to help create a concept map of the relationships between the different ideas in the chapter. (*Optional:* You may create a concept map as you read the chapter, instead of using the table.)

Particle family	What does the name mean?	What particles are included in this family?	What are these particles made of (or are they irreducible)?	Other notes
Leptons				
Mesons				
Baryons				
Quarks				

Be sure that you include the following particles somewhere on your table: proton, neutron, electron, and neutrino. Does the Higgs boson belong on this table? Why or why not?

Consider the following questions:

1. Where could antimatter belong on your table?
2. Some of these particles were difficult to observe. Describe what you understand the difficulties were.
3. Some particles were impossible to observe. What evidence appears to support their existence?

**Video:** Watch the video for Unit 1: *The Basic Building Blocks of Matter*. While you watch, consider the following focus questions. You may wish to make some notes to bring to the class discussion.

1. *Why do we care?* What would discovery of each of the particles discussed in the video (the Higgs boson and the neutrino) tell us about the universe? Why are they important?
2. *What is our approach?* Why is it difficult to detect the Higgs boson? The neutrino?
3. *How do we know?* What evidence would let researchers know if they have produced the Higgs boson? The neutrino?

**Interactive Lab:** You may wish to explore the interactive lab associated with this unit: *Discovering Neutrino Oscillation*. Explore how the basic properties of neutrinos affect their oscillations, and design an experiment to learn more about the quantum behavior of this elusive particle.

