Annenberg Media
Facilitator's Guide

Physics for the 21st Century

An 11-part multi-media course in modern physics

Produced by the Harvard-Smithsonian Center for Astrophysics

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is produced by the Harvard-Smithsonian Center for Astrophysics

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Table of Contents

About the Course

Course Overview

New tools and techniques have allowed physicists to probe the extent of the physical universe—from particles smaller than we can imagine to the outer reaches of the universe. Powerful, precision instruments—such as the most powerful particle accelerators ever created, finely-tuned atomic freezers, or galactic surveys providing terabytes of data about the universe—have opened the landscape of physics, allowing us to answer age-old questions about what makes up the universe, and how it works. As many questions as we have answered in recent decades, however, ever more crop up to be explored.

This course begins with an exploration of what is currently known at the very smallest realm—the fundamental particles, and the forces that they create and with which they interact (Units 1 and 2). Open questions regarding the nature of the most familiar force—gravity—and the potential of string theory to resolve these questions will be detailed in Units 3 and 4. The following three units (Units 5, 6, and 7) will cover quantum mechanics, and the surprising behaviors physicists have revealed through the manipulation of atoms and light. Looking at larger scales, Units 8 and 9 examine the collective behavior of individual pieces which give rise to new material properties and open up the frontiers of biophysics. With Units 10 and 11, the course concludes with an examination of the physics of the cosmos—the mysterious substance that created the structure in the universe, and the energy that is pushing it apart.

We intend this *Facilitator's Guide* to be used by a facilitator running an on-site professional development course for high school physics teachers. Thus, these materials are designed to be used by a facilitator in shaping such a course, rather than used directly by practicing teachers, although many of the activities are quite suitable for use in a high school classroom setting. Further, although designed for use in a professional development course, independent learners may also find the *Facilitator's Guide* valuable.

Each unit consists of:
- An online text written by an expert in the field;
- Video case studies describing two current research programs in that topical area;
- An interactive lab; and
- The written activities in the *Facilitator's Guide*.
  (*Note*: Some units also include an extra video segment.)

For more information about receiving graduate credit for participating in this course, either in on-site synchronous sessions or as an independent learner, please visit http://www.learner.org/workshops/graduate_credit.html.

Course Components

Online Text, Video, Interactive Labs

Introduction to the Online Text by Christopher Stubbs

For centuries, physicists have been trying to figure out the world around them. The accumulated work of these physicists is traditionally passed on to new students in a roughly historical sequence. It takes most people years to make the progression from mechanics to electromagnetism to quantum mechanics, and many leave their physics studies before even learning about the current research frontier of physics. The approach in *Physics for the 21st Century* is different. We jump directly to “the new stuff” by highlighting some of the fascinating topics currently studied by the physics community. The choice of topics in this course is representative, and is meant to convey the excitement, the mystery, and human aspects of modern physics.

Unit 1. The Basic Building Blocks of Matter by Natalie Roe

In this unit, we explore particle physics, the study of the fundamental constituents of matter. These basic building blocks lay the foundation for all of the ambitious projects detailed throughout this course. Dramatic discoveries over the last century have completely changed our view of the structure of matter.

Video: Matter's basic building blocks have been linked together into a theoretical framework—the Standard Model—that has been very successful in making predictions that were later confirmed by experiment. Even so, there are hints that the Standard Model is incomplete, and that a deeper theory lies behind it, waiting to be teased into the open. Learn how the Standard Model was developed and what it explains—and where it falls short—tantalizing 21st century physicists.

Featured Scientists:	Bonnie Fleming (Yale University) Mark Kruse (Duke University)

Interactive Lab: *Discovering Neutrino Oscillations.* 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.

Unit 2. The Fundamental Interactions by David Kaplan

This unit takes the story of the basic constituents of matter beyond the fundamental particles that we encounter in Unit 1. It focuses on the interactions that hold those particles together or tear them asunder. Today we recognize four fundamental forces: gravity, electromagnetism, and the strong and weak nuclear forces. Detailed studies of those forces suggest that the last three—and possibly all four—were themselves identical when the universe was young, but have since gone their own way. But while physicists target a grand unification theory that combines all four forces, they also seek evidence of the existence of new forces of nature.

Video: Key to physicists' search for a new underlying theory of the physical world is a better understanding of the fundamental interactions. One starting point is to investigate the microscopic description of forces: electromagnetism, gravity, the strong nuclear force, and the weak force. Such microscopic theories also explain other diverse phenomena, from the existence of solid materials, to all of chemistry, to the shining of stars and radioactivity. Discover how clues from echoes of the Big Bang and today's particle accelerators are driving the search for the unification of the fundamental interactions in a new theory of supersymmetry.

Featured scientists:	Ayanna Arce (Lawrence Berkeley National Laboratory)
	Srini Rajagopalan (Brookhaven National Laboratory)

Interactive Lab: *Discovering Neutrino Oscillations.* 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.

Unit 3. Gravity by Blayne Heckel

Although it is by far the weakest of the known forces in nature, gravity pervades the universe and has played an essential role in the evolution of the universe to its current state. Newton's law of universal gravitation and its elegant successor, Einstein's theory of general relativity, represent milestones in the history of science and provide the best descriptions we have of gravity. Current research is attempting to improve the precision to which the laws of gravity have been tested and to expand the realm over which tests of gravity have been made. Gravitational waves, predicted by general relativity, are expected to be observed in the near future. The unit reviews what we know about gravity and describes many of the directions that research in gravitation is following.

Video: How can gravity, which in many ways is the dominant force in the universe, be at the same time by far the weakest of the four known forces in nature? See how physicists are approaching this question through topics of intense research in gravitational physics today: short scale measurements of gravity, the study of black holes, the search for gravitational waves, and the search for clues to the composition and evolution of the universe.

Featured Scientists:	Eric Adelberger (University of Washington)
	Nergis Mavalvala (Massachusetts Institute of Technology)

Video Extra: Wolfgang Rueckner of Harvard University demonstrates a tabletop version of the Cavendish Experiment to confirm Newton’s law of gravitation for small masses.

Interactive Lab: *Discovering Neutrino Oscillations.* 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.

Unit 4. String Theory and Extra Dimensions by Shamit Kachru

One area of active work in physics is the effort to develop a “theory of everything” that brings all four forces of nature under the same conceptual umbrella. The most prominent aspect of that effort is the family of string theories that envision the basic units of matter as minuscule stretches of threadlike strings rather than point particles. The unit introduces string theory in the context of quantum gravity and explores the relationship of string theory to particle physics. The unit also details links between string theory and cosmic inflation, and, finally, summarizes the understanding that string theory brings to our fundamental understanding of gravity.

Video: In the 20th century, twin breakthroughs, quantum mechanics and general relativity, provided fresh insight into phenomena at the sub-atomic and cosmological scales, respectively. Yet physicists are still struggling to develop a consistent theory that bridges quantum mechanics and gravity. One approach to "quantum gravity" is string theory, a mathematical description of particles and forces at scales 10^{31} times smaller than a proton. So far, however, observational evidence for string theory has been elusive. Find out how string theory extends the Standard Model and where physicists are looking for the hard evidence needed to support it: from microscopic hidden dimensions to large-scale cosmological structures

Featured Scientists:	Juan Maldacena (Institute for Advanced Study) Henry Tye (Cornell University)

Interactive Lab: *Laser Cooling*. Learn the basics of how to manipulate atoms with light, and cool a hot atomic beam to a few millionths of a degree above absolute zero.

Unit 5. The Quantum World by Dan Kleppner

This unit covers a field of physics that is simultaneously one of the most powerful, transformational, and precise tools for exploring nature and yet, for non-physicists, one of the most mysterious and misunderstood aspects of all science. Developed early in the 20th century to solve a crisis in understanding the nature of the atom, quantum mechanics has laid the foundation for theoretical and practical advances in 21st century physics. The unit details the reasoning that led to ever-deeper awareness of the nature of particles, waves, and their interrelationships; provides a primer on present-day understanding of the field; and outlines ways in which that understanding has led to significant applications today.

Video: We are in a new quantum age in which the abstract concepts of the quantum revolution have become concrete due to rapid advances in controlling and manipulating atoms, molecules, and light. Practical applications, from lasers and atomic clocks to telecommunications and mp3 players, are only part of the story. Find out how laser cooling and trapping prompted the discovery of a new form of matter, the Bose-Einstein condensate, and how recent experiments are extending the frontiers of our understanding of how matter behaves.

Featured Scientists:	David J. Wineland (National Institute for Standards and Technology) Martin Zwierlein (Massachusetts Institute of Technology)

Video Extra. John Lowe of the National Institute for Standards and Technology (NIST) discusses atomic clocks.

Interactive Lab: *Laser Cooling*. Learn the basics of how to manipulate atoms with light, and cool a hot atomic beam to a few millionths of a degree above absolute zero.

Unit 6. Macroscopic Quantum Mechanics by William P. Reinhardt

The fundamentals of quantum mechanics that we met in Unit 5 characteristically appear on microscopic scales. Macroscopic quantum systems in which liquids, or electric currents, flow without friction or resistance have been known since the early part of the 20th century: These are the superfluids and superconductors of traditional condensed matter physics that are discussed in Unit 8. In this unit we focus on an entirely new state of matter only recently created in the laboratory—the gaseous macroscopic quantum mechanical system known as a Bose-Einstein condensate, or BEC.

Video: Quantum mechanics manifests itself in phenomena at macroscopic scales, including lasers, clouds of ultra-cold atoms, superfluids, and superconductivity. Of these phenomena, the recent discovery of new kinds of high-temperature superconducting materials is a particularly intriguing problem because there is still no widely accepted theory about how they work. Delve deeper into quantum mechanics using the example of how researchers are approaching this problem from two different directions: A "top-down" approach closely examining the materials themselves, and a "bottom-up" approach looking at model systems that mimic the quantum interactions of the superconducting electrons inside the materials

Featured Scientists: Jenny Hoffman (Harvard University)
Deborah S. Jin (NIST/University of Colorado)

Video Extra: Wolfgang Rueckner of Harvard University demonstrates the Meissner effect, where a magnet will levitate above a superconductor as the superconductor expels all magnetic field lines.

Interactive Lab: *Laser Cooling*. Learn the basics of how to manipulate atoms with light, and cool a hot atomic beam to a few millionths of a degree above absolute zero.

Unit 7. Manipulating Light by Lene Hau

This unit focuses on experimental achievements in reducing the speed of light by factors of tens of millions and delves into the implications of that research. First we look at the critical importance that the speed of light in a vacuum plays in our understanding of our universe. The unit then details the type of experimental setup used to slow down light in the laboratory and analyzes the fundamental quantum processes that permit physicists to reduce light's speed dramatically—and even to stop light altogether and hold it in storage. Next, the unit covers methods of converting light into matter and back again. And finally, it looks at some of the potential real-world applications that these incredible experimental achievements might open up in the future—such as quantum processing.

Video: Tools of the new quantum age are opening new possibilities for controlling and manipulating light. In 2001, Lena Vestergaard Hau stopped a pulse of light in a cloud of atoms and then released it, along with the information it contained. Explore not only how light interacts with matter at the quantum level, but also the concepts of entanglement and action at a distance, and see how experiments with storing information in matter might lead eventually to an entirely new technology: quantum computing and secure encryption.

Featured scientists: Lene Hau (Harvard University)
Paul Kwiat (University of Illinois at Urbana-Champaign)

Interactive Lab: *Laser Cooling*. Learn the basics of how to manipulate atoms with light, and cool a hot atomic beam to a few millionths of a degree above absolute zero.

Unit 8. Emergent Behavior in Quantum Matter by David Pines

This unit takes an approach to physics that differs markedly from much of what we have encountered in previous units. Rather than studying phenomena that occur at the microscopic level and involve the elementary components of matter, we look at what happens at the macroscopic scale when complex interactions among those components lead to entirely new—emergent—behavior. After introducing the concept of emergence, this unit examines emergent behavior in solids, the liquid forms of two very different isotopes of helium, conventional superconductivity, and superfluidity in stars.

Video: Reductionism—breaking things into their component parts to study how they work—is an effective tool in physics. But when the computational requirements are too massive or the theories that govern the component parts are inadequate, many complex systems have yielded to the physics of emergence, which seeks organizing principles at the system level. Find out how superconductors, hydrodynamics, and even the formation of structure in the universe, are all fruitful areas where the physics of emergence are leading to new understanding.

Featured scientists:	Paul Chaikin (New York University) Piers Coleman (Rutgers University)

Interactive Lab: *Laser Cooling*. Learn the basics of how to manipulate atoms with light, and cool a hot atomic beam to a few millionths of a degree above absolute zero.

Unit 9. Biophysics by Robert Austin

In many ways, biologists work in a very different realm than physicists, studying diverse and incredibly complex phenomena involving living systems. Even so, ideas and approaches from physics have provided key insights into the world of biology, helping advance the frontiers of both research and medicine. This unit explores some of the ways that physics has informed understanding in biology, especially the forces involved in DNA and protein folding, principles that describe organisms' fitness levels, and the emergent phenomenon of mind and consciousness.

Video: The broad, rapidly developing field of biophysics brings many disciplines under its umbrella. The physics of biological systems provides new insights into how flowers explode into bloom and how bacteria travel. Computational biophysics works to develop designer drugs and a new understanding of neural networks in the brain. Molecular biophysics opens the possibility of manipulating DNA and proteins, perhaps leading in the future to nanofabrication of biologically active molecules. And medical physics is already providing novel ways of imaging living tissues, as well as curing disease through new uses for old accelerators with radiation therapy.

Featured scientists:	Harald Paganetti (Massachusetts General Hospital/Harvard Medical School) Vinothan Manoharan (Harvard University)

Interactive Lab: *Laser Cooling*. Learn the basics of how to manipulate atoms with light, and cool a hot atomic beam to a few millionths of a degree above absolute zero.

Unit 10. Dark Matter by Peter Fisher

Most of the mass in galaxies like our own Milky Way does not reside in the stars and gas that can be directly observed with telescopes. Rather, around 90 percent of the mass in a typical galaxy is "dark matter," a substance that has so far evaded direct detection. Scientists can make this astonishing claim because we can infer dark matter's existence from the gravitational pull it exerts on the luminous material we *can* see. Additional evidence supports this claim as well. However, the nature of what dark matter is has yet to be understood. In this unit, we review the observational and theoretical evidence for dark matter, and describe the attempts that are under way to find it.

Video: Since Swiss astrophysicist Fritz Zwicky first inferred its existence in 1933, dark matter has remained one of the greatest unsolved mysteries in cosmology. Astronomical measurements have shown dark matter to be about 3/4ths of all matter, but at present it cannot be accommodated in the Standard Model of particle physics. See how both astrophysicists and particle physicists are developing more accurate methods of measuring the effects of dark matter and learn about their attempts to identify the particles or other phenomena responsible for it.

Featured scientists: Doug Finkbeiner (Harvard University)
Rick Gaitskell (Brown University)

Interactive Lab: *Evolution of Large Scale Structure in the Universe.* Experiment with different initial conditions to see what structures form, and try to build a universe similar to the one we live in today.

Unit 11. Dark Energy by Robert P. Kirshner

This unit focuses on one of the biggest questions in 21st century physics: what is the fate of the universe? In recent years, astronomers have been surprised to discover that the expansion of the universe is speeding up. We attribute this to the influence of a "dark energy" that may have its origin in the microscopic properties of space itself. Even very simple questions about dark energy, like "has there always been the same amount?" are very difficult to answer. Astronomers can observe the past but can only predict the future: If dark energy takes the simplest form we can think of, the universe will expand faster and faster, leaving our galaxy in a dark, cold, lonely place.

Video: Today's astronomical measurements show that dark energy makes up about 70% of the mass-energy in the universe. This deep mystery lies right at the heart of understanding gravity. See how observations that measure the history of cosmic expansion more precisely and the growth of lumpy structures in the universe are helping to pin down the nature of dark energy.

Featured scientists: Robert P. Kirshner (Harvard University)
David Spergel (Princeton University)

Interactive Lab: *Evolution of Large Scale Structure in the Universe*. Experiment with different initial conditions to see what structures form, and try to build a universe similar to the one we live in today.

Course Components

Facilitator-Led Components: On-Site Sessions

The *Physics for the 21st Century Facilitator's Guide* is intended to provide structure, resources, discussion questions, and activities for use in teacher professional development. These materials are designed to support a facilitator in creating an effective course for participants (practicing and/or future teachers). We recognize that these units will be (and are designed to be) tailored to local conditions. These materials may also be used as a self-study guide. These materials are based on research on student learning, best-practices in teacher education and professional development, and significant prior work in these content areas of modern physics.

The course consists of thirteen two-and-a-half hour sessions: an introductory unit, eleven content-focused units, and a review session. Each session has a consistent structure including pre-session assignments, descriptions of the unit, learning goals for participants, activities and discussions related to the content of the online text and videos, discussion of how to use these activities and topics in a high school classroom, connection to national standards and benchmarks, and online resources for further exploration. Each unit is developed based on principles of education research, and reviewed by experts in relevant fields. Below are the different components of each unit.

Introduction

Each unit includes a pertinent quotation from a scientist. You may wish to display this quotation in the beginning of the session for that unit. The introductory text summarizes the content of the unit, and how it relates more broadly to our understanding of the natural world.

What Will Participants Learn?

This section provides 3-4 learning goals which are intended outcomes for participants by the end of that unit. These goals are achieved primarily through the investigation of the activities in the unit, and by participating in discussions. The learning goals are directly related to the activities in that session, but assume that participants will also have read the online text and watched the video. Activities are built into each session to promote and support this pre-session work on the part of participants. The learning goals in each unit not only address the content knowledge that participants will learn, but also how that content relates to the nature of science (or, how science is done) and to classical physics.

What's in this Unit?

This section provides an overview of:

- The online text, and the key ideas covered
- The video, and the researchers highlighted therein
- The video extra, if there is one associated with the unit
- The interactive lab associated with the unit
- Activities in the unit, as well as suggested time length for each activity
- The nature of science theme associated with the unit

Important: The suggested activity times are approximate only! As each individual group of participants will vary quite widely in their familiarity with these sophisticated topics, as well as the kinds of activities that they find most enriching, the onus will be on the facilitator to determine how much or little to focus on a particular activity. In order to provide materials for a wide range of interests and knowledge levels, we have erred on the side of being *more* inclusive rather than less. This means that in most cases, facilitators may wish to choose to reduce the amount of coverage from that described. Use caution, as some activities build on the understanding from previous activities, and some learning goals are predicated on the completion of certain activities.

In-session viewing of the video: The timing allotted to each activity, above, assumes a two-and-a-half hour session length, with the video being viewed as part of that on-site session. If you have the flexibility to do so, we suggest assigning the video viewing as an at-home activity, with discussion of the video in-session. This allows participants to view the video at their own pace, and for session time to be used to make sense of that material.

Nature of science theme: Each unit has an associated nature of science theme, such as *Measurement & Observation* or *Logic & Implications*. These themes are described in the Introductory Unit. The online resource, *Facilitator's Guide High Resolution Graphics*, includes high-quality versions of the icons that accompany each theme, for use in handouts or digital presentations.

Exploring the Unit

THE HOOK

Each unit begins with a *Hook,* designed to pique participants' interest. These are intended to be short (10-15 minutes), and typically involve a striking visual, short demonstration or hands-on activity, or compelling question.

ACTIVITIES

Each unit includes between four and seven activities designed to help participants digest the content of the online text and video, and to achieve the learning goals outlined in *What Will Participants Learn*? These activities are based on principles of interactive engagement from the educational research literature, as well as the best practices in working with adult learners, who are able to direct their own learning and inquiry.

Each activity is organized into two main parts:

- ***To Do and To Notice.*** This contains instructions on what participants are meant to do, or questions for discussion.
- ***What's Going On?*** Here, both a description of the science, as well as the main points of the activity, are outlined. Answers to clicker questions, and explanations of what participants were meant to learn, are given.
  Take-home message. In most activities, especially longer ones, the main idea is encapsulated in a take-home message at the end of the *What's Going On?* portion of the activity.

This organization is intended to clearly separate the description of the activity from the discussion of the meaning of that activity. It is also intended to frame each activity as an exploration, rather than an exercise with clearly defined answers. This activity framing is borrowed from the Exploratorium's style at http://exploratorium.edu/snacks.

Some longer activities are divided into several numbered sub-sections, each with their own heading and *To Do and To Notice* and *What's Going On?* portions.

TYPES OF ACTIVITIES

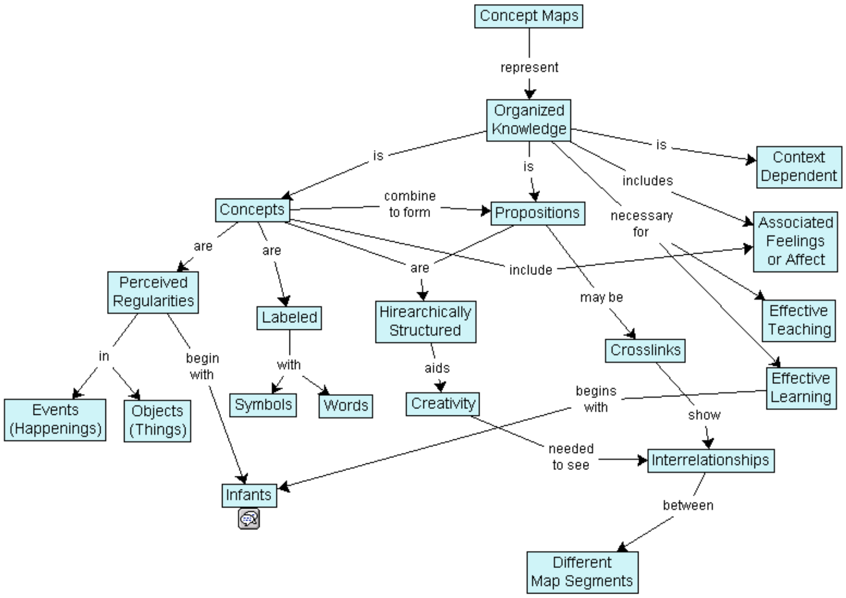
Activities take one of five main forms, as described below. All activities—except for discussion activities—are signaled in the text with an icon, so that facilitators are aware that additional equipment is needed at those times. Tips for facilitating the different types of activities are included in *HInts for Facilitators and Independent Learners*.

1. **Large or Small Group Discussion.** Participants are often asked to discuss concepts and problems in pairs, groups, or as a whole class. These discussions may take a more structured form, as described in the three formats below.

   Think-Pair-Share. In a Think-Pair-Share, participants are asked to *Think* about a question or questions on their own, *Pair* up to discuss it with a neighbor, and then *Share* the results of their discussion with the group as a whole.

   Jigsaw. In a jigsaw, individuals become experts on a particular topic or subtopic through reading or discussion in a group. Different groups are assigned different topics, so that different participants are experts on different topics. In this guide, we use a modified Jigsaw, where all smaller groups share their results with the larger group (rather than first rearranging into new small groups to share their expertise). This sharing of the individual pieces to develop a larger understanding on the part of the whole group is the essence of the jigsaw.

   Concept Mapping. A concept map is a diagram showing the relationship between a set of ideas, phrases, or concepts. The concepts are generally shown as circles or boxes, and connected with arrows or lines that are labeled to denote the relationship (such as "is a" or "results in" or "is an example of"). An example concept map is shown below.



Example Concept Map[1]

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[1] Source: (c) Wikimedia Commons, License: Gnu Free Documentation. Author: Vicwood40. http://commons.wikimedia.org/wiki/File:Conceptmap.gif

2. **Clicker/Discussion Questions.** These are another type of discussion strategy, but focused on a question. *Clicker* is another term for *classroom response system.* This is a technology-enabled means of asking a question to the class, allowing them to answer anonymously by pushing a button on an individualized remote, providing instantaneous feedback to the instructor and the participant, as well as a focal point for discussion. If clickers are not available, colored cards may be substituted. We promote the use of clickers in conjunction with *peer discussion*, rather than as a silent quiz-taking tool. As not every facilitator will have access to clicker hardware, we term these "clicker/discussion questions." All clicker questions are included in a form suitable for presentation software in the online resources.

CLICKER/DISCUSSION QUESTION

3. **Computer Simulations.** To assist learners with forming visual and conceptual models of the ideas in the units, we often include particularly illustrative or interactive computer simulations, many from the PhET project at http://phet.colorado.edu.

COMPUTER SIMULATION

4. **Hands-On Activities.** Several activities using physical manipulatives are included in this guide. These are called hands-on activities.

HANDS-ON ACTIVITY

5. **Watch and Discuss the Video.** The video is included in each unit, along with discussion questions. If you have the flexibility to do so, we suggest assigning participants to watch the video on their own, and reserving session time for discussion of the video. The location of *Watch and Discuss the Video* varies (i.e., it may be towards the beginning or towards the end of the session), depending on whether the activities are intended to help participants digest the content of the video, or to further explore the ideas described therein.

VIDEO

Back to the Classroom

Each unit contains the same questions for participants to consider:

- Where might this unit fit into your curriculum?
- What might your students know about this topic?
- Explore these topics on the Science Literacy Maps (see *Connection to National Standards,* below).

While the intent is that participants will brainstorm throughout the session how to bring these activities and topics into their classroom, this section provides a focused time to consider these important questions. It also provides a venue for participants to consider what common ideas their students might have about these topics, some of which may be complementary to instruction and some which may be contradictory.

This section also provides two valuable sub-sections: **Topics and Standards**, which lists the relevant concepts from the Science Literacy Maps (see *Connection to National Standards,* below), and **Classroom Resources**, which provides a list of exemplary online resources suitable for further exploration and/or classroom use.

Both of these sub-sections may be used as a jumping-off point for participant discussion. Participants may explore the Science Literacy Maps, and discover connections to other topics that they currently teach. You may wish to have participants look through several of the suggested *Classroom Resource* links, and report out to the group on the ones that they think would be most valuable.

Between Sessions

In preparation for the next session, participants are asked to both read the online text and to watch the video associated with the next unit. (Of course, if you plan to watch the video in class, then viewing of the video on their own is optional). It is suggested that the facilitator share the information from *What Will Participants Learn?* and the *Classroom Resources* sub-section of *Back to the Classroom* to guide participants' reading and exploration between sessions. You may also choose to have participants look through several of the suggested *Classroom Resource* links, and report to the group on the ones that they think would be most valuable at the beginning of the next session. This could be done as individuals or in teams, and can be a useful strategy to encourage participation and reading on the part of participants. It is particularly important that participants feel that the homework assignments are valuable, and will be used in the next session. See *Hints for Facilitators and Independent Learners,* below.

Hints for Facilitators and Independent Learners

General Hints

Creating a supportive learning environment. Be sure to give participants a chance to test their ideas about concepts in a non-threatening way. The material and concepts in this course are challenging. Solicit participant responses for questions, and hear from multiple people before explaining what answer you favor and why. Approach questions with a spirit of group curiosity, and seek to find the positive aspects of participants' answers as well as to correct misunderstandings of the material. Sometimes questions will arise that you, as the facilitator, do not know the answer to. This is a great opportunity to model how to deal with sophisticated and challenging questions for which you don't have the answer. "I don't know, but I know how to find out," is a great strategy for dealing with these types of questions. Another effective strategy to get at participant ideas is to ask, "What might your students say/think?" In addition, prompt participants to think about how these ideas and materials might be used in their classrooms.

Keep an eye on the clock. As described in *Course Components*, above, we have erred on the side of inclusivity in these materials. It's easy to lose track of the time and then run out of time before getting to key activities. Keep discussions focused. On the other hand, you don't want to cut valuable discussions short. Do your best to maintain a flexible balance between coverage of important concepts and allowing discussions to take their course.

Hints on Specific Course Elements

Hands-On Activities. Have enough materials for groups of 3-4 participants. If you have a document camera, you may use this to demonstrate material set-up in larger groups.

Videos. Be sure to check all videos and simulations on your computer before class on the computer that you will be using to project.

Simulations. Simulations can be valuable tools for visualization and exploration of ideas. However, if used as a demonstration, participants often do not come away with the most important ideas. Use simulations interactively, asking participants for suggestions on what to do with the simulation, questions they would like to answer with the simulation, and/or predictions ("what if" questions) of what will happen when you change a particular parameter in the simulation.

Clicker/Discussion Questions. Research on teaching and learning has shown that peer instruction (when two peers discuss a topic in order to better understand it) is a valuable method for facilitating learning. Thus, we recommend the use of clicker/discussion questions as a tool to facilitate peer instruction, rather than as a silent voting tool, especially if the concept is a difficult one. If the question is a review question, you may sometimes choose to have participants vote on their own. Some tips for successful use of clicker/discussion questions in the classroom:

1. Use them regularly. If participants are familiar with the process, they will feel more comfortable with peer discussion and voting.

2. Have participants discuss the questions with one another before they vote (peer instruction).
3. Allow 2-5 minutes per clicker question.
4. Facilitate a whole class discussion at the end of the question, and ensure that all participants know the correct answer at the end of that discussion. It is important to know not just why the right answer is right, but why the wrong answers are wrong.
5. Show the histogram of participant responses *after* the whole class discussion of the answer, unless the vote is clearly split across categories. This allows you to discuss all answer choices, before participants know how their peers voted. Remember, giving the answer shuts down participant thinking!

You can find many detailed resources on the use of clicker/discussion questions, including research on their use, clicker question banks, and short videos on best practices in the use of clickers, at http://STEMclickers.colorado.edu.

Think-Pair-Share, Clicker/Discussion Questions, Jigsaw—Facilitating Small-Group Discussion. Sometimes participants may be reluctant to talk to one another. Make it clear from the beginning that this is what we do in this course—discuss and debate ideas. This class is about reasoning and sense-making more than getting the answer. It's helpful to circulate around the room during a discussion to listen in, and to suggest additional questions for consideration. Be sure to allow adequate time for discussion, but pay attention to when discussion starts to turn to other things. Generally 2-4 minutes is adequate time for most discussions.

Think-Pair-Share, Clicker/Discussion Questions, Jigsaw— Facilitating Whole-Class Discussion. Oftentimes, participants are asked to discuss a question in small groups and then share out. This works well in smaller courses (under 10 participants), and allows the participants to take the role of teacher or facilitator for part of the course. However, with more than 10 participants in the course often a few people will tend to dominate. As a facilitator, you will need to be prepared to keep these participants in check, to keep the discussion within time limits, and allow all to participate. The use of clicker questions (see below) is intended to create an open environment where all feel comfortable discussing their ideas. Other techniques that you can use are requiring share-out from individual groups after participants discuss in pairs, or asking for an answer "from this side of the room." Whatever techniques you choose to use, set a clear example on the level of participation expected from all participants early in the course, and find techniques for allowing the more talkative participants to share their ideas without dominating conversation.

Between Sessions Assignments. It's important to provide participants incentive to complete the *Between Session* work before the next session. If session activities hinge on participants' completion of these assignments, then those who have not completed them will be motivated to do so the next time, and those who have completed it will be encouraged to continue. By the mid-point of a workshop series, this will allow engaging interactions between groups of participants who are, on the whole, dedicated to doing the work required to process the content of the course.

Notes for Individual Learners

If you are using this course as an individual learner for class credit, rather than enrolling in a synchronous course, you will need to translate the directions to facilitators in this guide in order to direct your own learning.

The separation of activities into *To Do and To Notice* and *What's Going On?* is designed to enable you to engage in the activities before seeking insight into the essential concepts and ideas in the activity—i.e., to not give the answer away. Thus, do the activities in *To Do and To Notice* before reading the discussions in *What's Going On?*

You can be creative in how you adapt these activities to your learning. You may wish to use the *Clicker/Discussion Questions* as guiding questions to answer through your reading and further exploration. You can do a jigsaw by choosing two topics and teaching them to a colleague at your school. You can create your own discussions by writing a short paragraph about your thinking on the topic. You may even choose to post this short paragraph on one of the many online discussion boards devoted to science topics, thus discussing with other individuals and broadening your understanding.

Note: You should still plan on a two-and-a-half hour long session devoted to each unit. This will include your viewing of the video associated with each unit as well as going through the unit's accompanying *Facilitator's Guide* activities. However, you should not include reading the online text or the other parts of the *Facilitator's Guide's Between Sessions* assignments in this two-and-a-half hour session.

For more information about obtaining graduate credit for independent study of the materials in this guide, see http://www.learner.org/workshops/graduate_credit.html.

Materials

For each session:

- Digital projector
- Classroom response (“clicker”) system (if you have one)
- High-quality graphics and Clicker/Discussion Questions from the online resource *Facilitator’s Guide High Resolution Graphics* (suitable for projection)

(*Note:* You do not need to be connected to the internet to run the PhET simulations described below. You may click “download” to download and run the simulations locally on your machine.)

Introductory Unit

The Hook: What We See Isn’t What We Get

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

Activity 1: Why Teach Physics?

- Nature of Science themes handout from the *Facilitator’s Guide High Resolution Graphics*
- Optional: Icons of Nature of Science themes from the *Facilitator’s Guide High Resolution Graphics*

Activity 2: The Shape of Things—Measurement & Observation

- 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)

Activity 3: How Do We Know? Evidence

- “What Can We Learn from a Tooth?” 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

Activity 5: Turning Gears—Logic & Implications

- Optional: Mirage toy (e.g., http://www.arborsci.com/prod-Mirage-210.aspx)

Activity 6: Rules of the Game—Coherence & Consistency

- Image of puzzle and solution from the *Facilitator’s Guide High Resolution Graphics*

Back to the Classroom

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

Unit 1: The Basic Building Blocks of Matter

The Hook: Our World as an Atom

- Tennis ball
- Computer with internet access

Activity 1: Revisiting *"The Shape of Things"* – Particle Accelerators

- *The Shape of Things* apparatus from the Introductory Unit

Activity 2: The Particle Zoo

- Optional: Handout of example concept map from online resources
- Optional: Physical cutouts of words for concept map

Activity 3: Quark Math

- Quark cards (3 copies for each group 3-4) from *Facilitator's Guide High Resolution Graphics*

Between Sessions

- Optional: Handout for table of the fundamental forces

Unit 2: The Fundamental Interactions

Activity 1: What is a Field? What is a Force?

- "Electric Field Hockey" PhET simulation http://phet.colorado.edu/simulations/sims.php?sim=Electric_Field_Hockey
- Optional: "Charges and Fields" PhET simulation http://phet.colorado.edu/simulations/sims.php?sim=Charges_and_Fields
- Optional: Van de Graaff generator
- Optional: Mylar balloon
- Optional: String

Activity 2: Feynman Theater

- 1-2 tennis balls
- Optional: skateboards

Unit 3: Gravity

The Hook: Defying Gravity (It's not so hard!)

- *Note:* you may choose the demonstration based on the materials available
- "Flying tinsel": an object like a piece of PVC or block of blue foam insulation; wool; tinsel
- "Balloon": balloon; wool
- "Magnets": paperclip; magnet
- "Surface Tension": pepper

Activity 1: The Problem with Newton's Law

- Butcher paper (or other large sketch paper)
- "Radio Waves and Electromagnetic Fields" PhET simulation http://phet.colorado.edu/simulations/sims.php?sim=Radio_Waves_and_Electromagnetic_Fields

Activity 4: Curved Spacetime

- *Note:* the model from this activity will be re-used in Units 4 and 10
- 5x5 foot spandex sheet, marked with a grid
- Dowels
- Marbles
- Safety pins
- Masses on hooks
- Beach ball marked with a grid

Activity 5: Fall into a Black Hole (optional)

- "Journey into a Schwarzschild Black Hole" simulation http://jila.colorado.edu/~ajsh/insidebh/schw.html

Unit 4: String Theory and Extra Dimensions

The Hook: Collapse the Dimensions

- A long (10 meters) rope at least 5mm thick, or garden hose, or phone cord, or a long strip of paper
- Two thumbtacks or pins with diameters smaller than the rope
- Pieces of paper for each participant
- A very small rubber band

Activity 1: Tiny Things Cause Big Problems

- Spandex model from Unit 3

Activity 2: What are Strings?

- One 25-foot length of rubber tubing for every two participants (or a coiled phone cord or soft and pliable rope)
- A Slinky® for every two participants
- A set of nesting Russian/Dutch dolls or nesting boxes

Between Sessions: Mini Lesson

- "The Photoelectric Effect" PhET Simulation http://phet.colorado.edu/simulations/sims.php?sim=Photoelectric_Effect
- "Quantum Wave Interference" PhET Simulation http://phet.colorado.edu/simulations/sims.php?sim=Quantum_Wave_Interference

Unit 5: The Quantum World

The Hook: How To Make Something Really Cold

- Ping-pong balls (about 15)
- 5 marbles
- An enclosure, such as a hula hoop
  Note: you may use different types of balls depending on your available materials

Activity 2: Photoelectric Effect (Optional)

- Digital projector
- "Photoelectric Effect" PhET simulation http://phet.colorado.edu/simulations/sims.php?sim=Photoelectric_Effect

Activity 3: The Wave/Particle Nature of Light

- Digital Projector
- "Quantum Wave Interference" PhET simulation http://phet.colorado.edu/simulations/sims.php?sim=Quantum_Wave_Interference

Activity 4: Matter is a Wave (But What's Waving?)

- "Quantum Wave Interference" PhET simulation http://phet.colorado.edu/simulations/sims.php?sim=Quantum_Wave_Interference

Unit 6: Macroscopic Quantum Mechanics

The Hook: Superfluid Coffee

- Mug of coffee or other liquid
- Video of superfluid helium (e.g. http://www.youtube.com/watch?v=2Z6UJbwxBZI)

Activity 1: Models of the Atom

- Optional: "How can atoms exist?" video from Alice and Bob's Adventures in Wonderland http://www.perimeterinstitute.ca/en/Outreach/Alice_and_Bob_in_Wonderland/Alice_and_Bob_in_Wonderland/
- Optional: Handout of different models of the atom from online resources

Activity 2: Periodic Chessboard

- Butcher paper
- Colored markers
- 30 small paper or plastic cups
- Copy of the periodic table
- Tape
- Copy of atomic orbital simulation http://www.falstad.com/qmatom/

Activity 4: Bose-Einstein Condensates

- Marbles and an enclosure (from Unit 5)
- Animation of the Bose-Einstein condensation at http://www.colorado.edu/physics/2000/bec/images/evap2.gif
- Optional: Video "Bose-Einstein Condensate" from BBC with Dan Kleppner http://www.youtube.com/watch?v=bdzHnApHM9A&feature=related
- Optional: "Quantum Bound States" PhET simulation http://phet.colorado.edu/simulations/sims.php?sim=Quantum_Bound_States

Unit 7: Manipulating Light

Activity 1: Slowing Light

- Internet access or downloaded simulation from http://webphysics.davidson.edu/applets/Superposition/GroupVelocity.html or http://galileo.phys.virginia.edu/classes/109N/more_stuff/Applets/sines/GroupVelocity.html)

Activity 3: Entangled Socks

- Two identical boxes (any size)
- Two different colored socks (such as pink and blue)

Unit 8: Emergent Behavior in Quantum Matter

The Hook: Who's the Leader?

- Images and video of flocking birds or schools of fish

Activity 3: To See the World in a Grain of Sand

- Circular fruit-flavored cereal (such as Froot Loops®)
- Rice
- Sugar
- Variety of funnels (1/4" opening works well)

- Cups
- Shallow containers
  Note: You will use the cereal again in Unit 9, so get plenty

Activity 4: Hard Condensed Matter

- Pitcher of water
- Circular fruit-flavored cereal (such as Froot Loops®)
- Bowls

Unit 9: Biophysics

The Hook: Big Forces at Small Distances

- A heavy ball (e.g. steel ball)
- A light ball (e. g. ping-pong ball)
- Digital projector
- “Gas Properties” PhET simulation
  http://phet.colorado.edu/simulations/sims.php?sim=Gas_Properties

Activity 1: Life and the Second Law

- Latex gloves (enough for every one or two participants)
- Digital projector
- “Stretching DNA” PhET simulation
  http://phet.colorado.edu/simulations/sims.php?sim=Stretching_DNA

Activity 2: Breakfast Proteins

- Fruit-flavored donut-shaped cereal (such as Froot Loops®)
- Chenille stems
- String
- Scissors
- Pencil
- Paper

Activity 5: Pulling it Together

- “Find the Highest Note” http://www.exploratorium.edu/exhibits/highest_note/
- Optional: related files at http://asa.aip.org/demo27.html
- Optional: Traveling salesman route through Germany from *Facilitator’s Guide High Resolution Graphics*

Unit 10: Dark Matter

The Hook: More Than We Can See

- Visualization of the Sloan Digital Sky survey
- Optional: example concept map from *Facilitator’s Guide High Resolution Graphics*

Activity 1: PhET My Solar System” PhET Simulation

- Tennis ball on string
- “My Solar System” PhET simulation
  http://phet.colorado.edu/simulations/sims.php?sim=My_Solar_System

Activity 2: Gravitational Lensing

- One or several wine glasses with a curved bottom
- Spandex model from Unit 3

- Heavy object (e.g. a stapler)
- Tennis ball
- Graph paper
- Optional: Images of light bending by a lens and light bending by gravity from *Facilitator's Guide High Resolution Graphics*

Unit 11: Dark Energy

The Hook: The Night Sky is Dark

- Optional: "Why is it dark at night?" video http://www.perimeterinstitute.ca/en/Outreach/Alice_and_Bob_in_Wonderland/Alice_and_Bob_in_Wonderland/

Activity 2: How Far Away Is It?

- Optional: Light meter

Activity 3: How Fast Is It Moving?

- Football or other ball with embedded buzzer (or a buzzer on a string)
- "Wave Interference" PhET simulation http://phet.colorado.edu/simulations/sims.php?sim=Wave_Interference
- Optional: "Sound" PhET simulation
- http://phet.colorado.edu/simulations/sims.php?sim=Sound
- Optional: "Doppler Shift" simulation http://scatter.colorado.edu/STEM-TPSoft/

Activity 4: The Universe is Expanding

- Balloons
- Paper
- Tape
- Hubble Plot and Closed/Open Universe plot (from the text)
- Optional: Transparencies and overhead projector, and image from http://www.exo.net/~pauld/activities/astronomy/ExpandingUniverse.html
- Optional: Digital image of expanding dots from *Facilitator's Guide High Resolution Graphics*

Activity 5: Looking Back in Time (Optional)

- Drawing paper
- Optional: "Is that star really there?" from Alice and Bob's Adventures in Wonderland http://www.perimeterinstitute.ca/en/Outreach/Alice_and_Bob_in_Wonderland/Alice_and_Bob_in_Wonderland/

Review Unit

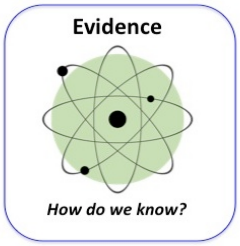
Activity 1: How Does It Hook Together?

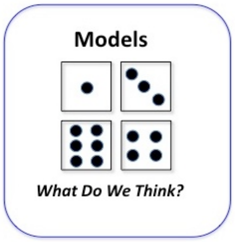
- Butcher paper
- Index cards
- Markers
- Digital camera
- Optional: Handout of recommended concept-mapping terms from *Facilitator's Guide High Resolution Graphics*

Connection to National Standards
and Nature of Science Themes

Each unit has an associated theme related to the Nature of Science—or, the views that the scientific community has about the natural world and how we can study it. The frontiers of research provide a natural platform for discussing the nature of the scientific enterprise and investigation. These themes also help support the science standards regarding the nature of science. See the Introductory Unit for more information on these themes, and how they relate to the content of this course. High quality versions of the icons for these themes are available in the online resource: *Facilitator's Guide High Resolution Graphics*.

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





In order to provide alignment with the National Science Education Standards (NSES), and the American Association for the Advancement of Science (AAAS) Project 2061 Benchmarks, we have provided linkages of the topics in each unit to the AAAS Atlas of Science Literacy. These Science Literacy Maps form a tool for teachers to find how topics relate to specific science and math topics, and how concepts build upon one another across grade levels. The online versions of these Science Literacy Maps are found at http://strandmaps.nsdl.org. Each unit ends with recommendations that participants explore the online Science Literacy Maps, and gives a list of relevant concepts from those maps. *Note:* The text in the Science Literacy Maps is primarily derived from the Project 2061 Benchmarks, in conjunction with the NSES.

	Unit										
	1	2	3	4	5	6	7	8	9	10	11
Forces and Motion											
If a force acts towards a single center, the object's path may curve into an orbit around the center (centripetal motion).			✓							✓	
Gravitational force is an attraction between two masses; its strength is proportional to the masses and weakens rapidly with distance.										✓	✓
The change in motion of an object is proportional to the applied force and inversely proportional to the mass (F=ma).			✓						✓	✓	
All motion is relative to whatever frame of reference is chosen.			✓								✓
An unbalanced force acting on an object changes its speed, or direction of motion, or both.	✓	✓							✓		
Any object maintains a constant speed and direction unless an unbalanced force acts on it.		✓	✓						✓		
The idea of absolute motion or rest is misleading.			✓								
Energy											
The total amount of energy in a system remains constant if no energy is transferred in or out.	✓				✓	✓				✓	
Energy appears in many forms (such as kinetic and potential).					✓	✓			✓	✓	
Thermal energy in a system is associated with the disordered motions of its atoms or molecules.					✓	✓			✓		
Chemical energy is associated with the configuration of atoms in molecules that make up a substance.								✓	✓		
The total amount of order in the universe always tends to decrease.									✓		
Electricity and Magnetism											
Moving electrically charged objects produce magnetic forces.	✓										
The nuclear forces that hold the protons and neutrons in the nucleus of an atom are much stronger than the electric forces between the protons and electrons of the atom.		✓		✓							

	1	2	3	4	5	6	7	8	9	10	11
Electric forces hold solid and liquid materials together and act between objects when they are in contact—as in sticking or sliding friction.		✓									
Electric forces acting within and between atoms are vastly stronger than the gravitational forces acting between atoms.		✓	✓	✓					✓		
At larger scales, gravitational forces accumulate to produce a large and noticeable effect, whereas electric forces tend to cancel.		✓	✓								
In many conducting materials, such as metals, some of the electrons are not firmly held by the nuclei of the atoms that make up the material.						✓					
At very low temperatures, some materials become superconductors and offer no resistance to the flow of electrons.						✓		✓			
Atoms and Molecules											
Atoms are made of protons, neutrons and electrons.	✓			✓		✓					
Scientists continue to investigate atoms and have discovered even smaller constituents of which neutrons and protons are made.	✓	✓		✓							
The nuclear forces that hold the protons and neutrons in the nucleus of an atom are much stronger than the electric forces between the protons and electrons of the atom.		✓		✓							
Atoms are made of a positively charged nucleus surrounded by negatively charged electrons.					✓	✓					
An atom's electron configuration, particularity the outermost electrons, determines how the atom can interact with other atoms.						✓					
When elements are listed in order by the masses of their atoms, the same sequence of properties appears over and over again in the list.						✓					
Size and Scale											
When describing and comparing very small and very large quantities, express them using powers-of-ten notation.	✓	✓		✓						✓	✓
Natural phenomena often involve sizes, durations, or speeds that are extremely small or extremely large.	✓	✓		✓	✓				✓	✓	✓
Gravity											
Gravitational force is an attraction between two masses; the strength of the force is proportional to the masses and weakens rapidly with distance between them.		✓	✓								
Gravity is the force that keeps planets in orbit around the sun.		✓	✓								

	1	2	3	4	5	6	7	8	9	10	11
Everything on or anywhere near the Earth is pulled towards the Earth's center by gravitational force.		✓	✓								
Electric forces acting within and between atoms are vastly stronger than the gravitational forces acting between atoms.			✓								
At larger scales, gravitational forces accumulate to produce a large and noticeable effect, whereas electric forces tend to cancel.			✓								
Waves and Light											
For an object to be seen, light must be emitted by or scattered from it.										✓	
Visible light is a small band in the electromagnetic spectrum.							✓			✓	✓
The observed wavelength of a wave depends on the relative motion of the source and the observer.											✓
Wave behavior can be described in terms of how fast the disturbance spreads, and in terms of the wavelength.					✓	✓					
The wavelength of light varies from radio waves, the longest, to gamma rays, the shortest.					✓						
Light acts like a wave in many ways.					✓	✓	✓				
Waves can superpose on one another, bend around corners, reflect off surfaces, be absorbed by materials they enter, and change direction when entering a new material.							✓				
The energy of waves (like any form of energy) can be changed into other forms of energy.							✓				
The Universe											
Galaxies are made of billions of stars and are most of visible mass of universe.											
The Big Bang theory suggests that the universe began 10-20 billion years ago in a hot dense state.				✓						✓	✓
Some distant galaxies are so far away that their light takes several billion years to reach the Earth										✓	
Astronomers believe the whole universe is expanding				✓							✓
Historical Perspectives											
Isaac Newton, building on earlier descriptions of motion by Galileo, Kepler, and others, created a unified view of force and motion in which motion everywhere in the universe can be explained by the same few rules.			✓								
Among the counterintuitive ideas of special relativity is that the speed of light is the same for all observers. In addition, nothing can travel faster than the speed of light.			✓				✓				

	1	2	3	4	5	6	7	8	9	10	11
Einstein's development of the theories of special and general relativity ranks as one of the greatest human accomplishments in all of history. Many predictions from the theories have been confirmed on both atomic and astronomical scales.			✓								
A decade after Einstein developed the special theory of relativity, he proposed the general theory of relativity, in which the gravitational force is a distortion of space and time.			✓	✓							
The Mathematical World											
How probability is estimated depends on what is known about the situation.					✓	✓					
States of Matter											
A system usually has some properties that are different from those of its parts, but appear because of the interaction of those parts.								✓			
Different arrangements of atoms into groups compose all substances and determine the characteristic properties of substances.						✓	✓	✓			
Atoms may link together in well-defined molecules, or may be packed together in crystal patterns.								✓			
An enormous variety of biological, chemical, and physical phenomena can be explained by changes in the arrangement and motion of atoms and molecules.						✓	✓	✓			
Systems											
Most systems above the molecular level involve so many parts that it is not practical to determine the existing conditions, and thus the precise behavior of every part of the system cannot be predicted. Even in some very simple systems, it may not always be possible to predict accurately the result of changing some part or connection.								✓			
As the number of parts in a system grows in size, the number of possible internal interactions increases much more rapidly, roughly with the square of the number of parts.								✓			
Nature of Science											
Scientific investigations usually involve the collection of relevant data, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected data.			✓	✓		✓					

	1	2	3	4	5	6	7	8	9	10	11
Observation, evidence, and logic are important in the interpretation of experimental results.	✓		✓	✓						✓	✓
New technologies make it possible for scientists to extend their research in new ways or to undertake entirely new lines of research; technology often sparks scientific advances.							✓				
Investigations are conducted for different reasons, including to explore new phenomena.							✓				
The selection of appropriate measurement and observation tools is important in answering a particular experimental question.										✓	
Increasingly sophisticated technology is used to learn about the universe.										✓	
Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.		✓		✓		✓		✓		✓	✓
A mathematical model uses rules and relationships to describe and predict objects and events in the real world.		✓						✓			
A scientific model is judged, in part, by its power to predict the outcome of experiment. Theories shift as new observations show inconsistencies or flaws in the previous model.	✓		✓	✓	✓	✓		✓			
Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations.					✓	✓		✓		✓	✓
From time to time, major shifts occur in the scientific view of how the world works. More often, however, the changes that take place in the body of scientific knowledge are small modifications of prior knowledge.			✓					✓			
Values in Science											
Curiosity motivates scientists to ask questions about the world around them and seek answers to those questions. Being open to new ideas motivates scientists to consider ideas that they had not previously considered. Skepticism motivates scientists to question and test their own ideas and those that others propose.				✓							
Scientists value evidence that can be verified, hypotheses that can be tested, and theories that can be used to make predictions.				✓							
To be useful, a hypothesis should suggest what evidence would support it and what evidence would refute it.				✓							

About the Contributors

Note: More detailed information about all the contributors may be found in the *Physics for the 21st Century* course materials on-line at www.learner.org.

Course Developer

Christopher Stubbs: Harvard University
Christopher Stubbs is an experimental physicist working at the interface between particle physics, cosmology, and gravitation. His interests include experimental tests of the foundations of gravitational physics, searches for dark matter, and observational cosmology.

Course Liaison

Claire Cramer: National Institute of Standards and Technology
Claire Cramer is a physicist at the National Institute of Standards and Technology. Her work centers around developing novel techniques for using lasers to improve the precision of astronomical measurements, with applications to dark energy surveys, finding and characterizing extrasolar planets, and mapping dark matter within our galaxy.

Content Developers

UNIT 1
Natalie Roe: Lawrence Berkeley National Laboratory
Natalie Roe is a senior scientist in the physics division at the Lawrence Berkeley National Laboratory, a fellow of the American Physical Society, and former Chair of the APS Division of Particles and Fields. Roe has worked on a variety of particle physics experiments at CERN, Fermilab, and SLAC.

UNIT 2
David Kaplan: Johns Hopkins University
David E. Kaplan is a professor in the Department of Physics and Astronomy of Johns Hopkins University. His primary research interests are in theoretical particle physics with particular focus on electroweak superconductivity and potentially related physics such as supersymmetry, new fundamental forces, extra dimensions, and dark matter.

UNIT 3
Blayne Heckel: University of Washington
Blayne Heckel is professor of physics and chair of the Department of Physics at the University of Washington. His research interests focus on tests of fundamental symmetries: torsion balance tests of spatial isotropy, the equivalence principle, and the gravitational inverse square law, and searching for time reversal symmetry violation in the electric dipole moments of atoms.

UNIT 4
Shamit Kachru: Stanford University
Shamit Kachru is a professor of physics at Stanford University. His research interests include string theory and quantum field theory, and their applications in cosmology, condensed matter physics, and elementary particle theory.

UNIT 5
Daniel Kleppner: Massachusetts Institute of Technology
Daniel Kleppner is the Lester Wolfe Professor of Physics, Emeritus at MIT. He is the founding Director of the MIT-Harvard Center for Ultracold Atoms, funded by the National Science Foundation. He is the coauthor of two textbooks and the recipient of the Oersted Medal of the National Association of Physics Teachers and of the National Medal of Science.

UNIT 6
William P. Reinhardt: University of Washington
William P. Reinhardt is a professor of chemistry and adjunct professor of physics at the University of Washington. His research is in two main areas: (1) modeling the structure and dynamics of the newest state of matter, the gaseous Bose-Einstein condensate (BEC); and (2) development of novel techniques for determination of the entropies and free energies of complex molecular systems, including clusters and polymers.

UNIT 7
Lene Hau: Harvard University
Lene Vestergaard Hau is the Mallinckrodt Professor of Physics and of Applied Physics at Harvard University. Prior to joining the Harvard faculty in 1999, she was a member of the scientific staff at the Rowland Institute for Science at Harvard in Cambridge, Massachusetts. She earned a Ph.D. in physics from the University of Aarhus, Denmark.

UNIT 8
David Pines: UC Davis and University of Illinois at Urbana-Champaign
David Pines is the founder and co-director of the Institute for Complex Adaptive Matter (http://icam-i2cam.org), a global institute with over 60 branches worldwide, dedicated to promoting research and education in emergent behavior in matter and society. He is also a Distinguished Professor of Physics at UC Davis, where he teaches one quarter every year, and Research Professor of Physics and Professor Emeritus of Physics and Electrical and Computer Engineering in the Center for Advanced Study, University of Illinois at Urbana-Champaign, where he was a faculty member from 1959-1999.

UNIT 9
Robert H. Austin: Princeton University
Robert H. Austin is a researcher in the Department of Physics of Princeton University, who probes the biological limits of evolving organisms under stress. His research focuses primarily on the use of microarrays and nanotechnology to further our physical understanding of biological processes, such as the dynamics of cells when subjected to stress. He ultimately wants to understand, and possibly guide, the evolution of microrganisms by culturing them inside custom-made microenvironments.

UNIT 10
Peter Fisher: Massachusetts Institute of Technology
Peter Fisher is a professor of physics and division head of Particle and Nuclear Experimental Physics at MIT. His main activities are the experimental detection of dark matter using a new kind of detector with directional sensitivity.

UNIT 11
Robert P. Kirshner: Harvard University
Robert P. Kirshner is Clowes Professor of Science at Harvard University. Professor Kirshner is an author of over 250 research papers dealing with supernovae and observational cosmology. His work with the "High-Z Supernova Team" on the acceleration of the universe was dubbed the "Science Breakthrough of the Year for 1998" by *Science Magazine*.

Facilitator's Guide Developers

Stephanie Chasteen: University of Colorado at Boulder and sciencegeekgirl enterprises
Stephanie Chasteen is a science teaching fellow at the University of Colorado at Boulder, funded through the Science Education Initiative, and owns and operates an independent science education consulting business. Her primary interests are in creating effective teacher professional development programs and in engaging the public in scientific inquiry. She earned her PhD in condensed matter physics from the University of California at Santa Cruz. Her interest in communicating science to the public led her to an AAAS Mass Media Fellowship at National Public Radio's science desk in Washington, D.C. She was a postdoctoral fellow in the Teacher Institute at the Exploratorium Museum of Science, Art, and Human Perception in San Francisco where she produced teacher workshops and several audio podcast series, one of which won Best Professional Development Podcast from *The Teacher's Podcast*. She has created over 50 feature articles, academic publications, and videos, and over 60 audio podcasts, primarily aimed at K-14 teachers or the general public. Her research on student learning and educational reform has been published in key journals in the field. She maintains a popular blog on science education at http://sciencegeekgirl.com.

Noah Finkelstein: University of Colorado at Boulder
Noah Finkelstein is currently an associate professor of Physics at the University of Colorado at Boulder and conducts research in physics education. He received a Bachelor's degree in mathematics from Yale University and his PhD. for work in applied physics from Princeton University. He serves as a director of the Physics Education Research (PER) group at Colorado, one of the world's largest research groups in physics education. Finkelstein is PI or Co-PI for many nationally funded research grants to create and study conditions that support students' interest and ability in physics. These research projects range from the specifics of student learning to the departmental and institutional scales, and have resulted in over 70 publications. Finkelstein is also a co-PI and a Director of the Integrating STEM Education initiative (iSTEM), an NSF-i3 funded program to establish a Center for STEM education. Finkelstein serves on five national boards in physics education, including: the Physics Education Research Leadership Organizing Council, and the Committee on Education of the American Physical Society. In 2007 he won the campus-wide teaching award and in 2009 he won the campus Diversity and Excellence award. More on Noah can be found at http://spot.colorado.edu/~finkelsn.