Annenberg/CPB
Professional Development Course Guide

Essential Science for Teachers

Physical Science

An eight-part professional development course
for K-6 science teachers

Produced by the Harvard-Smithsonian Center for Astrophysics

Essential Science for Teachers: Physical Science

is produced by
the Harvard-Smithsonian Center for Astrophysics

ISBN: 1-57680-763-0

Funding for
Essential Science for Teachers: Physical Science
is provided by Annenberg/CPB.

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About the Course

Course Overview

What does a block of wood have in common with a cluster of galaxies billions of light years away? What about a giant sequoia tree in a rare coastal rainforest and the grains of sand found on beaches all over the world? The answer lies in what each is made of—matter. Matter is a fundamental concept in all of the sciences that links the infinitesimal world observed under a microscope to the vast reaches of space revealed by the world's most powerful telescopes. It is what we and everything else are made of.

Matter is a topic that can be an integral and engaging part of science learning at all educational levels—starting in grades K-6 or even earlier. In the elementary school, a study of matter provides the foundation for understanding the physical nature of all things. *Essential Science for Teachers: Physical Science* is a content course designed to help K-6 teachers enhance their understandings of matter as one of the "big ideas" in the physical sciences. The main goal of this course is to provide teachers with learning opportunities that will directly inform their own classroom practice. To do this, the course addresses concepts that are appropriate at a variety of grade levels and does so in a cyclical manner, revisiting concepts at more sophisticated levels as the course progresses.

Essential Science for Teachers: Physical Science is one in a series of three video-, print-, and Web-based science courses for elementary school teachers. These courses will help teachers better understand the science concepts that underlie the content they teach. Other courses include *Essential Science for Teachers*: *Life Science* and *Essential Science for Teachers: Earth and Space Science.*

Essential Science for Teachers: Physical Science is composed of eight three-hour sessions, each with a one-hour video program addressing a topic related to matter that is likely to be part of any elementary school science curriculum. Posing the question "What is matter?", the course begins by generating a working definition of matter, followed by an introduction to the properties of matter and classification. Next, the course focuses on modeling in science by looking at historical models of matter followed by a close examination of the model that is used today: the particle model. Participants look at what happens on a molecular level when matter changes state or is mixed with other matter, which leads to a distinction between physical and chemical changes. Then, the particle model is extended to explore why matter rises or sinks. Finally, the course highlights the difference between heat and temperature, and participants extend their understanding of the particle model to explain additional macroscopic phenomena.

Essential Science for Teachers: Physical Science also focuses on the ideas that children bring to the classroom about these topics. In order to keep the content grounded at the elementary school level, we interview and observe children in a clinical setting—what we call the "Science Studio"—to uncover their thinking. The research literature confirms that their ideas are typical of students in the K-6 age group. The video content is supplemented by a bibliography that suggests readings from the research literature.

Each program also features one or more elementary school classrooms where teachers and students explore concepts using exemplary curriculum materials. A curriculum spokesperson may be interviewed to provide insight into the importance of the topic at the elementary school level. Finally, interviews with one or more scientists and/or science historians offer applications of important concepts to real-world examples, past and present.

By exploring topics that range from the essential properties of aluminum foil to the plasma that makes up the Sun, *Essential for Teachers: Physical Science* strives to provide participants not only with enhanced content knowledge, but also with understandings of how this content connects to the elementary school classroom.

About the Course, cont'd.

Session Descriptions

Session 1. What Is Matter? Properties and Classification of Matter

Matter is all around us—it's what we and everything else are made of. Yet how do we define matter? What are the properties of matter that set it apart from something that is definitely *not* matter, like light? In this session, participants build a working definition of matter, distinguish among the different forms it can take, investigate the difference between "essential" and "accidental" properties of matter, and look at the role of classification in science.

Session 2. The Particle Nature of Matter: Solids, Liquids, and Gases

What simple idea links together all of chemistry and physics? How can a close study of the macroscopic differences among solids, liquids, and gases support a microscopic model of tiny, discrete, and constantly moving particles? In this session, participants learn how the "particle model" can be turned into a powerful tool for generating predictions about the behavior of matter under a wide range of conditions.

Session 3. Physical Changes and Conservation of Matter

What happens when sugar is dissolved in a glass of water or when a pot of water on the stove boils away? Do things ever really "disappear"? In everyday life, observations that things "disappear" or "appear" seem to contradict one of the fundamental laws of nature: matter can be neither created nor destroyed. In this session, participants learn how the principles of the particle model are consistent with conservation of matter.

Session 4. Chemical Changes and Conservation of Matter

How can the particle model account for what happens when two clear liquids are mixed together only to produce a milky-white solid? What happens when iron rusts? Where do the elements come from? In this session, participants extend the particle model by looking inside the particles, learn about some early chemical pioneers, and in the process discover how the law of conservation of matter applies even at the scale of atoms and molecules.

Session 5. Density and Pressure

What makes a block of wood rise to the surface of a bucket of water? Why do your ears pop when you swim deep underwater? In this session, participants examine density, an essential property of matter. They also look at how particles of matter are in constant motion, which leads to a deeper understanding of fluid pressure. Lastly, the concepts of pressure and density are investigated to explain the macroscopic phenomenon of rising and sinking.

Session 6. Rising and Sinking

Why does a hot air balloon rise into the sky? Why does ice rise in water, when a lump of solid wax will sink in a jar full of molten wax? In this session, participants generalize the model that has been developed about what rises and what sinks, using the idea of balance of forces.

Session 7. Heat and Temperature

What makes the liquid in a thermometer rise or fall in response to temperature? Which contains more heat—a boiling teakettle on the stove or a swimming pool of lukewarm water? In this session, participants focus on the difference between heat and temperature, and examine how both are defined in terms of particles. The particle model is then used to explain a number of everyday phenomena, from why things expand when they are heated to the role that temperature plays in changes of state.

Session 8. Extending the Particle Model of Matter

In this session, participants extend their understanding of the particle model to explain additional macroscopic phenomena, including the electrical properties of matter. Participants review the progression of ideas covered in the course and anticipate future developments in the understanding of matter.

About the Course, cont'd.

Featured Classrooms

Session 1

Fayerweather Street School, Cambridge, Massachusetts

Joanie Grisham's first and second graders have a group discussion in which they begin to construct a working definition of matter.

Blanchard Memorial Elementary School, Boxborough, Massachusetts

Cindy Plunkett's first graders examine a variety of solids and classify them according to their properties. The students then explain their classification schemes to one another.

Saltonstall School, Salem, Massachusetts

Chris Bash's fourth and fifth graders explore the properties of a "mystery substance" that blurs the line between a solid and a liquid.

Session 2

Joseph P. Mulready School, Hudson, Massachusetts

Linsey Newton's third grade class grapples with possible explanations of changes of state by observing the evaporation and condensation of water.

Cabot School, Newtonville, Massachusetts

Russell Springer's fifth graders seek to understand the constant motion of particles by modeling the behavior of water molecules surrounding a droplet of oil.

Session 3

Benjamin Banneker Charter School, Cambridge, Massachusetts

Rosinda Almeida's second graders conduct a "dissolving race" between sugar in warm and cold water to see under which conditions it "disappears" faster.

Session 4

Portsmouth Middle School, Portsmouth, Rhode Island

Rebecca Cituk's sixth graders add baking soda to vinegar to create a chemical change, and then predict whether the resulting substance will weigh more or less than its component parts.

Session 5

Thompson School, Arlington, Massachusetts

Understandings of Consequences Project (UCP) curriculum developer Tina Grotzer leads Nicole Scalzo's fifth-grade class through the UCP "Causal Patterns in Density" lesson, in which they observe the macroscopic effects of density and draw their own models for its microscopic explanation.

Session 6

Young Achievers Science and Mathematics Pilot School, Boston, Massachusetts

Third graders in Monique Brinson's class try to make "slow sinkers" using the Education Development Center's Insights "Liquids" curriculum.

About the Course, cont'd.

W.H. Lincoln Elementary School, Brookline, Massachusetts

Joe Reilly's first graders get us thinking about objects "floating" in air with a parachute-making activity.

Session 7

Roosevelt School, Worcester, Massachusetts

Science facilitator Paula Proctor and teacher Gina Robertson use Delta Education's "States of Matter" curriculum to explore the effects of heat on the volume of liquid in a thermometer with Gina's sixth graders.

Session 8

Independent Elementary School, Castro Valley, California

Linda Block's fifth graders investigate the electrostatic properties of a variety of materials both in their classroom and on a field trip to the Exploratorium.

Course Components

On-Site Activities

Essential Science for Teachers: Physical Science consists of eight sessions (see Note below), each of which includes group activities and discussions as well as an hour-long video program.

Weekly sessions, which should be scheduled for approximately three hours, may be scheduled around live broadcasts, in which case you will want to begin at least 60 minutes before the scheduled broadcast. You may prefer to pre-record the programs on videocassette and schedule the sessions at a time that is more convenient for all participants and that would allow you to stop and restart the video as you discuss it.

This guide provides activities and discussion topics for pre- and post-viewing investigations that complement each of the eight one-hour video programs.

Getting Ready (Site Investigation)

In preparation for watching the program, you will engage in 60 minutes of investigation through discussion and activity.

Watch the Course Video

Then, you will watch the 60-minute video, which includes classroom footage, commentary, science demonstrations, and more.

Going Further (Site Investigation)

Wrap up the session with an additional 60 minutes of investigation through discussion and activity.

Note: See the Scheduling Course Sessions section for suggestions for scheduling the eight programs into an intensive 15-week course.

Course Components, cont'd.

Between Sessions

Homework Assignments

Each session will contain some or all of the following homework activities. All participants should complete the assignments marked with *—the Reading Assignment, the Problem Set, the Ongoing Concept Mapping, and Preparing for the Next Session. Participants taking the course for graduate credit must complete all of the listed assignments, including those described in the Graduate Course Requirements section.

Note: Required Hours for Graduate Credit: If you are taking this course for graduate credit, the complete set of homework activities has been designed to fulfill the additional three hours required per session. The time taken to complete each assignment will vary among individuals, so no time estimates have been given. Each assignment will result in some form of evidence of learning. This evidence may be useful in building a portfolio for course assessment purposes.

* Reading Assignment

Reading Assignments will help you to draw connections between the session topics and research on children's ideas. Readings will be discussed at the session that follows their assignment. The readings can be found in the Appendix.

* Physical Science Problem Set

Each session will be accompanied by a problem set that will reinforce content learning by asking questions that apply or extend physical science concepts addressed in the video. Possible answers for the problem set will be provided at the end of the session materials. It should be emphasized that many questions have a variety of answers—answers that vary depending on the understandings of the person answering the question. The intent is not to give you "right answers," but to allow you to compare yours with more advanced learners in physical science.

* Ongoing Concept Mapping

Within each session, several fundamental concepts are explored. Beginning with Session 2, the creation of a concept map will provide you with an opportunity to reflect on your evolving understandings of these concepts and their connections to one another, as well as to see how the content in each session relates to that of other sessions. A more detailed explanation of concept mapping is included in Session 2.

Guided Journal Entry

As you proceed through this course, one way of building and connecting understandings is to reflect upon your learning as you go. In each session, one or more questions will be suggested to guide a journal entry. At the end of the course, these entries should help you see how your ideas have progressed.

Guided Channel-TalkPhysicalSci Posting

Although this is a course designed to help enhance your understandings of physical science concepts, the intention is for you to use this knowledge to inform your teaching. Often, a community of learners who are also teachers can collaborate to support one another in transforming content knowledge into successful classroom action. In each session, one or more questions will be suggested to guide a discussion on Channel-TalkPhysicalSci to facilitate this type of collaboration among participants.

Textbook Reading Suggestions

We strongly recommend that you acquire a college-level physics text to refer to in this course. Reading topics will be listed in each session, and can be located in most textbooks in the Table of Contents and/or Index.

* Preparing for the Next Session

This section will get you thinking about upcoming topics and remind you to bring materials needed for the next session's activities.

Course Components, cont'd.

Ongoing Activities

The following are activities that you should work on between sessions for the duration of the course:

Course Web Site

http//www.learner.org/channel/courses/essential/physicalsci

Go online for additional activities and resources.

Channel-TalkPhysicalSci

You can communicate with other course participants throughout the country via the course's email discussion list. To subscribe to **Channel-TalkPhysicalSci,** visit http://www.learner.org/mailman/listinfo/channel-talkphysicalsci.

Graduate Course Requirements

Graduate Course Assignments

The *Essential Science for Teachers: Physical Science* professional development course is designed to be a three-credit graduate-level course for teachers. For more information about how to obtain graduate credit, go to www.learner.org/channel/workshops/graduate_credit.html.

To be eligible for graduate credit, participants must complete the following projects in addition to all of the regular course activities and assignments. Homework assignments should take approximately three hours per week to complete.

Annotated Bibliography

Prepare an annotated bibliography of a minimum of 25 resources, which can include articles given as reading assignments. Readings can relate to physical science content, conceptual change, constructivism, or inquiry teaching and learning. Each entry in the bibliography should include the bibliographical information on the resource, a summary of the content in the reading, and notes on ideas you find helpful or interesting.

Action Research Project

Action research is an effective method of professional development that seeks to improve teaching practices, expand a teacher's knowledge base, and improve the quality of student learning. Your action research project should address new understandings you have developed through this course, and how they relate to your classroom practice. As part of your project, maintain a research diary that documents your experiences as you implement new practices in your classroom. Your diary might contain research data, explanatory comments, and information on students gathered from classroom interactions or interviews, written reflections, ideas and insights, and/or recommendations for improving practice.

Graduate Course Requirements, cont'd.

The second component of the project is a final paper, minimally 10 pages in length, double spaced, using 10- or 12-point fonts, that summarizes your findings, reflects on the research process, outlines your professional development during your research, and makes recommendations for improving future practice. Additional readings to support your action research are recommended. Refer to the Appendix for the Action Research Guide, which provides week-by-week directions for conducting your project as well as a list of recommended readings on the action research process.

Portfolio

Create a portfolio evidencing your work for the course. The portfolio might be divided into the following sections: action research diary and final paper; journal that includes guided entries and reflective entries; annotated bibliography; and homework assignments. Additional sections may be added at participants' discretion.

Physics Text

It is *strongly* recommended that participants acquire a college-level physics text. Suggested readings will be listed for physical science topics being addressed in each session.

Graduate Course Assessment

The successful participant will:

- Attend and actively participate in all class sessions
- Come prepared to class sessions, having completed all reading and homework assignments
- Assemble a course portfolio with all required components present
- Create journal entries that demonstrate an in-depth understanding of relevant concepts and processes, reflect on new knowledge, and communicate ideas clearly
- Prepare an action research diary that exhibits well-organized thoughts and insightful interpretations and extensions
- Write an action research final paper that meets length and organization requirements and evidences growth in developing research skills
- Compile an annotated bibliography that contains a minimum of 25 resources with the required bibliographical information, summaries, and comments

Scheduling Course Sessions

Below are recommended options for scheduling credit and non-credit class meetings, based on how participants are viewing the video programs. Because of the amount and kinds of work associated with a graduate-level course, it is recommended that participation in the course for credit be over a 15-week period. "Work weeks" are scheduled to allow participants time to work on their assignments required for graduate credit.

Option One: Viewing the Programs Recorded on Tape or on learner.org's Video on Demand (VoD) (for Graduate Credit)	
Week 1	View Program 1 and complete assignments
Week 2	View Program 2 and complete assignments
Week 3	Work Week
Week 4	View Program 3 and complete assignments
Week 5	View Program 4 and complete assignments
Week 6	Work Week
Week 7	View Program 5 and complete assignments
Week 8	View Program 6 and complete assignments
Week 9	Work Week
Week 10	View Program 7 and complete assignments
Week 11	View Program 8 and complete assignments
Weeks 12-15	Complete long-term coursework: assemble portfolio components, action research project and paper, and annotated bibliography

Option Two: Viewing the Programs Live in Real Time (for Graduate Credit)	
Week 1	View Program 1 and complete assignments
Week 2	View Program 2 and complete assignments
Week 3	View Program 3 and complete assignments
Week 4	View Program 4 and complete assignments
Week 5	View Program 5 and complete assignments
Week 6	View Program 6 and complete assignments
Week 7	View Program 7 and complete assignments
Week 8	View Program 8 and complete assignments
Weeks 9-15	Complete long-term coursework: assemble portfolio components, action research project and paper, and annotated bibliography

Scheduling Course Sessions, cont'd.

Option Three: **Viewing the Programs Recorded on Tape or Live in Real Time on the Annenberg/CPB Channel** **(Not for Graduate Credit)**	
Week 1	View Program 1 and complete assignments
Week 2	View Program 2 and complete assignments
Week 3	View Program 3 and complete assignments
Week 4	View Program 4 and complete assignments
Week 5	View Program 5 and complete assignments
Week 6	View Program 6 and complete assignments
Week 7	View Program 7 and complete assignments
Week 8	View Program 8 and complete assignments

About the Site Investigations

Helpful Hints

Included in the materials for each session you will find detailed instructions for the content of your Getting Ready and Going Further activities (Site Investigations). The following hints are intended to help you and your colleagues get the most out of these pre- and post-video discussions.

Designate a Facilitator

Each week, one person should be responsible for facilitating the Site Investigations (or you might select two people—one to facilitate Getting Ready, the other to facilitate Going Further). We recommend that participants rotate the role of facilitator on a weekly basis.

Review the Site Investigations and Bring the Necessary Materials

Be sure to read over the Getting Ready and Going Further sections of your materials before arriving at each session. The Site Investigations will be the most productive if you and your colleagues come to the sessions prepared for the discussions. A few of the Site Investigations require materials for use at the session (see the following pages). The facilitator should be responsible for bringing these when necessary.

Keep an Eye on the Time

Sixty minutes go by very quickly, and it is easy to lose track of the time. You should keep an eye on the clock so that you are able to get through everything before the course video begins. (Sites that are watching the course on videotape will have more flexibility if their Site Investigation runs longer than expected.)

About the Site Investigations, cont'd.

Record Your Discussions

We recommend that someone take notes during each site discussion, or, even better, that you make an audiotape recording of the discussions each week. These notes and/or audiotape can serve as make-up materials in case anyone misses a session.

Share Your Discussions on the Internet

The Site Investigations are merely a starting point. We encourage you to continue your discussions with participants from other sites on Channel-TalkPhysicalSci, the course e-mail discussion list.

Materials

General Materials

Note to facilitators: During each session, different activities may require various supplies for writing, displaying, and conducting activities. These may be provided at your location, or you may wish to bring a set of supplies for the course.

- Writing/drawing paper (8.5 X 11)
- Kraft paper (rolls)
- Colored pencils, markers, or crayons
- Scissors
- Paper plates
- Newsprint paper (18 X 24)
- Chalk or dry-erase markers
- Sticky notes of various colors
- Paper towels
- Cutting knives

Specialized Materials

Essential Science for Teachers: Physical Science requires a source of running water for each session.

Individual Session Materials

Facilitators should bring the listed materials to the course sessions.

Session 1. What Is Matter? Properties and Classification of Matter

The facilitator will bring the "mystery substance" ingredients:

- 1 bottle of liquid starch
- 1 clear container (such as a clear jar, clear plastic cup, or bowl)
- Assortment of small pieces of candy per participant
- 1 bottle of white glue
- Spoons or stirrers

Directions: Make the mystery substance at least an hour before the session. Put 1/2 cup of liquid starch in a bowl. Add two cups of glue without mixing or stirring. Let the mixture sit for five minutes. Then knead the mixture in the bowl for a minute or so until it has a thick, rubbery consistency. There may be some starch left in the bowl. Remove the mixture from the bowl, and continue kneading until it has a smooth consistency and is dry enough to use. It will be damp but should not be wet. This will make enough for eight people. To make more or less, adjust the recipe, maintaining the one-to-four ratio of starch to glue.

Materials, cont'd.

Session 2. The Particle Nature of Matter: Solids, Liquids, and Gases

- Roll of aluminum foil
- Tweezers
- Large plastic syringe or empty jar with a lid
- Beaker, drinking glass, or clear plastic cup
- Scissors
- Magnifying glasses
- Small water dropper
- Food coloring

Session 3. Physical Changes and Conservation of Matter

- 250 ml beakers, glasses, or clear plastic cups
- Sand
- Sugar
- Stirrers
- Funnels
- Magnifying glasses
- Tablespoon
- Salt
- Plastic cups
- Gram scales
- Filter paper

Session 4. Chemical Changes and Conservation of Matter

- Plastic soda bottles
- Tablespoon
- Vinegar
- Blocks or pieces of metal, wood, plastic, clay, and/or rubber
- Measuring cup
- Baking soda
- Balloons
- Gram scales

Session 5. Density and Pressure

- Aquarium or similar-sized tank filled with water
- Balloons
- 250 ml beakers, or same-sized glass/clear plastic cups
- Long wax dinner candles that can be cut into pieces (save for the next session)
- Rubbing alcohol (Isopropyl)
- Drinking glasses
- Rubber bands
- Gram scales

Session 6. Rising and Sinking

- Graduated cylinders or beakers with volume markings
- Rubbing alcohol (Isopropyl)
- Handful of small, different-volume objects, e.g. small ball bearings, marbles, golf balls, solid rubber ball, small pencil, dice (different sizes) or other solid game board pieces, action figures (not the hollow kind)
- Pennies
- Pieces of cork
- Several graduated cylinders or narrow vases
- Several different colors of food coloring
- Gram scales
- Handful of film canisters
- Extra marbles
- Pieces of wax candle
- Epsom salts

Materials, cont'd.

Session 7. Heat and Temperature

- Hot plate
- Same-sized wooden and aluminum blocks (or spoons)
- Ice cubes (bring in a cooler)
- Cups or mugs
- Tea kettle or large beaker

Session 8. Extending the Particle Model of Matter

- Styrene (Styrofoam) chips
- Aluminum pie plates
- Pieces of wool or similar cloth
- Answers to "Tracking Your Understanding" Physical Science Questions from Session 1
- Styrene dinner plates
- Scrap paper

About the Contributors

Course Developers

Noah Finkelstein

Dr. Noah Finkelstein received a doctorate in applied physics from Princeton in 1998. Following graduate school, with the support of a National Science Foundation fellowship, Dr. Finkelstein studied student learning in physics jointly at the University of California at San Diego and at the University of California Berkeley. Over the past six years, he has taught extensively in physics at the undergraduate and graduate levels and in undergraduate, pre-service, and in-service teacher education. He has also taught physical science at the high school level and in informal K-12 programs such as museums and clubs. His research examines student learning in context, the factors that shape and are shaped by student learning, and how institutional structures support or inhibit such learning. Dr. Finkelstein is currently a part of the development of a graduate program and research group in physics education at the University of Colorado.

Jamie Bell

Jamie Bell received an Ed.M. from the Harvard Graduate School of Education in 1996. He was the project manager for physics exhibit development at the Exploratorium in San Francisco from 1998 to 2002. Prior to that, he co-directed the High School Explainer program there for eight years. Mr. Bell has been a consultant and trainer for museums and science centers committed to the public understanding of science, both nationally and internationally.

Mark Hartman

Mark Hartman is currently a Ph.D. candidate in the Department of Astronomy at Harvard University, and he has a B.S. in physics from Case Western Reserve University. His current research involves observational cosmology, but he has also worked in industry as an optical engineer and freelance science writer. He is also working with the National Science Foundation GK12 program to bring science graduate students into partnerships with public school science programs.

About the Contributors, cont'd.

Onscreen Guides

Sallie Baliunas

Dr. Sallie Baliunas is an astrophysicist at the Harvard-Smithsonian Center for Astrophysics. She served as deputy director and director of science programs at Mount Wilson Observatory from 1991 to 2002. She has been a contributing editor to the *World Climate Report* and a receiving editor for *New Astronomy* and *New Astronomy Reviews*. Her awards include the Newton-Lacy-Pierce Prize of the American Astronomical Society, the Petr Beckmann Award for Scientific Freedom, and the Bok Prize from Harvard University. In 1991, *Discover* magazine profiled her as one of America's outstanding women scientists. From 1997 to 2000, she was science advisor for the science-fiction television series "Gene Roddenberry's Earth: Final Conflict." She received her A.M. and Ph.D. degrees in astrophysics from Harvard University. Her studies include the Sun's changes and their influence on life and the environment of Earth, exoplanets, and sunlike stars.

Robin Moriarty

Robin Moriarty has worked in the Boston area as a classroom teacher in both public and private settings for 14 years. During that time, she has taught kindergarten, first, second, third, and fifth grades. Ms. Moriarty joined the Educational Development Center (EDC) as a research associate in June 1999 to work on the Tool Kit for Early Childhood Science Education. Her work involves developing, piloting, revising, and field-testing three curriculum guides in pre-school science to be published by Redleaf Press, along with professional development materials and videos. In addition, Ms. Moriarty has co-taught four courses for credit sponsored by the Connecticut State Department of Education and developed by the Center for Children & Families at EDC called "Science Explorations: Facilitating Science Inquiry with Young Children" and "Constructing a Cognitively Challenging Curriculum."

Curriculum Developer

Tina Grotzer

Dr. Tina Grotzer is a research associate at Project Zero at the Harvard Graduate School of Education. Her research focuses on topics at the intersection of cognition, development, and educational practice, such as the learnability of intelligence and how children develop causal models for complex science concepts. She works with students and teachers in several school systems on an ongoing basis, linking theory and practice such that they inform one another. She has studied cognitive development both as a teacher and as a researcher. Dr. Grotzer is co-principal investigator on the Understandings of Consequence Project, funded by the National Science Foundation (NSF). The project identifies ways in which student explanations of scientific concepts have different forms of causality at the core than those of scientists. She and her colleagues have developed a set of curriculum modules designed to teach the causal forms implicit in the scientific explanations. She received her Ed.D. in 1993 and Ed.M. in 1985 from Harvard University and her A.B. in developmental psychology from Vassar College in 1981.

Science Historians

Alberto Martinez

Dr. Alberto Martinez received his Ph.D. from the University of Minnesota and is currently the Dibner Library Resident Scholar, Smithsonian Institution. He was an organizer for the Seminar on the Investigation of Difficult Things in 1999 to 2000 and for the Seminar on Natural Philosophy in 1996, both at the University of Minnesota, and has been a participant in the Seven Pines Symposium for History and Philosophy of Physics in 1997 and 1999. At the Dibner Institute, Dr. Martinez will prepare a book on the history of kinematics, the modern science of motion. He is currently a fellow in the History Department at Boston University and will be lecturing at California Institute of Technology beginning in the fall of 2005.

About the Contributors, cont'd.

Mi Gyung Kim

Dr. Kim is associate professor of history at North Carolina State University. She has been working on chemical affinity for the past two decades. Her research trajectory includes the development of physical chemistry in Germany and of organic chemistry in France during the nineteenth century. Her recent book, *Affinity, That Elusive Dream: A Genealogy of the Chemical Revolution* (MIT Press, 2003), deals with the institutionalization of theoretical chemistry in eighteenth-century France that led to the Chemical Revolution. She is currently working on a cultural history of ballooning in pre-revolutionary France.

Scientists

Session 1

Robert S. Granetz

Dr. Granetz is a principal research scientist on the Alcator C-Mod project, coordinator of the diagnostic neutral beam (DNB) collaboration, and MHD program leader. He has concentrated on the study of MHD instabilities and disruptions in tokamaks and has made important contributions to the understanding of current-rise instabilities, the sawtooth instability, and pellet injection. Dr. Granetz has also taught graduate student courses in plasma physics and fusion for the MIT Department of Nuclear Engineering. In 1985, Dr. Granetz was invited to be a visiting scientist at the JET Project in Europe, and he concentrated on the analysis of data from their soft x-ray arrays. He has helped pioneer the use of x-ray tomographic imaging for studying the physics of MHD instabilities and plasma equilibria, particularly with respect to the fast sawtooth crash. Dr. Granetz returned from JET in 1987 to take on his present responsibilities for the Alcator C-MOD project. One of Dr. Granetz's principal areas of research on C-Mod has been the study of disruptions, particularly halo currents and disruption mitigation. He developed instrumentation that clearly showed the magnitude and toroidally-asymmetric nature of halo currents, and compiled a large database that formed the bulk of the ITER disruption design constraints.

Session 2

Robert A. Childs

Robert Childs is a vacuum engineer and technical supervisor of the Alcator Vacuum Lab at the Plasma Science and Fusion Center of the Massachusetts Institute of Technology. After completing his term of service in the U.S. Air Force, he began his 33-year career at the Massachusetts Institute of Technology in 1969 as an electronic technician in the Instrumentation Lab (Draper Lab). He quickly transferred to the Center for Space Research (CSR) the following year to begin work on the Lunar Surface Experiment that was one of the successful experiments of the Apollo 17 mission, the last manned Moon mission. With the successful completion of the Apollo Program at MIT, Bob became involved in the construction of the first of three major Tokamak Fusion Reactor Experiments that would last from 1971 to the present Alcator C-MOD. The Alcator program has been and is today the leader in producing low Z effective plasmas necessary for fusion research, which is in great part due to the high quality of the vacuum system. Alcator C-MOD continues in this lead as one of only two major fusion projects in operation in the U.S. funded by the Department of Energy. Bob was the third recipient of the George T. Hanyo Award from The AVS Science and Technology Society in 1999. He is presently serving as the president of the society for 2004.

Session 3

Ark W. Pang

Ark W. Pang is vice president for business development for Ionics, Incorporated, a 56-year old water and wastewater services company with corporate headquarters located in Watertown, Massachusetts. Ark has over 30 years of experience in the treatment of water and wastewater, and for the past 25 years has been dedicated to the application of membrane separation technologies for desalination and water reclamation. He has a degree in chemical engineering and has held various senior product and market development positions for DuPont Chemical Company, Permutit USA, and, for the past 20 years, with Ionics.

About the Contributors, cont'd.

In his current role for Ionics, his team is leading the worldwide development of major Build-Own-and-Operate long-term water supply opportunities. His team, with a Kuwaiti partner, was successful in obtaining project financing for the world's largest advanced membrane wastewater reclamation project in Kuwait. This 400,000-cubic-meters-per-day facility will be commissioned at the end of 2004. He is currently leading the development of a 200,000-cubic-meters-per-day seawater desalination project for the newly formed Algerian project company, Hamma Water Desalination SpA, on whose board of directors he serves.

Peter Schuerch

For the past 17 years, Peter Schuerch has been the superintendent of MacMahan Island, Maine. One of his duties is to provide the island community with an adequate supply of potable water. Since island wells were no longer able to meet increased demands, it was decided to produce fresh water from the sea. Four years ago, Schuerch installed two reverse osmosis machines. These units are capable of producing 8,000 gallons per day. It is believed that MacMahan Island was the first island community in New England to produce its fresh water by this method.

Session 4

Robert Kirshner

Robert Kirshner earned his Ph.D. in astronomy from California Institute of Technology. After working on exploding stars at the Kitt Peak National Observatory in Tucson, and teaching for nine years at the University of Michigan, Kirshner was called to the Harvard Astronomy Department in 1985. He is now Clowes Professor of Science.

Dr. Kirshner's scientific work concentrates on using supernova explosions to measure the expansion of the universe. This has led to the discovery of the acceleration of cosmic expansion, now attributed to a strange "dark energy" that pervades the observable universe. He was elected to the National Academy of Sciences in 1998 and elected president of the American Astronomical Society in 2003. His popular-level book, *The Extravagant Universe—Exploding Stars, Dark Energy, and the Accelerating Cosmos* came out in fall 2002. Each spring, Kirshner teaches Science A-35, "Matter in the Universe," a core curriculum course for Harvard undergraduates.

Session 5

Steve Bailey

Steve Bailey is the curator of fishes at the New England Aquarium. He has been a key staff person there for over 20 years. Recently, Steve was one of two principal investigators for a major new exhibit on sea jellies that was funded by the National Science Foundation. Called "Amazing Jellies," the multi-million dollar exhibit explores the increasing impact of sea jellies on coastal environments. Steve was also the staff ichthyologist for two National Geographic expeditions in search of the world's most pristine coral reef systems in the exceptionally remote Phoenix Islands of the South Pacific. There, he helped identify some previously unknown species of coral fish. Steve did graduate work at Northeastern University and received a B.S. in zoology from Wilkes University.

Session 6

Halsey C. Herreshoff

Halsey C. Herreshoff of Bristol, Rhode Island. is a naval architect and marine engineer, builder of yachts, member of the Bristol Town Council, and president of the Herreshoff Marine Museum and of America's Cup Hall of Fame. Educated at Webb Institute of Naval Architecture with a master's degree from Massachusetts Institute of Technology, Mr. Herreshoff enjoys a distinguished career in his field. More than 10.000 vessels have been built to his designs, and he has provided engineering consultation to government, industry, and private clients.

A noted sailor, Halsey Herreshoff has skippered his own racing and cruising boats in many locations, and has participated in important yacht races around the world. He was a member of the crew of *Columbia,* the 1958 America's Cup Defender, and was navigator in three America's Cup defenses: *Courageous* in 1974, *Freedom* in 1980; and *Liberty* in 1983.

About the Contributors, cont'd.

Session 7

William Babcock

William Babcock is a senior meteorologist for the National Weather Service. Bill is a native of southeast Massachusetts. He earned a B.S. in meteorology from the University of Lowell, Massachusetts, in 1981. Bill also did graduate work at the Atmospheric Science program of Oregon State University in 1984 and 1985.

Bill worked for a small private weather forecast service in New Hampshire's Lakes Region during the early 1980s. During that time, he was heard on a dozen radio stations around New England and New York. Bill was hired by the National Weather Service in 1987, and has served at offices in Williamsport, Pennsylvania, and Ann Arbor, Michigan, before coming home to southern New England in 1995.

In addition to producing weather forecasts and warnings for southern New England, Bill oversees the region's severe weather spotter program, as well as the local aviation forecast program. Bill also visits schools and community groups to talk about weather and weather safety.

Session 8

Melissa Franklin

Dr. Franklin is professor of physics at Harvard University. She is an experimental particle physicist who is working on studies of proton/anti-proton collision produced by the Fermi National Accelerator Laboratory with the Collider Detector Facility, which she helped to build. She works in a collaboration of over 600 international physicists who discovered the top quark, and continue to study particle interactions and symmetries at the highest energies now available worldwide. Dr. Franklin, a Canadian, received her B.Sc. from the University of Toronto and her doctorate from Stanford University. She has worked as a post-doctoral fellow at Lawrence Berkeley Lab, as assistant professor at the University of Illinois in Champagne/Urbana, and as a Junior Fellow in the Society of Fellows at Harvard, before joining the Harvard faculty.

Wolfgang Ketterle

Dr. Ketterle is a principal investigator in the atomic, molecular, and optical physics group in the Research Laboratory of Electronics at MIT. He is one of the three 2001 recipients of the Nobel Prize in Physics. Dr. Ketterle's research activities focus on ultracold neutral atoms at high densities. Such systems offer exciting new possibilities: When the atoms' De Broglie wavelength is comparable to atomic dimensions (the range of the interaction potential), they exhibit novel collisional properties. For interatomic separations approaching the wavelength of light, one expects novel features in light scattering and spectroscopy. Of particular interest are quantum statistical effects such as spin waves and Bose-Einstein condensation. The latter occurs when the De Broglie wavelength becomes comparable to the interatomic spacing.

In order to obtain dense samples of ultracold atoms, Dr. Ketterle's group uses a variety of techniques: slow atomic beams, laser cooling, spontaneous light force traps, magnetic traps, and evaporative cooling. The development of novel trapping and cooling schemes is a major part of his research activities. The recent observation of Bose-Einstein condensation allows him to study ultracold matter in a completely new regime. A Bose condensate is a coherent cloud of atoms with a macroscopic population of the ground state of a trap. Dr. Ketterle's short-term goal is to study and understand the properties of a Bose condensate. In the long term, his group plans to use coherent atoms for precision measurements and atom optics.

Barry Kluger-Bell

Barry Kluger-Bell is assistant director for science at the Exploratorium Institute for Inquiry in San Francisco. He holds an A.B. in physics and mathematics from the University of California at Berkeley, and a Ph.D. in physics from the University of Colorado. Dr. Kluger-Bell has worked as a research physicist, college-level physics teacher, science teacher-educator, and as director of the Bay Area Science Project. At the Exploratorium, he has served as science resource teacher, developed curriculum materials, worked with elementary teachers and children in their classrooms, developed and led inquiry education workshops for teachers, university graduate students, and faculty, and professional developers. He is author of *The Exploratorium Guide to Scale and Structure*. He has served as an advisor for video projects by WGBH-Boston and Annenberg/CPB.

About the Contributors, cont'd.

Joseph V. Minervini

Joseph Minervini is division head for technology and engineering in the Plasma Science and Fusion Center at MIT. He also holds an academic appointment as senior research engineer in the Nuclear Engineering Department where he teaches a course and supervises graduate student research. His present duties include spokesperson for the U.S. Magnetics Program organized under the Virtual Laboratory for Technology of the DOE Office of Fusion Energy Science (OFES).

Dr. Minervini has played a leading role in the field of large-scale applications of superconductors for more than 20 years. His work has spanned the range from laboratory research to management of engineering groups and large-scale projects pursuing advanced superconducting and energy technology goals. His research interests include applied superconductivity, electromagnetics, cryogenic heat transfer, supercritical helium fluid dynamics, and low-temperature measurements. He has worked on magnet systems covering nearly every major application of large-scale superconductivity including fusion energy, magnetic levitation, energy storage, power generation, magnetic separation, and high-energy physics, as well as medical applications.

Christine Ortiz

Professor Ortiz is an associate professor of materials science and engineering at MIT. She received a B.S. in materials science and engineering from Rensselaer Polytechnic Institute in 1992 and completed M.S. and Ph.D. work at Cornell University. Upon graduation from Cornell, Prof. Ortiz accepted an NSF-NATO Post-Doctoral Research Fellowship in Science and Engineering that she carried out between 1997 to 1999 in the Department of Polymer Chemistry in the University of Groningen (Netherlands).

In 1999, Prof. Ortiz joined the faculty of MIT where she developed a research program that focuses on the ultrastructure and nanomechanics of biological, biomedical, and biomimetic materials, with the primary goal being to quantify and understand the fundamental nanoscale structure-property relationships responsible for material function and dysfunction. Her research is divided into three main thrust areas including 1) soft and hard biological tissues: cartilage, bone, and natural exoskeletons, 2) molecular origins of biocompatibility and bioactivity of biomedical material surfaces, and 3) synthetic biomimetic macromolecular architectures with noncovalent intramolecular interactions. In addition, she runs an organic polymer synthesis laboratory and adjacent tissue/cell culture facility.

Since coming to MIT, she has won an NSF-PECASE award given by President George W. Bush at the White House, designed and taught a popular new undergraduate course entitled "Nanomechanics of Materials and Biomaterials," and given 70 invited lectures (including 20 international lectures in 10 countries).

Instructional Materials Appearing in the Course

Science and Technology for Children Curriculum
National Science Resources Center

Science and Technology for Children™ (STC) is an innovative, hands-on science program for children in grades one through six developed by the National Science Resources Center (NSRC). The 24 units of the STC program are designed to provide students with stimulating experiences in the life, Earth, and physical sciences and technology while simultaneously developing their critical-thinking and problem-solving skills.

The STC units provide children with the opportunity to learn age-appropriate concepts and skills and to acquire scientific attitudes and habits of mind. In the primary grades, children begin their study of science by observing, measuring, and identifying properties. Then they move on through a progression of experiences that culminate in grade six with the design of controlled experiments. For more information, contact:

Carolina Biological Supply Company
1-800-334-5551
http://www.carolina.com

Insights
Education Development Center, Inc.

Insights is an elementary level, hands-on inquiry science program designed to develop children's understanding of key concepts and to improve students' abilities to think creatively and critically. Insights also encourages problem solving and integrates science with the rest of the curriculum.

The Insights curriculum is made up of 17 modules, each of which contains 12 to 20 "learning experiences" (hands-on, inquiry activities) in which teachers guide students as they explore new concepts. Throughout the modules, six major science themes are represented: systems, change, structure and function, diversity, cause and effect, and energy.

Originally funded by a grant from the National Science Foundation, the Insights program was developed by science education specialists at the Education Development Center, Inc. For more information, contact:

Kendall/Hunt Publishing Company
1-800-542-6657
http://www.kendallhunt.com

Instructional Materials Appearing in the Course, cont'd.

Full Option Science System (FOSS) Lawrence Hall of Science

The Full Option Science System is a research-based science curriculum for grades K–8 developed at the Lawrence Hall of Science, University of California at Berkeley. FOSS is also an ongoing research project dedicated to improving the learning and teaching of science. The FOSS project began over 20 years ago during a time of growing concern that our nation was not providing young students with an adequate science education. The FOSS program materials are designed to meet the challenge of providing meaningful science education for all students in diverse American classrooms and to prepare them for life in the 21st century. Development of the FOSS program was, and continues to be, guided by advances in the understanding of how youngsters think and learn.

Science is an active enterprise, made active by our human capacity to think. Scientific knowledge advances when scientists observe objects and events, think about how they relate to what is known, test their ideas in logical ways, and generate explanations that integrate the new information into the established order. Thus the scientific enterprise is both what we know (content) and how we come to know it (process). The best way for students to appreciate the scientific enterprise, learn important scientific concepts, and develop the ability to think critically is to actively construct ideas through their own inquiries, investigations, and analyses. The FOSS program was created to engage students in these processes as they explore the natural world.

Delta Education
1-800-258-1303
http://www.deltaeducation.com

The Understandings of Consequence Project Project Zero

The Understandings of Consequence Project, part of Project Zero at the Harvard Graduate School of Education, aims to help students learn difficult science concepts by engaging them in how scientists think about the underlying causality. Students have limited knowledge of the nature of causality so they often distort information that they are learning to fit with a simpler causal model. With funding from the National Science Foundation, the project has developed a series of curriculum modules that present ways of thinking about cause and effect that students need to master in order to develop deep understandings of scientific concepts. Each unit identifies the difficulties that students tend to have in that topic and offers activities to address the difficulties. For more information, contact:

Dr. Tina A. Grotzer
Understandings of Consequence Project
Project Zero, Harvard Graduate School of Education
Phone: 617-496-4386
http://pzweb.harvard.edu/ucp

(Note: The Understandings of Consequence Project was developed with funding from the National Science Foundation (Grant No. REC-9725502 and REC-0106988). All opinions, findings, conclusions or recommendations expressed therein are those of the authors and do not necessarily reflect the views of the National Science Foundation.)

Instructional Materials Appearing in the Course, cont'd.

Delta Science Modules

Inquiry-based, or hands-on, science is a method of teaching and learning that involves the use of activities and investigative equipment. This process involves students of all ages and learning abilities. Using inquiry-based science, students assume the proactive role of a scientist by observing the environment around them, establishing the issues present, asking questions, and conducting experiments to try out ideas and verify results.

In addition, students using inquiry-based methods of learning develop other important skills. For example, communication and collaboration are strengthened through classmates discussing, writing, reading, and even drawing together. Furthermore, inquiry-based learning allows students to strengthen their math skills through measuring, graphing, adding, and subtracting.

We encourage all science teachers to incorporate inquiry-based science into their curriculum. Doing so will ensure students receive the best educational experience to advance their college and career paths.

Delta Science Modules
Phone: 1-800-258-1302 Fax: 1-800-282-9560
http://www.delta-education.com/index.html

Exploratorium Field Trip Pathways

Pathways are collections of support materials for teachers who bring their students to the Exploratorium. Pathways are designed to:

- Help provide direction and structure for the field trip.
- Focus the attention of field trip students on a particular set of exhibits or topic.
- Suggest links to related materials and additional experiments for pre- and post-trip learning.

There are two types of Pathways: Guided and Open.

Guided Pathways are intended to be a set course of exploration in the museum. Each Pathway includes a student worksheet and a matching teacher's edition. The teacher's edition links the Pathway's content to state science standards and provides additional support materials as well as sample answers to the worksheet questions.

Open Pathways suggest creative ways for you to structure your Exploratorium field trip to motivate students.

Teachers who visit the Exploratorium have developed their own methods for making the most of their field trips. Some of these methods have been gathered and described in Open Pathways.

Exploratorium
http://www.exploratorium.edu/pathways

Standards

National Science Education Standards

http://bob.nap.edu/readingroom/books/nses/html

National Research Council (NRC)

Physical Science Content Standards: K-4

http://bob.nap.edu/readingroom/books/nses/html/6c.html#ps

Properties of Objects and Materials

- Objects have many observable properties, including size, weight, shape, color, temperature, and the ability to react with other substances. Those properties can be measured using tools, such as rulers, balances, and thermometers.
- Objects are made of one or more materials, such as paper, wood, and metal. Objects can be described by the properties of the materials from which they are made, and those properties can be used to separate or sort a group of objects or materials.
- Materials can exist in different states—solid, liquid, and gas. Some common materials, such as water, can be changed from one state to another by heating or cooling.

Physical Science Content Standards: 5-8

http://bob.nap.edu/readingroom/books/nses/html/6d.html#ps

Properties and Changes of Properties in Matter

- A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample. A mixture of substances often can be separated into the original substances using one or more of the characteristic properties.
- Substances react chemically in characteristic ways with other substances to form new substances (compounds) with different characteristic properties. In chemical reactions, the total mass is conserved. Substances often are placed in categories or groups if they react in similar ways; "metals" is an example of such a group.
- Chemical elements do not break down during normal laboratory reactions involving such treatments as heating, exposure to electric current, or reaction with acids. There are more than 100 known elements that combine in a multitude of ways to produce compounds, which account for the living and nonliving substances that we encounter.

Benchmarks

Project 2061 Benchmarks

http://www.project2061.org/tools/benchol/bolintro.htm

American Association for the Advancement of Science (AAAS)

The Physical Setting

http://www.project2061.org/tools/benchol/ch4/ch4.htm

Benchmark 4B: The Earth

By the end of the second grade, students should know that:

- Water can be a liquid or a solid and can go back and forth from one form to the other. If water is turned into ice and then the ice is allowed to melt, the amount of water is the same as it was before freezing.

By the end of the fifth grade, students should know that:

- When liquid water disappears, it turns into a gas (vapor) in the air and can reappear as a liquid when cooled, or as a solid if cooled below the freezing point of water.
- Air is a substance that surrounds us, takes up space.

Benchmark 4D: Structure of Matter

By the end of the second grade, students should know that:

- Objects can be described in terms of the materials that they are made of (clay, cloth, paper, etc.) and their physical properties (color, size, shape, weight, texture, flexibility, etc.).
- Things can be done to materials to change some of their properties, but not all materials respond the same way to what is done to them.

By the end of the fifth grade, students should know that:

- Heating and cooling cause changes in the properties of materials. Many kinds of changes occur faster under hotter conditions.
- No matter how parts of an object are assembled, the weight of the whole object made is always the same as the sum of the parts; and when a thing is broken into parts, the parts have the same total weights as the original thing.
- Materials may be composed of parts that are too small to be seen without magnification.
- When a new material is made by combining two or more materials, it has properties that are different from the original materials. For that reason, a lot of different materials can be made from a small number of basic kinds of materials.

By the end of the eighth grade, students should know that:

- All matter is made up of atoms, which are far too small to see directly. The atoms of any element are alike but are different from atoms of other elements. Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances.

Benchmarks, cont'd.

- Equal volumes of different substances usually have different weights.
- Atoms and molecules are perpetually in motion. Increased temperature means greater average energy of motion, so most substances expand when heated. In solids, the atoms are closely locked in position and can only vibrate. In liquids, the atoms or molecules have higher energy, are more loosely connected, and can slide past one another; some molecules may get enough energy to escape into a gas. In gases, the atoms or molecules have still more energy and are free of one another except during occasional collisions.
- No matter how substances within a closed system interact with one another, or how they combine or break apart, the total weight of the system remains the same. The idea of atoms explains the conservation of matter: if the number of atoms stays the same no matter how they are rearranged, then their total mass stays the same.

Benchmark 4E: Transformation of Energy Motion

By the end of the fifth grade, students should know that:

- Energy cannot be created or destroyed, but only changed from one form into another.
- Heat can be transferred through materials by the collisions of atoms or across space by radiation. If the material is fluid, currents will be set up in it that aid the transfer of heat.
- Energy appears in different forms. Heat energy is in the disorderly motion of molecules; chemical energy is in the arrangement of atoms; mechanical energy is in moving bodies or in elastically distorted shapes; gravitational energy is in the separation of mutually attracting masses.

Benchmark 4F: Motion

By the end of the fifth grade, students should know that:

- Changes in speed or direction of motion are caused by forces. The greater the force is, the greater the change in motion will be. The more massive an object is, the less effect a given force will have.

By the end of the eighth grade, students should know that:

- An unbalanced force acting on an object changes its speed or direction of motion, or both. If the force acts toward a single center, the object's path may curve into an orbit around the center.

The Living Environment

http://www.project2061.org/tools/benchol/ch5/ch5.htm

Benchmark 5E: Flow of Matter and Energy

By the end of the eighth grade, students should know that:

- Over a long time, matter is transferred from one organism to another repeatedly and between organisms and their physical environment. As in all material systems, the total amount of matter remains constant, even though its form and location change.

Notes