AP® Physics 1 and 2 Inquiry-Based Lab Investigations:

A Teacher's Manual

CollegeBoard
New York, NY

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AP Science lab vision team

In 2010, the College Board convened a group of subject matter and laboratory investigation experts to provide a model of excellence for what the investigative labs should be in AP Science courses. These individuals worked diligently to create a vision for exemplary AP science labs that would serve to assist teachers in facilitating inquiry-based and student-directed investigative work. This vision also serves as the input for professional development and resource materials that will support lab investigations for the redesigned science courses.

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Chapter 1:
About This Manual

The AP Physics 1 and Physics 2 Algebra-Based courses are designed to promote student learning of essential physics content and foster development of deep conceptual understanding through an inquiry-based model of instruction. The instructional approaches utilized in this manual are informed by several decades of research on student learning and knowledge construction, especially with regard to physics principles. (Further discussion of inquiry-based instructional approaches is found in chapter 4.)

In this inquiry-based model, students learn by engaging in the seven AP Science Practices that develop their experimental and reasoning skills. By engaging in the science practices students begin to see that the study of physics is much more than just learning about our physical world; it also requires practices that are "used to establish, extend, and refine that knowledge" over time (NRC, 2012). The science practices (set out in Appendix A) enable students to make predictions of natural phenomena, develop and refine testable explanations, and use established lines of evidence and reasoning to support claims.

The laboratory investigations presented in this manual are examples of the kind of investigations that students should engage in, but they are **not to be considered mandatory;** nor are they intended to be the only investigations that students engage in during the course of study in AP Physics. It should not be assumed that any of these investigations would be specific targets for assessment on AP Exams. The investigations provided in this manual are simply models of inquiry-based labs that illustrate a variety of approaches and different levels of guidance and support that teachers can use when implementing inquiry-based laboratory work. You are also encouraged to develop your own inquiry-based investigations that meet the same cognitive objectives.

How This Manual Was Developed

To create a model of excellence for the lab component in AP science courses, the College Board, in conjunction with the Lab Vision Team and Physics Lab Development Team, worked to create an innovative vision and approach to lab investigations. Both teams of subject-matter experts consisted of master AP Physics teachers and higher-education faculty members, as well as experts in the field of inquiry-based instructional design, quantitative skill application, and lab investigations. The labs were written by physics teachers and higher education faculty members, as well as experts in the field of inquiry-based instructional design, quantitative skill application, and lab investigations. Each lab was piloted by AP teachers and students.

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Goals of Investigations in AP Physics 1 and AP Physics 2

Inquiry-based laboratory experiences support the AP Physics 1 and AP Physics 2 courses and curricular requirements by providing opportunities for students to engage in the seven science practices as they design plans for experiments, make predictions, collect and analyze data, apply mathematical routines, develop explanations, and communicate about their work. The inquiry-based investigations in this manual demonstrate a range of teacher guidance, from moderate to more fully student-directed, and support the content and science practices within the AP Physics 1 and AP Physics 2 courses.

The investigations in this manual provide examples of investigations that support recommendations by the National Science Foundation (NSF) that science teachers should include opportunities in their curricula for students to develop skills in communication, teamwork, critical thinking, and commitment to life-long learning (NSF 1996, NSF 2012, AAPT Committee on Physics in High Schools, 1992). Investigations in the style of those in this manual should engage and inspire students to investigate meaningful questions about the physical world, and they should align with the best practices described in *America's Lab Report: Investigations in High School Science* — a comprehensive synthesis of research about student learning in science laboratories from the National Research Council. Note that the investigations in this manual are neither mandatory nor all-inclusive. Feel free to use any investigations that capture the spirit of these examples.

How Inquiry-Based Investigations Support the AP Physics 1 and 2 Curriculum Framework

The AP Physics 1 and AP Physics 2 courses, equivalent to the first and second semesters of a typical introductory, algebra-based college physics course, emphasize depth of understanding over breadth of content. By delivering the content across two full-year courses, students will have more time to engage in inquiry-based learning experiences to develop conceptual understanding of content while at the same time building expertise in the science practices.

The AP Physics Exams will assess students' abilities to apply the science practices to the learning objectives in the curriculum framework. These science practices and learning objectives can be addressed by the labs in this manual and other inquiry-based labs that you may choose. This instructional approach to laboratory investigations typically takes more time than simple verification/confirmation labs; however, the reduced amount of content covered in each course will allow you to meet the curricular requirement that 25 percent of course time must be devoted to "hands-on laboratory work with an emphasis on inquiry-based investigations."

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The labs in this manual are intended to serve as models, **not as required activities**; you are encouraged to develop your own teacher-guided or student-directed, inquiry-based labs that address the learning objectives in the curriculum framework. To assist and support you in this process, the College Board operates the online AP Teacher Community (https://apcommunity.collegeboard.org/), which provides opportunities for collaboration and sharing of resources and ideas. There are multiple strategies that can be applied to modify traditional confirmation investigations into guided-inquiry labs, as further discussed in chapter 4. Regardless of the approach, the goal is to engage students in the investigative process of science and allow them to discover knowledge for themselves in a self-reflective, safe, and organized manner.

How the Investigations in This Manual Connect to the AP Physics 1 and 2 Curriculum Framework

The key concepts and related content that define the AP Physics 1 and AP Physics 2 courses are organized around seven underlying principles called the big ideas, which address (1) Properties of Objects and Systems, (2) Fields and Interactions, (3) Object Interactions and Forces, (4) System Interactions and Changes, (5) Conservation Laws, (6) Waves and Wave Models, and (7) Probability, Complex Systems, and Quantum Systems. The big ideas, as described in the curriculum framework, encompass the core scientific principles, theories, and processes modeling physical interactions and systems. For each big idea, enduring understandings are identified, which incorporate the core concepts that students should retain from the learning experience.

Learning objectives for each big idea detail what students are expected to know and be able to do. Because content, inquiry, and reasoning are equally important in AP Physics 1 and AP Physics 2, each learning objective in the curriculum framework combines content with inquiry and reasoning skills as described in the science practices.

Each investigation in this manual is structured to align to one or more learning objectives from the AP Physics 1 or AP Physics 2 course and specifies the big idea(s), enduring understandings, learning objectives, and science practices most relevant to and/or addressed by the various activities in that investigation. (See A Lab at a Glance in chapter 3.)

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Chapter 2 gives an overview of the investigations, showing their connections to the curriculum framework. Although each experiment may address one primary learning objective, there is often significant overlap of the learning objectives within a given enduring understanding, and often across different big ideas. There is no particular sequence to the labs in each course, and you may choose whatever learning sequence makes sense for you and your students. It is often desirable to have students gain experience with phenomena at the beginning of a topic, to help them build a conceptual model that describes the phenomena, but it can also be desirable to have students use a model to predict the outcome of an experiment and then design the experiment to test their prediction. As suggested by *America's Lab Report: Investigations in High School Science*, the AAPT Committee on Physics in High Schools position paper, "Role of Labs in High School Physics," and a recent research summary published in *Science* (de Jong, Linn, and Zacharia, 2013), it is highly desirable to integrate laboratory work to align with work students are doing in other parts of the course. Students will gain greater conceptual understanding from a learning sequence that fully integrates laboratory work with other course content.

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Chapter 2:
Overview of the Investigations

AP Physics 1 Investigations

Lab 1: 1D and 2D Kinematics

AP Physics 1

Connection to Curriculum Framework		Material and Equipment	Time Estimated
Learning Objectives	**Science Practices**	• Ramps	**TOTAL: ~ 1.5–2 hours**
3.A.1.1	1.5	• Stopwatches	Teacher Prep/Set-up: 10–15 minutes
3.A.1.2	2.1	• Metersticks	Student Investigation: 70–80 minutes
3.A.1.3	2.2	• Steel balls (1.5–2 cm in diameter)	Postlab Discussion: 15–20 minutes
	4.2	• Carbon paper	
	4.3	• Bubble levels	
	5.1	• (Optional) Toy car that accelerates	

Lab 2: Newton's Second Law

AP Physics 1

Connection to Curriculum Framework		Material and Equipment	Time Estimated
Learning Objectives	**Science Practices**	• Dynamics tracks	**TOTAL: ~ 3.5 hours**
1.C.1.1	1.1	• Carts	Teacher Prep/Set-up: 15–20 minutes
3.A.2.1	4.1	• Assorted masses	Prelab: 30 minutes
	4.2	• Mass hangers, slotted masses	Student Investigation: 110–120 minutes
	4.3	• Low-friction pulleys	Postlab Discussion: 30 minutes
	5.1	• String	
	5.3	• Metersticks	
		• Stopwatches	

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Lab 3: Circular Motion

AP Physics 1

Connection to Curriculum Framework		Material and Equipment	Time Estimated
Learning Objectives	**Science Practices**		
3.B.1.1 3.B.1.2 3.B.2.1 3.E.1.3 4.A.2.1 4.A.3.1	1.1 1.4 2.2 4.2 4.3 5.1 6.4	◆ Battery-operated flying toys with new 1.5-volt AA cells ◆ Metersticks ◆ Stopwatches ◆ (Optional) Extra sets of semidrained AA cells ◆ (Optional) Multimeter	**TOTAL: ~ 1.5–2 hours** Teacher Prep/Set-up: 15 minutes Prelab: 10 minutes Student Investigation: 45–60 minutes Postlab Discussion: 15–30 minutes

Lab 4: Conservation of Energy

AP Physics 1

Connection to Curriculum Framework		Material and Equipment	Time Estimated
Learning Objectives	**Science Practices**		
5.B.3.1	2.2 3.1 4.1 4.3 4.4 5.1 6.1 6.4 7.2	◆ Low-friction dynamics carts with spring bumper (or spring-loaded plunger carts) ◆ Ramps ◆ Metersticks ◆ Stopwatches ◆ Assorted masses ◆ Objects to prop up an inclined ramp ◆ Poster-size whiteboards	**TOTAL: ~ 3.5 hours** Teacher Prep/Set-up: 10–15 minutes Student Investigation: 90 minutes Postlab Discussion: 80 minutes

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Lab 5: Impulse and Momentum

AP Physics 1

Connection to Curriculum Framework

Learning Objectives	**Science Practices**
5.D.1.1	4.1
5.D.1.6	4.2
5.D.2.1	4.3
5.D.2.4	4.4
	5.1
	5.3
	6.4
	7.2

Material and Equipment

- Spring-loaded carts
- Tracks
- Bubble level
- Known and unknown calibrated masses
- Calculators
- Metersticks
- Stopwatches
- Computers with Internet access
- (Optional) Video cameras and video analysis software
- (Optional) Force sensor
- (Optional) Motion sensor with calculator or computer interface

Time Estimated

TOTAL: ~ 2 hours

Teacher Prep/Set-up:
15 minutes

Student Investigation:
70 minutes

Postlab Discussion:
25 minutes

Lab 6: Harmonic Motion

AP Physics 1

Connection to Curriculum Framework

Learning Objectives	**Science Practices**
3.B.3.1	2.2
3.B.3.2	4.2
3.B.3.3	4.3
	5.1
	6.4

Material and Equipment

- String
- Set of calibrated masses (20–500 g)
- Stopwatches or timers
- Metersticks
- Protractors
- Support rods
- Paper and tape (to create scrolls)
- Leaking bobs
- (Optional) Pendulum
- (Optional) Constant speed buggies
- (Optional) Motion detectors, software, computers
- (Optional) Video cameras and video analysis software
- (Optional) Spring

Time Estimated

TOTAL: ~ 3.5 hours

Teacher Prep/Set-up:
10–15 minutes

Student Investigation:
170 minutes

Postlab Discussion:
15 minutes

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Lab 7: Rotational Motion

AP Physics 1

Connection to Curriculum Framework

Learning Objectives	Science Practices
3.A.1.1	1.4
3.A.1.2	1.5
3.A.1.3	2.1
4.C.1.1	2.2
5.E.2.1	4.2
	4.3
	5.1

Material and Equipment

- Objects of different shapes, masses, and diameters (that can roll down an incline)
- Inclined plane or grooved track
- Objects to prop up an inclined plane (books, bricks, etc)
- Rulers
- Metersticks
- Stopwatches
- Mass scales
- (Optional) Motion sensor or video analysis tools

Time Estimated

TOTAL:
~ 3.5–4.5 hours

Teacher Prep/Set-up:
5–10 minutes

Student Investigation:
180–265 minutes

Lab 8: Mechanical Waves

AP Physics 1

Connection to Curriculum Framework

Learning Objectives	Science Practices
6.B.2.1	1.1
6.B.4.1	1.4
6.C.1.1	2.1
6.C.1.2	3.2
6.D.1.1	4.1
6.D.1.2	4.2
6.D.1.3	4.3
6.D.3.1	5.1
6.D.3.2	5.2
6.D.3.3	5.3
	6.4

Material and Equipment

- Slinkys, other common wave demonstrators, and/or ball-link chains
- Thick string
- Video cameras (or smartphones)
- Video or graphical analysis software
- Metersticks
- Stopwatches
- (Optional) Ring stands, clamps, pulleys, calibrated masses
- (Optional) Mechanical oscillator equipment that can setup standing waves on a string

Time Estimated

TOTAL:
~ 2.5–3 hours

Teacher Prep/Set-up:
10 minutes

Prelab:
20–30

Student Investigation:
80–120 minutes

Postlab Discussion:
30 minutes

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Lab 9: Resistor Circuits

AP Physics 1

Connection to Curriculum Framework		Material and Equipment	Time Estimated
Learning Objectives	**Science Practices**	- Four-cell battery holders	**TOTAL: ~ 3–3.5 hours**
5.B.9.1	1.1	- D-cell batteries	Teacher Prep/Set-up: 20–25 minutes
5.B.9.2	1.4	- #14 bulbs, #48 bulbs, corresponding holders	Prelab: 20 minutes
5.B.9.3	2.2	- Connecting wire	Student Investigation: 90 minutes
5.C.3.1	4.1	- Basic multimeters or student single-value meters (voltmeter, ammeter)	Postlab Discussion: 30–60 minutes
5.C.3.2	4.2	- Extra fuses for the ammeter	
5.C.3.3	4.3	- (Optional) Basic single pole throw switch	
	5.1		
	6.4		

AP Physics 2 Investigations

Lab 1: Boyle's Law

AP Physics 2

Connection to Curriculum Framework		Material and Equipment	Time Estimated
Learning Objectives	**Science Practices**		
5.B.5.4 5.B.5.5 5.B.5.6 5.B.7.1 5.B.7.2 5.B.7.3	1.1 1.4 2.2 4.2 4.3 5.1 6.4	• Boyle's law apparatus • Mass scales • Rulers • Graph paper or graphing calculators • Objects with mass large enough to compress air in a syringe • (Optional) Pressure sensors	**TOTAL: ~ 1 hour** Teacher Prep/Set-up: 5–10 minutes Student Investigation: 35–50 minutes Postlab Discussion: 10–15 minutes

Lab 2: Fluid Dynamics

AP Physics 2

Connection to Curriculum Framework		Material and Equipment	Time Estimated
Learning Objectives	**Science Practices**		
5.B.10.1 5.B.10.2 5.B.10.3 5.B.10.4 5.F.1.1	2.1 2.2 4.3 6.2 7.1	• Plastic transparent bottles or discharge containers with largely vertical walls • Masking tape • Metersticks • Stopwatches • Sinks or large containers to catch discharging water • Graphical analysis program on computers or calculators • (Optional) Video cameras and video analysis software	**TOTAL: ~ 1.5–2.5 hours** Teacher Prep/Set-up: 20–30 minutes Prelab: 10–20 minutes Student Investigation: 30–45 minutes Postlab Discussion: 40–50 minutes

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Lab 3: RC Circuits

AP Physics 2

Connection to Curriculum Framework

Learning Objectives	Science Practices
4.E.5.1	1.4
4.E.5.2	2.2
4.E.5.3	4.2
5.B.9.5	4.3
5.C.3.6	5.1
	6.1
	6.4

Material and Equipment

- D-cell batteries and battery holders
- Connecting wires
- Minature screw lamps (#40 or #50 bulbs with holders)
- Nonpolar microfarad capacitors
- Resistors with variable resistance
- Stopwatches
- Multimeters, voltmeters, and/or ammeters
- Single pole switches

Time Estimated

TOTAL: ~ 4 hours

Teacher Prep/Set-up:
15–20 minutes

Prelab:
60 minutes

Student Investigation:
120 minutes

Postlab Discussion:
45 minutes

Lab 4: Magnetism

AP Physics 2

Connection to Curriculum Framework

Learning Objectives	Science Practices
2.D.2.1	1.1
2.D.3.1	1.2
2.D.4.1	1.4
	2.2
	4.2
	4.3
	5.1
	7.1

Material and Equipment

- Small compasses
- Iron and ceramic magnets
- Containers filled with iron filings
- Sheets of paper, plastic bags, or sheet protectors
- Pith balls or paper clips hung on insulated strings
- Rubber rods or PVC pipes
- Glass or acrylic rods
- Rabbit fur or similar material
- Silk or equivalent material
- Styrofoam cups
- Aluminum foil
- Battery holders
- Copper wire (16–22 gauge)
- Switches
- Magnaprobes
- Magnetic field probes
- Flat pieces of wood or cardboard
- Clamps
- Rod stands
- 1.5-volt D-cell batteries
- (Optional) 3 × 3-inch sheets of magnetically senstive film, linear variable resistors, ammeters

Time Estimated

TOTAL:
~ 3–3.5 hours

Teacher Prep/Set-up:
15–20 minutes

Student Investigation:
130–160 minutes

Postlab Discussion:
30 minutes

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Lab 5: Electromagnetic Induction

AP Physics 2

Connection to Curriculum Framework		Material and Equipment	Time Estimated
Learning Objectives	**Science Practices**		
2.D.3.1 3.A.1.3 4.E.2.1	1.2 4.3 5.1 6.4	Enameled magnet wire Plastic/cardboard tubes Neodymium axially polarized nickel-plated disc magnets Digital multimeter with a setting that will indicate to the tenths of a millivolt Connecting wires, preferably with alligator clips Electrical tape Sandpaper String Masking tape Compasses (Optional) eightpenny or tenpenny nails (Optional) Two coils, one that fits inside the other (Optional) Demonstration transformer (Optional) Old AC to DC wall transformer (Optional) Digital multimeter with AC voltmeter capability, or dedicated AC voltmeter	**TOTAL: ~ 1.5–2 hours** Teacher Prep/Set-up: 5–10 minutes Prelab: 10–20 minutes Student Investigation: 60–70 minutes Postlab Discussion: 15–20 minutes

Lab 6: Geometric Optics

AP Physics 2

Connection to Curriculum Framework		Material and Equipment	Time Estimated
Learning Objectives	**Science Practices**		
6.E.5.1 6.E.5.2	1.4 2.2 4.1 4.3 5.1 5.2	Light sources Converging lenses, focal length 15–25 cm Lens holders Metersticks Index cards (5 × 7 inches or larger) (Optional) Diverging lenses	**TOTAL: 3.5 hours** Teacher Prep/Set-up: 15 minutes Student Investigation: 90 minutes Extension: 60 minutes Postlab Discussion: 45 minutes

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Lab 7: The Particle Model of Light

AP Physics 2

Connection to Curriculum Framework		Material and Equipment	Time Estimated
Learning Objectives	**Science Practices**		
5.B.8.1 6.F.3.1 6.F.4.1	1.2 1.4 3.2 4.2 4.3 5.1 6.2 6.4 7.1	◆ Electroscope ◆ Plastic cylinder (e.g., piece of PVC pipe) ◆ Metal plates (zinc, copper, steel) ◆ Steel wool ◆ Mercury vapor lamp or ultraviolet light source ◆ Emery cloth ◆ Fur, felt, or wool cloth ◆ Silk or equivalent material ◆ Power supply with variable potential difference ◆ Small incandescent bulb with base ◆ Light-emitting diodes (red, green, blue) ◆ 2–6 volt variable DC power supplies ◆ Alligator clips and jumper wires ◆ Potentiometers or trimpots ◆ Multimeters ◆ (Optional) Breadboards ◆ (Optional) Cardboard tubes from paper towel rolls ◆ (Optional) Small resistors (330–660 ohms) ◆ (Optional) Photovoltaic measurement kit	**TOTAL:** **~ 2.5 hours** Teacher Prep/Set-up: 15–20 minutes Prelab: 45–60 minutes Student Investigation: 45–60 minutes Postlab Discussion: 30 minutes

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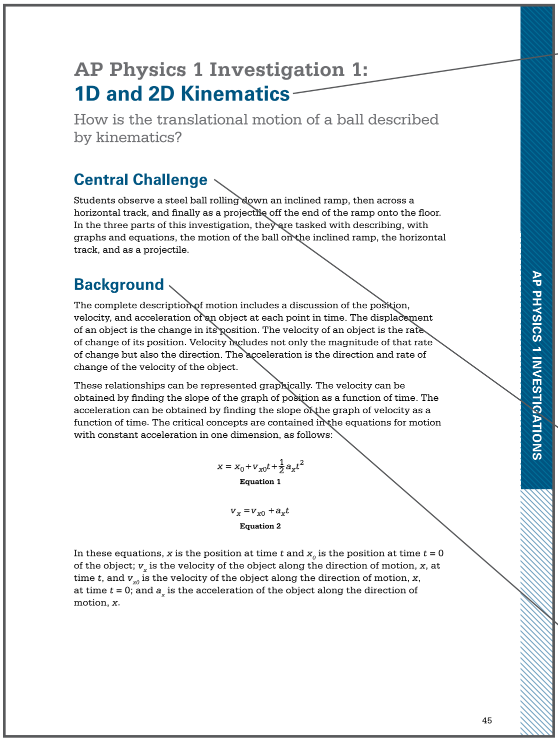
Chapter 3:
A Lab at a Glance

Although each lab investigation in this manual is unique and focuses on specified learning objectives and science practices, the overall formats are similar. As shown below, each investigation includes the following:



AP Physics 1 Investigation 1:
1D and 2D Kinematics

How is the translational motion of a ball described by kinematics?

Central Challenge

Students observe a steel ball rolling down an inclined ramp, then across a horizontal track, and finally as a projectile off the end of the ramp onto the floor. In the three parts of this investigation, they are tasked with describing, with graphs and equations, the motion of the ball on the inclined ramp, the horizontal track, and as a projectile.

Background

The complete description of motion includes a discussion of the position, velocity, and acceleration of an object at each point in time. The displacement of an object is the change in its position. The velocity of an object is the rate of change of its position. Velocity includes not only the magnitude of that rate of change but also the direction. The acceleration is the direction and rate of change of the velocity of the object.

These relationships can be represented graphically. The velocity can be obtained by finding the slope of the graph of position as a function of time. The acceleration can be obtained by finding the slope of the graph of velocity as a function of time. The critical concepts are contained in the equations for motion with constant acceleration in one dimension, as follows:

$$x = x_0 + v_{x0}t + \frac{1}{2}a_x t^2$$

Equation 1

$$v_x = v_{x0} + a_x t$$

Equation 2

In these equations, x is the position at time t and x_0 is the position at time $t = 0$ of the object; v_x is the velocity of the object along the direction of motion, x, at time t, and v_{x0} is the velocity of the object along the direction of motion, x, at time $t = 0$; and a_x is the acceleration of the object along the direction of motion, x.

AP PHYSICS 1 INVESTIGATIONS

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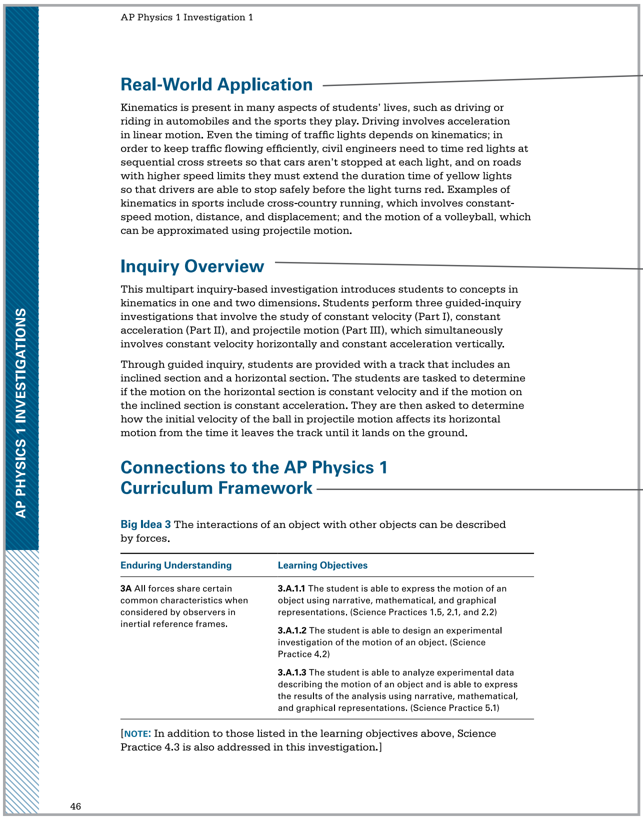
The title introduces the topical focus of the lab, and the primary question that follows frames the question for students to investigate. These questions are generated from the enduring understandings, key concepts, and principles articulated in the curriculum framework.

Describes the challenge or problem students will solve and helps orient you to the investigation.

Derived from the curriculum framework, this information provides the theory or principles students should understand in order to conduct the investigation.

FOR THE TEACHER



AP Physics 1 Investigation 1

AP PHYSICS 1 INVESTIGATIONS

Real-World Application

Kinematics is present in many aspects of students' lives, such as driving or riding in automobiles and the sports they play. Driving involves acceleration in linear motion. Even the timing of traffic lights depends on kinematics; in order to keep traffic flowing efficiently, civil engineers need to time red lights at sequential cross streets so that cars aren't stopped at each light, and on roads with higher speed limits they must extend the duration time of yellow lights so that drivers are able to stop safely before the light turns red. Examples of kinematics in sports include cross-country running, which involves constant-speed motion, distance, and displacement; and the motion of a volleyball, which can be approximated using projectile motion.

Inquiry Overview

This multipart inquiry-based investigation introduces students to concepts in kinematics in one and two dimensions. Students perform three guided-inquiry investigations that involve the study of constant velocity (Part I), constant acceleration (Part II), and projectile motion (Part III), which simultaneously involves constant velocity horizontally and constant acceleration vertically.

Through guided inquiry, students are provided with a track that includes an inclined section and a horizontal section. The students are tasked to determine if the motion on the horizontal section is constant velocity and if the motion on the inclined section is constant acceleration. They are then asked to determine how the initial velocity of the ball in projectile motion affects its horizontal motion from the time it leaves the track until it lands on the ground.

Connections to the AP Physics 1 Curriculum Framework

Big Idea 3 The interactions of an object with other objects can be described by forces.

Enduring Understanding	Learning Objectives
3A All forces share certain common characteristics when considered by observers in inertial reference frames.	**3.A.1.1** The student is able to express the motion of an object using narrative, mathematical, and graphical representations. (Science Practices 1.5, 2.1, and 2.2) **3.A.1.2** The student is able to design an experimental investigation of the motion of an object. (Science Practice 4.2) **3.A.1.3** The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis using narrative, mathematical, and graphical representations. (Science Practice 5.1)

[**NOTE:** In addition to those listed in the learning objectives above, Science Practice 4.3 is also addressed in this investigation.]

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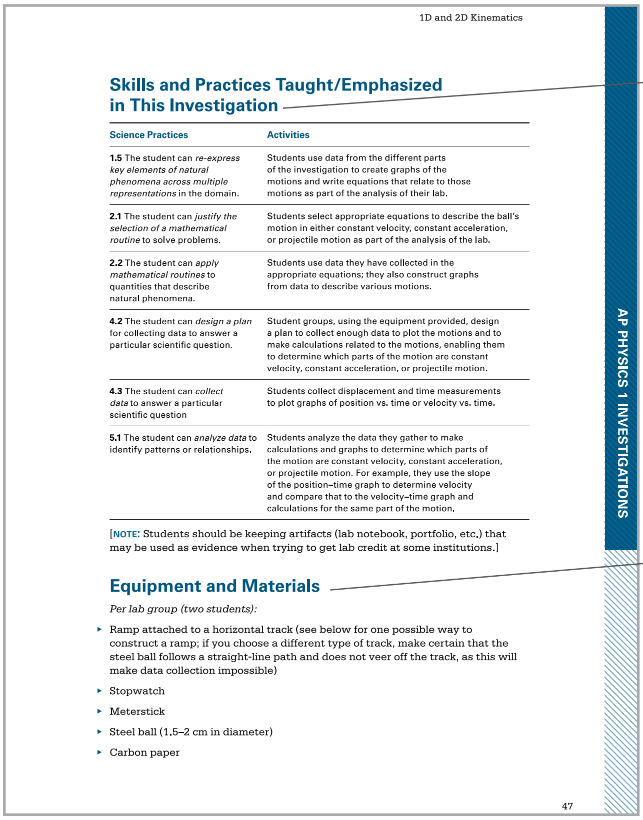
Suggestions for helping students make connections to the real-world application of the physics principles they are investigating.

Describes the scenario of the investigation and the levels of inquiry (e.g., guided versus open) present in each part of the investigation.

Connections to big ideas, enduring understandings, learning objectives, and science practices demonstrate the alignment to the curriculum framework as well as what students should *know* and be able to *do* after completing the investigation.



1D and 2D Kinematics

AP PHYSICS 1 INVESTIGATIONS

Skills and Practices Taught/Emphasized in This Investigation

Science Practices	Activities
1.5 The student can *re-express key elements of natural phenomena across multiple representations* in the domain.	Students use data from the different parts of the investigation to create graphs of the motions and write equations that relate to those motions as part of the analysis of their lab.
2.1 The student can *justify the selection of a mathematical routine* to solve problems.	Students select appropriate equations to describe the ball's motion in either constant velocity, constant acceleration, or projectile motion as part of the analysis of the lab.
2.2 The student can *apply mathematical routines* to quantities that describe natural phenomena.	Students use data they have collected in the appropriate equations; they also construct graphs from data to describe various motions.
4.2 The student can *design a plan* for collecting data to answer a particular scientific question.	Student groups, using the equipment provided, design a plan to collect enough data to plot the motions and to make calculations related to the motions, enabling them to determine which parts of the motion are constant velocity, constant acceleration, or projectile motion.
4.3 The student can *collect data* to answer a particular scientific question	Students collect displacement and time measurements to plot graphs of position vs. time or velocity vs. time.
5.1 The student can *analyze data* to identify patterns or relationships.	Students analyze the data they gather to make calculations and graphs to determine which parts of the motion are constant velocity, constant acceleration, or projectile motion. For example, they use the slope of the position–time graph to determine velocity and compare that to the velocity–time graph and calculations for the same part of the motion.

[**NOTE:** Students should be keeping artifacts (lab notebook, portfolio, etc.) that may be used as evidence when trying to get lab credit at some institutions.]

Equipment and Materials

Per lab group (two students):

- Ramp attached to a horizontal track (see below for one possible way to construct a ramp; if you choose a different type of track, make certain that the steel ball follows a straight-line path and does not veer off the track, as this will make data collection impossible)
- Stopwatch
- Meterstick
- Steel ball (1.5–2 cm in diameter)
- Carbon paper

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This chart explains how each activity in the investigation relates to the science practices in the curriculum framework.

Details the recommended equipment and materials for the investigation, as well as suggestions for purchasing, construction, and set-up where helpful.

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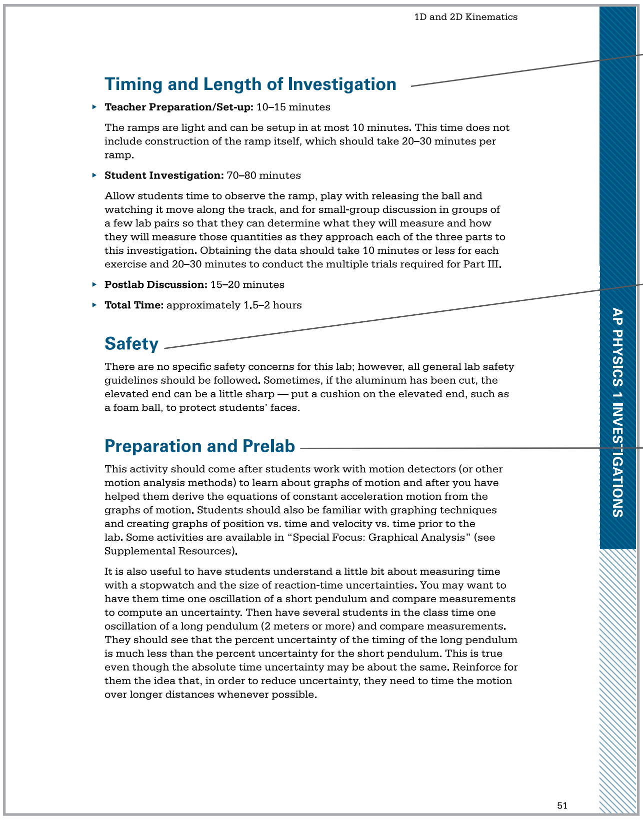

1D and 2D Kinematics

Timing and Length of Investigation

- **Teacher Preparation/Set-up:** 10–15 minutes

  The ramps are light and can be setup in at most 10 minutes. This time does not include construction of the ramp itself, which should take 20–30 minutes per ramp.

- **Student Investigation:** 70–80 minutes

  Allow students time to observe the ramp, play with releasing the ball and watching it move along the track, and for small-group discussion in groups of a few lab pairs so that they can determine what they will measure and how they will measure those quantities as they approach each of the three parts to this investigation. Obtaining the data should take 10 minutes or less for each exercise and 20–30 minutes to conduct the multiple trials required for Part III.

- **Postlab Discussion:** 15–20 minutes
- **Total Time:** approximately 1.5–2 hours

Safety

There are no specific safety concerns for this lab; however, all general lab safety guidelines should be followed. Sometimes, if the aluminum has been cut, the elevated end can be a little sharp — put a cushion on the elevated end, such as a foam ball, to protect students' faces.

Preparation and Prelab

This activity should come after students work with motion detectors (or other motion analysis methods) to learn about graphs of motion and after you have helped them derive the equations of constant acceleration motion from the graphs of motion. Students should also be familiar with graphing techniques and creating graphs of position vs. time and velocity vs. time prior to the lab. Some activities are available in "Special Focus: Graphical Analysis" (see Supplemental Resources).

It is also useful to have students understand a little bit about measuring time with a stopwatch and the size of reaction-time uncertainties. You may want to have them time one oscillation of a short pendulum and compare measurements to compute an uncertainty. Then have several students in the class time one oscillation of a long pendulum (2 meters or more) and compare measurements. They should see that the percent uncertainty of the timing of the long pendulum is much less than the percent uncertainty for the short pendulum. This is true even though the absolute time uncertainty may be about the same. Reinforce for them the idea that, in order to reduce uncertainty, they need to time the motion over longer distances whenever possible.

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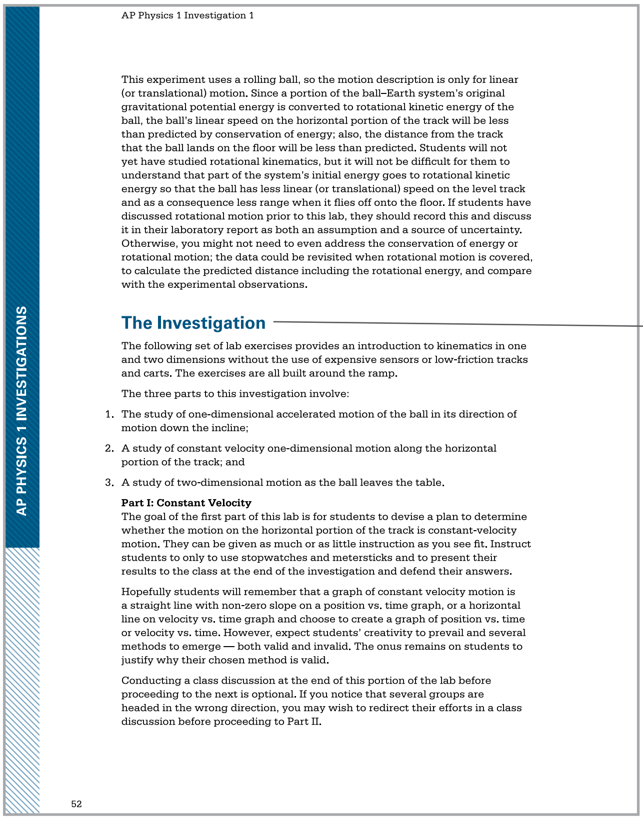
Gives guidance on the amount of time necessary for teacher preparation, student investigation, and discussion.

Suggestions for avoiding potential safety concerns or misuse of equipment during the investigation.

Suggestions for determining students' knowledge and skill levels and for preparing them for the laboratory investigation.



AP Physics 1 Investigation 1

This experiment uses a rolling ball, so the motion description is only for linear (or translational) motion. Since a portion of the ball–Earth system's original gravitational potential energy is converted to rotational kinetic energy of the ball, the ball's linear speed on the horizontal portion of the track will be less than predicted by conservation of energy; also, the distance from the track that the ball lands on the floor will be less than predicted. Students will not yet have studied rotational kinematics, but it will not be difficult for them to understand that part of the system's initial energy goes to rotational kinetic energy so that the ball has less linear (or translational) speed on the level track and as a consequence less range when it flies off onto the floor. If students have discussed rotational motion prior to this lab, they should record this and discuss it in their laboratory report as both an assumption and a source of uncertainty. Otherwise, you might not need to even address the conservation of energy or rotational motion; the data could be revisited when rotational motion is covered, to calculate the predicted distance including the rotational energy, and compare with the experimental observations.

The Investigation

The following set of lab exercises provides an introduction to kinematics in one and two dimensions without the use of expensive sensors or low-friction tracks and carts. The exercises are all built around the ramp.

The three parts to this investigation involve:

1. The study of one-dimensional accelerated motion of the ball in its direction of motion down the incline;
2. A study of constant velocity one-dimensional motion along the horizontal portion of the track; and
3. A study of two-dimensional motion as the ball leaves the table.

Part I: Constant Velocity
The goal of the first part of this lab is for students to devise a plan to determine whether the motion on the horizontal portion of the track is constant-velocity motion. They can be given as much or as little instruction as you see fit. Instruct students to only to use stopwatches and metersticks and to present their results to the class at the end of the investigation and defend their answers.

Hopefully students will remember that a graph of constant velocity motion is a straight line with non-zero slope on a position vs. time graph, or a horizontal line on velocity vs. time graph and choose to create a graph of position vs. time or velocity vs. time. However, expect students' creativity to prevail and several methods to emerge — both valid and invalid. The onus remains on students to justify why their chosen method is valid.

Conducting a class discussion at the end of this portion of the lab before proceeding to the next is optional. If you notice that several groups are headed in the wrong direction, you may wish to redirect their efforts in a class discussion before proceeding to Part II.

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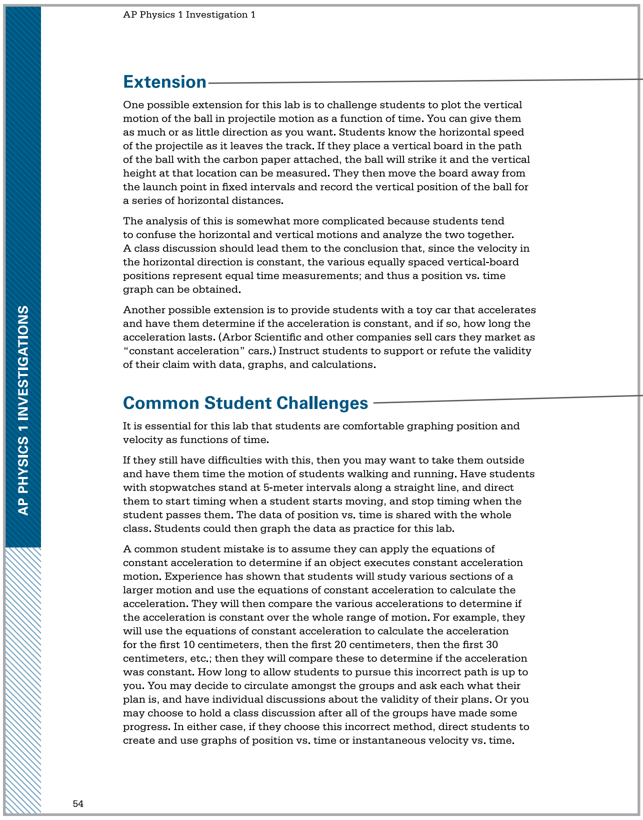
This section provides an overview of the investigation and guidance on how to engage students in developing and carrying out the different components of the lab, as well as their own procedures to collect data and evidence.



Extension

One possible extension for this lab is to challenge students to plot the vertical motion of the ball in projectile motion as a function of time. You can give them as much or as little direction as you want. Students know the horizontal speed of the projectile as it leaves the track. If they place a vertical board in the path of the ball with the carbon paper attached, the ball will strike it and the vertical height at that location can be measured. They then move the board away from the launch point in fixed intervals and record the vertical position of the ball for a series of horizontal distances.

The analysis of this is somewhat more complicated because students tend to confuse the horizontal and vertical motions and analyze the two together. A class discussion should lead them to the conclusion that, since the velocity in the horizontal direction is constant, the various equally spaced vertical-board positions represent equal time measurements; and thus a position vs. time graph can be obtained.

Another possible extension is to provide students with a toy car that accelerates and have them determine if the acceleration is constant, and if so, how long the acceleration lasts. (Arbor Scientific and other companies sell cars they market as "constant acceleration" cars.) Instruct students to support or refute the validity of their claim with data, graphs, and calculations.

Common Student Challenges

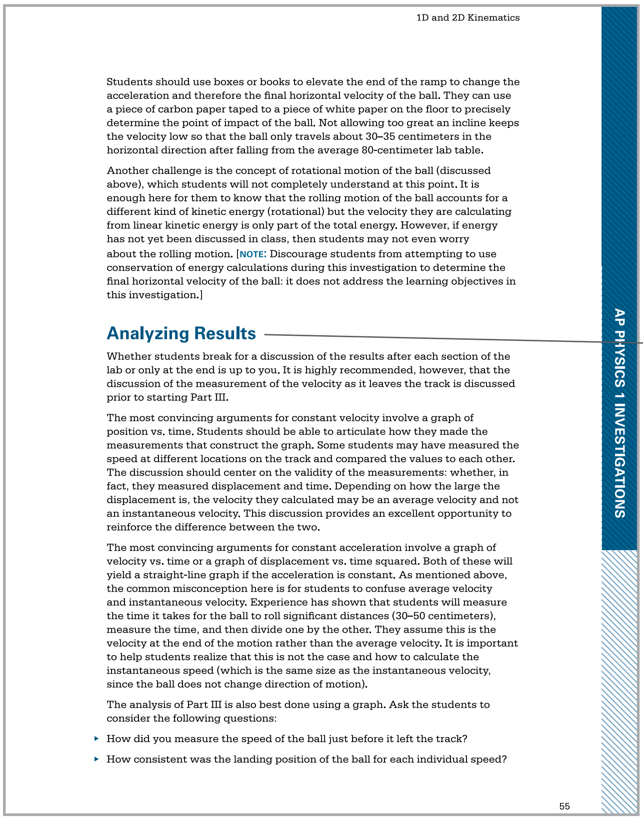
It is essential for this lab that students are comfortable graphing position and velocity as functions of time.

If they still have difficulties with this, then you may want to take them outside and have them time the motion of students walking and running. Have students with stopwatches stand at 5-meter intervals along a straight line, and direct them to start timing when a student starts moving, and stop timing when the student passes them. The data of position vs. time is shared with the whole class. Students could then graph the data as practice for this lab.

A common student mistake is to assume they can apply the equations of constant acceleration to determine if an object executes constant acceleration motion. Experience has shown that students will study various sections of a larger motion and use the equations of constant acceleration to calculate the acceleration. They will then compare the various accelerations to determine if the acceleration is constant over the whole range of motion. For example, they will use the equations of constant acceleration to calculate the acceleration for the first 10 centimeters, then the first 20 centimeters, then the first 30 centimeters, etc.; then they will compare these to determine if the acceleration was constant. How long to allow students to pursue this incorrect path is up to you. You may decide to circulate amongst the groups and ask each what their plan is, and have individual discussions about the validity of their plans. Or you may choose to hold a class discussion after all of the groups have made some progress. In either case, if they choose this incorrect method, direct students to create and use graphs of position vs. time or instantaneous velocity vs. time.

Optional classroom or laboratory activities to further guide students to achieve related learning objectives and develop the science practices.

Gives potential student challenges and misconceptions based on educators' experiences and physics education research.



Students should use boxes or books to elevate the end of the ramp to change the acceleration and therefore the final horizontal velocity of the ball. They can use a piece of carbon paper taped to a piece of white paper on the floor to precisely determine the point of impact of the ball. Not allowing too great an incline keeps the velocity low so that the ball only travels about 30–35 centimeters in the horizontal direction after falling from the average 80-centimeter lab table.

Another challenge is the concept of rotational motion of the ball (discussed above), which students will not completely understand at this point. It is enough here for them to know that the rolling motion of the ball accounts for a different kind of kinetic energy (rotational) but the velocity they are calculating from linear kinetic energy is only part of the total energy. However, if energy has not yet been discussed in class, then students may not even worry about the rolling motion. [**NOTE:** Discourage students from attempting to use conservation of energy calculations during this investigation to determine the final horizontal velocity of the ball: it does not address the learning objectives in this investigation.]

Analyzing Results

Whether students break for a discussion of the results after each section of the lab or only at the end is up to you. It is highly recommended, however, that the discussion of the measurement of the velocity as it leaves the track is discussed prior to starting Part III.

The most convincing arguments for constant velocity involve a graph of position vs. time. Students should be able to articulate how they made the measurements that construct the graph. Some students may have measured the speed at different locations on the track and compared the values to each other. The discussion should center on the validity of the measurements: whether, in fact, they measured displacement and time. Depending on how the large the displacement is, the velocity they calculated may be an average velocity and not an instantaneous velocity. This discussion provides an excellent opportunity to reinforce the difference between the two.

The most convincing arguments for constant acceleration involve a graph of velocity vs. time or a graph of displacement vs. time squared. Both of these will yield a straight-line graph if the acceleration is constant. As mentioned above, the common misconception here is for students to confuse average velocity and instantaneous velocity. Experience has shown that students will measure the time it takes for the ball to roll significant distances (30–50 centimeters), measure the time, and then divide one by the other. They assume this is the velocity at the end of the motion rather than the average velocity. It is important to help students realize that this is not the case and how to calculate the instantaneous speed (which is the same size as the instantaneous velocity, since the ball does not change direction of motion).

The analysis of Part III is also best done using a graph. Ask the students to consider the following questions:

- How did you measure the speed of the ball just before it left the track?
- How consistent was the landing position of the ball for each individual speed?

Guidance on the qualitative and quantitative analysis students may utilize to draw conclusions from their data.

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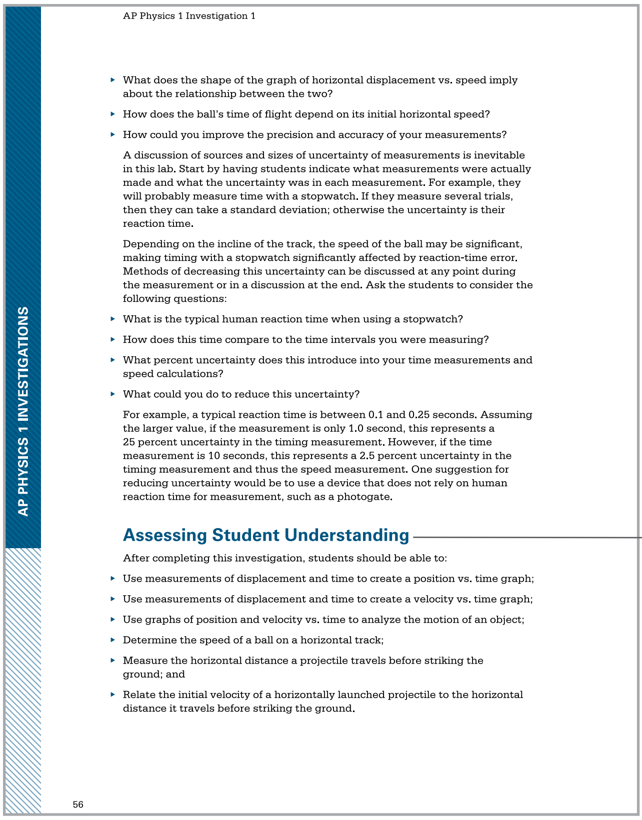

AP Physics 1 Investigation 1

AP PHYSICS 1 INVESTIGATIONS

- What does the shape of the graph of horizontal displacement vs. speed imply about the relationship between the two?
- How does the ball's time of flight depend on its initial horizontal speed?
- How could you improve the precision and accuracy of your measurements?

A discussion of sources and sizes of uncertainty of measurements is inevitable in this lab. Start by having students indicate what measurements were actually made and what the uncertainty was in each measurement. For example, they will probably measure time with a stopwatch. If they measure several trials, then they can take a standard deviation; otherwise the uncertainty is their reaction time.

Depending on the incline of the track, the speed of the ball may be significant, making timing with a stopwatch significantly affected by reaction-time error. Methods of decreasing this uncertainty can be discussed at any point during the measurement or in a discussion at the end. Ask the students to consider the following questions:

- What is the typical human reaction time when using a stopwatch?
- How does this time compare to the time intervals you were measuring?
- What percent uncertainty does this introduce into your time measurements and speed calculations?
- What could you do to reduce this uncertainty?

For example, a typical reaction time is between 0.1 and 0.25 seconds. Assuming the larger value, if the measurement is only 1.0 second, this represents a 25 percent uncertainty in the timing measurement. However, if the time measurement is 10 seconds, this represents a 2.5 percent uncertainty in the timing measurement and thus the speed measurement. One suggestion for reducing uncertainty would be to use a device that does not rely on human reaction time for measurement, such as a photogate.

Assessing Student Understanding

After completing this investigation, students should be able to:

- Use measurements of displacement and time to create a position vs. time graph;
- Use measurements of displacement and time to create a velocity vs. time graph;
- Use graphs of position and velocity vs. time to analyze the motion of an object;
- Determine the speed of a ball on a horizontal track;
- Measure the horizontal distance a projectile travels before striking the ground; and
- Relate the initial velocity of a horizontally launched projectile to the horizontal distance it travels before striking the ground.

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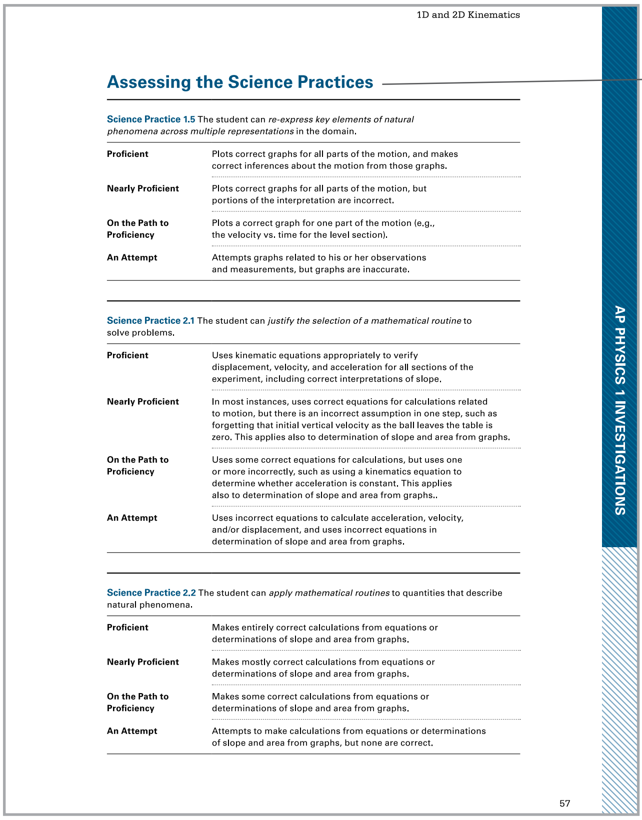
Describes what claims and connections students should be able to justify based on the evidence provided in the data they analyze.



1D and 2D Kinematics

AP PHYSICS 1 INVESTIGATIONS

Assessing the Science Practices

Science Practice 1.5 The student can *re-express key elements of natural phenomena across multiple representations* in the domain.

Proficient	Plots correct graphs for all parts of the motion, and makes correct inferences about the motion from those graphs.
Nearly Proficient	Plots correct graphs for all parts of the motion, but portions of the interpretation are incorrect.
On the Path to Proficiency	Plots a correct graph for one part of the motion (e.g., the velocity vs. time for the level section).
An Attempt	Attempts graphs related to his or her observations and measurements, but graphs are inaccurate.

Science Practice 2.1 The student can *justify the selection of a mathematical routine* to solve problems.

Proficient	Uses kinematic equations appropriately to verify displacement, velocity, and acceleration for all sections of the experiment, including correct interpretations of slope.
Nearly Proficient	In most instances, uses correct equations for calculations related to motion, but there is an incorrect assumption in one step, such as forgetting that initial vertical velocity as the ball leaves the table is zero. This applies also to determination of slope and area from graphs.
On the Path to Proficiency	Uses some correct equations for calculations, but uses one or more incorrectly, such as using a kinematics equation to determine whether acceleration is constant. This applies also to determination of slope and area from graphs..
An Attempt	Uses incorrect equations to calculate acceleration, velocity, and/or displacement, and uses incorrect equations in determination of slope and area from graphs.

Science Practice 2.2 The student can *apply mathematical routines* to quantities that describe natural phenomena.

Proficient	Makes entirely correct calculations from equations or determinations of slope and area from graphs.
Nearly Proficient	Makes mostly correct calculations from equations or determinations of slope and area from graphs.
On the Path to Proficiency	Makes some correct calculations from equations or determinations of slope and area from graphs.
An Attempt	Attempts to make calculations from equations or determinations of slope and area from graphs, but none are correct.

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Provides rubrics for evaluating the application of the science practices aligned to the learning objectives addressed in the investigation.

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Supplemental Resources

Drake, Stillman. *Galileo: Two New Sciences.* Madison, Wisconsin: University of Wisconsin Press, 1974.

"Mechanics: 1-Dimensional Kinematics." The Physics Classroom. Accessed September 1, 2014. http://www.physicsclassroom.com/calcpad/1dkin/problems.cfm. [*This website allows students to explore extra practice problems on kinematics.*]

"The Moving Man." PhET. University of Colorado Boulder. Accessed September 1, 2014. http://phet.colorado.edu/en/simulation/moving-man. [*This simulation provides an interactive way to learn about position, velocity, and acceleration graphs.*]

The Physlet Resource. Davidson College. Accessed September 1, 2014. http://webphysics.davidson.edu/physlet_resources. [*This resource provides sample "physlet" illustrations, explorations, and problems in 1-dimensional kinematics.*]

"Projectile Motion." PhET. University of Colorado Boulder. Accessed September 1, 2014. http://phet.colorado.edu/en/simulation/projectile-motion. [*Provides multiple visual representations of kinematics in one and two dimensions.*]

"Special Focus: Graphical Analysis." AP Physics 2006–2007 Professional Development Workshop Materials. College Board. Accessed September 1, 2014. http://apcentral.collegeboard.com/apc/public/repository/AP_Physics_Graphical_Analysis.pdf.

AP PHYSICS 1 INVESTIGATIONS

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Supplemental resources for the teacher, including online simulations and activities that are useful as prelab, postlab, or extensions to the investigation.

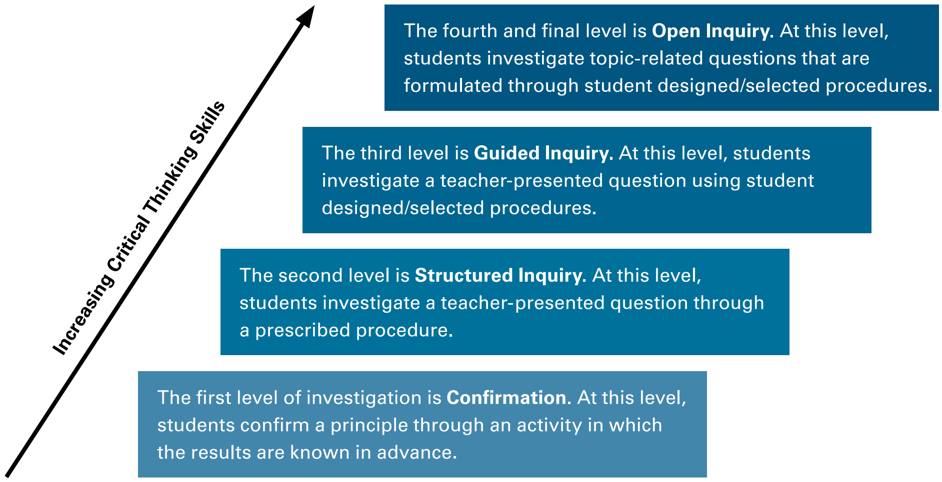
Chapter 4:
Creating an Inquiry-Based Learning Environment

"The problem is to provide students with enough Socratic guidance to lead them into the thinking and the forming of insights but not so much as to give everything away and thus destroy the attendant intellectual experience (I deliberately use the word 'guidance' to imply a distinction between this mode and the more conventional modes of providing instructions and answers)." (Arons, 1993)

Integrating Inquiry-Based Learning

Although laboratory work has often been separated from classroom work, research shows that experience and experiment are often more instructionally effective when flexibly integrated into the development of concepts. When students build their own conceptual understanding of the principles of physics, their familiarity with the concrete evidence for their ideas leads to deeper understanding and gives them a sense of ownership of the knowledge they have constructed.

Scientific inquiry experiences in AP courses should be designed and implemented with increasing student involvement to help enhance inquiry learning and the development of critical-thinking and problem-solving skills and abilities. Adaptations of Herron's approach (1971) and that of Rezba, Auldridge, and Rhea (1999) define inquiry instruction for investigations in four incremental ways:



The fourth and final level is **Open Inquiry**. At this level, students investigate topic-related questions that are formulated through student designed/selected procedures.

The third level is **Guided Inquiry.** At this level, students investigate a teacher-presented question using student designed/selected procedures.

The second level is **Structured Inquiry**. At this level, students investigate a teacher-presented question through a prescribed procedure.

The first level of investigation is **Confirmation**. At this level, students confirm a principle through an activity in which the results are known in advance.

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Typically, the level of investigations in an AP classroom should focus primarily on the continuum between guided inquiry and open inquiry. However, depending on students' familiarity with a topic, a given laboratory experience might incorporate a sequence involving all four levels or a subset of them. For instance, students might first carry out a simple confirmation investigation that also familiarizes them with equipment, and then proceed to a structured inquiry that probes more deeply into the topic and gives more practice with equipment. They would then be presented with a question and asked to design/select their own procedure. A class discussion of results could then lead to student-formulated questions that could be explored differently by different groups in open inquiry.

The idea of asking questions and inquiry is actually natural to students. However, in the classroom setting it may not seem natural to them as they may have developed more teacher-directed procedural habits and expectations in previous lab courses. As students experience more opportunities for self-directed investigations with less teacher guidance, they will become more sophisticated in their reasoning and approach to inquiry. You can promote inquiry habits in students throughout the course — during class and in the laboratory — by handing over to them more of the planning of experiments and manipulation of equipment.

Getting Students Started with Their Investigations

There are no prescriptive "steps" to the iterative process of inquiry-based investigations. However, there are some common characteristics of inquiry that will support students in designing their investigations. Often, this simply begins with using the learning objectives to craft a question for students to investigate. You may choose to give students a list of materials they are allowed to utilize in their design or require that students request the equipment they feel they need to investigate the question.

Working with learning objectives to craft questions may include:

- Selecting learning objectives from the curriculum framework that relate to the subject under study, and which may set forth specific tasks, in the form of "Design an experiment to…".

  For Example:

  > **Learning Objective 3.B.3.2:** The student is able to design a plan and collect data in order to ascertain the characteristics of the motion of a system undergoing oscillatory motion caused by a restoring force.
  >
  > Students are asked to: Design a plan and collect data in order to ascertain the characteristics of the motion of a system undergoing oscillatory motion caused by a restoring force.

- Rephrasing or refining the learning objectives that align to the unit of study to create an inquiry-based investigation for students.

For Example:

> **Learning Objective 3.B.3.1:** The student is able to predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties.
>
> Students are asked to: Make predictions about what properties determine the motion of a simple harmonic oscillator and then design an experiment that tests your predictions and allows for analysis of the dependence of the motion on those properties.

After students are given a question for investigation, they may:

- Refine the question you posed so the question or purpose best fits the experimental design.
- In small groups, prior to lab day, determine how they will manipulate the equipment to accomplish the goal and how they will process the data. (This may involve some initial play with the equipment to inform their plan.) Students should record their predictions and assumptions prior to collecting data.
- Conduct the experiment and then develop and record their analysis. The analysis should include a discussion of their prior predictions and assumptions as well as possible sources of uncertainty.
- Present their findings either in a written or oral report to you and the class for feedback and critique on their final design and results. Students should be encouraged to critique and challenge one another's claims based on the evidence collected during the investigation. (See chapter 5 for further information on scientific argumentation strategies).

Students should be given latitude to make design modifications or ask for additional equipment appropriate for their design. It is also helpful for individual groups to report out to the class on their basic design to elicit feedback on feasibility. With you as a guide, student groups proceed through the experiment, while you allow them the freedom to make mistakes — as long as those mistakes don't endanger students or equipment or lead the groups too far off task. Students should also have many opportunities for postlab reporting so that groups can hear of the successes and challenges of individual lab designs.

Demonstrations:

Can demonstrations occasionally count as inquiry laboratory experience if necessary? In the high school classroom, where equipment can be limited, teachers can compensate by implementing "Interactive Lecture Demonstrations" (Sokoloff and Thornton, 1997). Such demonstrations can be effectively used as low-tech alternatives by having students make and record their predictions, assist in carrying out the demonstration, record and evaluate the data, and present their conclusions. With the right guiding questions, even larger classes can be effectively engaged in such demonstration experiments, and demonstration experiments may be designed to involve students in several different levels of inquiry.

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Simulations:

There are now a large variety of well-designed simulations available for physics (e.g., those on the PhET website) that can be used to allow students to investigate areas such as solar-system dynamics in a virtual laboratory where they can modify masses and orbital parameters in the simulation to explore and analyze relationships among variables. In a recent review, several studies have shown that a course sequence that includes both real and virtual laboratory experiments may be more effective than either alone (de Jong, Linn, and Zacharia, 2013). Simulations in addition to hands-on lab investigations can greatly benefit students, but simulations alone should not be considered a substitute for labs and should not represent a significant amount of authentic lab investigation time.

Creating a Safe Environment for Investigation

Giving students the responsibility for the design of their own laboratory experience involves special responsibilities for teachers. To ensure a safe working environment, you must, up front, provide the limitations and safety precautions necessary for potential procedures and equipment students may use during their investigation. You should also provide specific guidelines prior to students' discussion on investigation designs for each experiment, so that those precautions can be incorporated into final student-selected lab design and included in the background or design plan in a laboratory record. It may also be helpful to print the precautions that apply to that specific lab as Safety Notes to place on the desk or wall near student workstations. Additionally, a general set of safety guidelines should be set forth for students at the beginning of the course. The following is a list of possible general guidelines you may post:

- Before every lab, make sure you know and record the potential hazards involved in the investigation and the precautions you will take to stay safe.
- Before using equipment, make sure you know the proper use to acquire good data and avoid damage to equipment.
- Know where safety equipment is located in the lab, such as the fire extinguisher, safety goggles, and the first aid kit.
- Follow the teacher's special safety guidelines as set forth prior to each experiment. (Students should record these as part of their design plan for a lab.)
- When in doubt about the safety or advisability of a procedure, check with the teacher before proceeding.

You should interact constantly with students as they work to observe safety practices and anticipate and discuss with them any problems that may arise. Walking among student groups, asking questions, and showing interest in students' work allows you to keep the pulse of what students are doing as well as maintain a watchful eye for potential safety issues.

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Material and Equipment Use

A wide range of equipment may be used in the physics laboratory, from generic lab items, such as metersticks, rubber balls, springs, string, metal spheres, calibrated mass sets, beakers, glass and cardboard tubes, electronic balances, stopwatches, clamps, and ring stands to items more specific to physics, such as tracks, carts, light bulbs, resistors, magnets, and batteries. Successful guided-inquiry student work can be accomplished both with simple, inexpensive materials and with more sophisticated physics equipment, such air tracks, force sensors, and oscilloscopes. Use the inquiry-based labs in this manual, with equipment listed for each experiment, to get an idea of what equipment is necessary for the lab. However, remembering that the AP lab should provide experience for students equivalent to that of a college laboratory, you should make every effort to provide a range of experiences – from those experiments students contrive from plumbing pipe, string, and duct tape to experiments in which students gather and analyze data using calculators or computer-interfaced equipment.

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Chapter 5:
The Role of the Science Practices

Students begin their study of physics with some prior knowledge based on their experiences in the physical world — knowledge that serves them well in particular contexts. This knowledge is often piecemeal, may be unarticulated, and is often not able to be explicitly organized into any broad coherent scheme. Some of their ideas are scientifically accurate, while others may be partially correct or incorrect according to our present collective understanding of natural phenomena. Research in physics education has shown that merely telling students about concepts in physics has little effect on their conceptual understanding.

The role of inquiry-based physics laboratory investigations is to provide students with the opportunity to design and carry out organized investigations of the physical world, to analyze their observations in an attempt to find coherent patterns that can serve as a basis for developing conceptual and mathematical models of phenomena, and, ultimately, to organize and consolidate their understanding of these models within the theories of physics. Laboratory investigations provide students with opportunities to experience and observe phenomena by engaging in science practices, whereby they design and carry out organized investigations of phenomena in order to build models and test predictions stemming from the models they have constructed. Through this process, students begin to value the reasoning skills associated with the construction of knowledge within the scientific community.

Throughout the study of the history and philosophy of science, there are 10 key points that have emerged about the development of scientific knowledge over time. In total, these points lead to one key conclusion: science is not a body of theories and laws but rather an approach to understanding observations that allows us to make sense of the world around us. If we think about these key points, they can help us understand the reasons for using inquiry in the physics laboratory.

These key points about the nature of science (as modified from McComas, 2004) are:

- Scientific knowledge is tentative but durable.
- Laws and theories serve different roles in science and are not hierarchal relative to one another.
- There is no universal step-by-step scientific method.
- Science is a highly creative endeavor, grounded by theory.
- Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, creativity, and skepticism.
- Scientific progress is characterized by competition between rival theories.
- Scientists can interpret the same experimental data differently.

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- Development of scientific theories at times is based on inconsistent foundations.
- There are historical, cultural, and social influences on science.
- Science and technology impact each other, but they are not the same.

The science practices that align to the concept outline of the curriculum framework capture important aspects of the work that scientists engage in, at the level of competence expected of AP Physics students. AP Physics teachers will see how these practices are articulated within each learning objective and therefore allow laboratory investigations and instruction to emphasize both content and scientific practice.

The seven science practices for physics are set out in Appendix A.

Assessing the Science Practices

Each investigation in this manual includes sample rubrics specific to that particular lab that may be used to assess students' understanding of the science practices. Each rubric provides you with guidance on the range of student understanding and proficiency for each science practice. The rubrics provided align directly to the investigation's learning objectives. However, the very nature of inquiry-based investigation often elicits numerous other science practices that you may also want to assess.

Accordingly, a sample rubric that serves all of the science practices is set out in Appendix B, which can be used to assess student understanding in any lab you use.

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Chapter 6:
Overview of Quantitative Analysis

Experimental physics relies heavily on quantitative skills and analysis. Successful data collection and analysis in the AP Physics laboratory requires many skills, including making accurate and precise measurements of quantities using a range of instruments, converting units, making estimates, carrying out algebraic and statistical calculations, and constructing and interpreting graphs. The information obtained using these skills must then be integrated with reasoning and higher-order thinking skills in order for students to successfully analyze and interpret data and formulate and communicate conclusions. This chapter describes how the investigations in this manual can support the development and successful application of the quantitative skills needed in the AP Physics laboratory.

How Quantitative Skills Are Addressed in This Manual

Most students come to AP Physics with some quantitative skills from earlier course work. The 16 investigations in this manual provide opportunities for students to practice and improve their existing skills and develop new skills. Since each investigation by its nature demands a different combination of skills, the particular skills needed for each lab activity are described in the section "Skills and Practices Taught/Emphasized in This Investigation."

For example, in *AP Physics 1 Investigation #6: Harmonic Motion*, students first use Science Practice 4.2 (design a plan for collecting data) as they make a plan to determine the factors that affect the period of a simple pendulum. They are then asked to graph the period as a function of mass, angle, and length, and to derive an equation relating period and length, involving Science Practice 1.4 (use representations and models) and Science Practice 2.2 (apply mathematical routines).

In choosing lab investigations, you should assess your students' existing skills in order to plan appropriate instruction prior to the lab, anticipate student challenges and questions, and provide extra monitoring during the lab. You should also consider what new skills you want your students to develop while carrying out the investigation.

Most of the labs in this manual contain a prelab or preparation component in order to introduce new techniques and equipment and reinforce fundamental skills before students undertake the investigation and apply their quantitative and other skills to address the central challenge of the lab.

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Key Quantitative Skills in AP Physics Labs

The most important quantitative skills in the AP Physics laboratory can be roughly classified into four types: measuring that includes estimation of uncertainties, calculating, creating representations such as tables and graphs, and analyzing results. In practice and as seen in the examples below, these skills can overlap, since in the laboratory setting they are often used in conjunction with each other to accomplish experimental goals.

Measuring

Measurement skills encompass choosing the appropriate measuring tools for different tasks, calibrating the tools that require calibrating, using the tools to make accurate and precise measurements, and making and recording appropriate estimates of uncertainty. Tools needed for the investigations in this manual range from metersticks to motion sensors to video analysis software. Students might not have gained prior experience with some of these tools prior to their first AP Physics course, so you might need to provide instruction on how to use a particular tool the first time they encounter it. You can do this by demonstrating a technique yourself or showing them a short video or simulation that demonstrates the device (several of the labs in this manual provide references to such materials).

During a lab, you should monitor students' measuring technique, estimation of uncertainty, and use of significant figures, providing feedback and coaching as needed. Emphasize the importance of carefully taking multiple measurements in order to help students realize that sufficient and accurate data is essential to solve problems and answer questions. No amount of analysis or calculation can make up for insufficient data.

Calculating

Most labs require several types of calculations. These include converting units, solving for unknowns in algebraic calculations, and making statistical calculations such as percent error and standard deviation. Many calculations involve using logarithms and scientific notation. Some of these calculations mirror those required in other parts of the AP Physics course, so you will find it helpful to discuss connections between the content students are studying and the calculations they are doing as part of other tasks, such as homework problems. For example, in *AP Physics 2 Investigation #1: Boyle's Law*, students need to use mathematical equations to calculate the area of the piston and volume of gas for each value of height. Students also need to calculate the area under the PV graph that represents the work done on the system by the external force. These types of calculations should be familiar to students. If an experiment uses mathematical routines that students have not yet studied in other parts of the course, you might need to model calculations related to the content or provide resources for student reference.

Most students will have had experience with unit conversions, simple algebraic calculations, and the use of significant figures and scientific notation; but they may not have performed calculations of uncertainty, and may require instruction in such calculations as mean, standard deviation, and percent error, which are central to data analysis and interpretation. Labs also provide an opportunity for students to use spreadsheet programs, such as Microsoft Excel®, and graphing programs, such as Vernier Graphical Analysis™, to perform calculations and share data. Facility with spreadsheets is a valuable skill both within and beyond AP Physics, and it is well worth the instructional time for you to demonstrate their use and for students to practice with them (see Resources at the end of this chapter for links to online tutorials on Excel).

The following labs in this manual provide opportunities for students to use spreadsheets and/or graphing programs for data analysis:

- *AP Physics 1 Investigation #1: 1D and 2D Kinematics*. Students tabulate their data and graph the suggested position vs. time and velocity vs. time relationships.
- *AP Physics 1 Investigation #5: Impulse and Momentum*. Students tabulate data and graph position vs. time to calculate the velocity of the carts before and after the collision, and/or use a data table and equation definition to multiply mass times velocity to calculate momentum for each trial.
- *AP Physics 1 Investigation #6: Harmonic Motion*. Students can use average and standard deviation spreadsheet functions to analyze data from multiple measurements of the pendulum period.
- *AP Physics 1 Investigation #7: Rotational Motion*. In the quantitative part of this lab, students determine the speed of objects arriving at the bottom of a ramp. They can use a spreadsheet to plot a position vs. time graph and take a slope, and for multiple trials they can create a data table and use spreadsheet functions to calculate averages and standard deviations.
- *AP Physics 1 Investigation #8: Mechanical Waves*. Students use graphical analysis software to plot the relationship between Slinky tension and wave speed and/or to plot data, such as wavelength and frequency, used to find the speed of the standing wave on the string.
- *AP Physics 2 Investigation #1: Boyle's Law*. Students design a plan to find the area under the curve. Solutions include "counting squares," making a best-fit line that includes and excludes approximately equal areas, using a graphing program with an integration function to plot the data and calculate the area, or using a spreadsheet and the method of trapezoids to find the area.
- *AP Physics 2 Investigation #2: Fluid Dynamics*. Students can use a graphical analysis program on a computer or calculator to go from an h vs. t graph to a v vs. t graph.
- *AP Physics 2 Investigation #6: Geometric Optics*. Students can use a spreadsheet to create graphs to determine the focal length of a lens.
- *AP Physics 2 Investigation #7: Photoelectric Effect*. Students can use a spreadsheet or graphing program to calculate the slope using a large number of data points.

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Using Web tools such as Google Sheets® allows students to share data and collaborate online as well. For example, in *AP Physics 1 Investigation #6: Harmonic Motion*, two groups can investigate the effect of length on period, two groups can investigate the effect of mass on period, and another two groups can investigate the effect of angle on period. You can then create a Google spreadsheet that the groups can use to input and share their data, with one sheet for each of the variables: length, mass, and angle. All students would then make three graphs: period as a function of length, period as a function of mass, and period as a function of angle.

Tabulating data, generating graphs by hand, and interpreting graphs is an essential skill in AP Physics. Using software tools to generate and interpret graphs is not essential, but it is highly desirable because they allow for relatively fast analysis, are generally more accurate and precise, and are more professional in appearance than hand-drawn graphs. Use of spreadsheets for graphing and analysis is also a transferable skill that is useful in many other courses and scientific contexts.

Creating tables and graphs

Creating and using representations and models (Science Practice 1) are skills that are essential to organizing data in the laboratory for analysis. Learning to construct data tables requires students to:

a. Identify dependent and independent variables and controlled quantities;

b. Choose appropriate quantities and units for measurement; and

c. Use word processing or spreadsheet programs (if possible) as needed.

Presentation and analysis of data often calls for the use of graphs of different types. Generating and using graphs requires the skills of plotting coordinates, determining independent and dependent variables, and choosing appropriate scales. The laboratory section of the AP Physics 1 and 2 Exams requires graphing skills with questions relating to analyzing data, including displaying data in graphical or tabular form; fitting curves (which may be lines) to data points in graphs; determining slopes; and performing calculations with data or making extrapolations and interpolations from data.

These skills can be applied differently in different contexts. For example, in *AP Physics 1 Investigation #6: Harmonic Motion*, students use their data to make predictions about the period of a pendulum with a given mass, angle, and length by interpolating or extrapolating from their graphical data or by using the equation they obtained for period versus length to calculate a predicted value.

Different types of graphs may be appropriate for different types of analysis. In studying one-dimensional kinematics, graphing and graphical analysis of position, velocity, and acceleration versus time can be used to determine functional relationships. In energy experiments, energy bar graphs constructed for different configurations of a system are useful for tracking how energy is distributed in a system. PV diagrams are useful for representing thermodynamic processes as in the Boyle's law experiment. Energy-level diagrams are used to represent atomic transitions in studying topics in modern physics.

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Students should be able to recognize whether their laboratory data implies a linear, quadratic, inverse, inverse-square, exponential, logarithmic, sinusoidal, or power-law relationship. They should be familiar with graphing techniques that allow them to alter the graphical axes to show a linear relationship.

As with the measurement and calculation skills discussed earlier, students are likely to have prior experience with some graphing skills, while other uses of graphs may be new and will require you to provide instruction and extra guidance in order to support successful skill development.

Analyzing results

Data analysis and evaluation of evidence (Science Practice 5) helps to derive meaning out of quantitative information generated through measurement, calculations, and graphing. Often the most difficult part of the quantitative work in the laboratory, this process is essential in order to answer experimental questions successfully. Students can develop and strengthen these skills through practice over time in a variety of laboratory experiences. Three quantitative analysis tasks in laboratory work are discussed below: interpreting data, assessing accuracy and precision, and analysis of uncertainty (error analysis).

Interpreting data

Interpreting measured and calculated values in terms of the physical principles under study is something many students find challenging, especially as experiments and calculations become more sophisticated. A relatively simple example is in *AP Physics 1 Investigation #1: Kinematics*, where students measure position and velocity as functions of time. Once they make these measurements, they need to analyze the data in order to answer the central experimental question — how the initial velocity of the ball in projectile motion affects its horizontal motion from the time it leaves the track until it lands on the ground.

Assessing accuracy and precision

Quantitative analysis also includes assessing the accuracy and precision of results. In *AP Physics 1 Investigation #3: Circular Motion* for example, students make various measurements needed to make predictions about the period of motion of a conical pendulum. They need to decide how many trials are needed; determine if their measurements are sufficiently close together; decide if any of their calculations are outliers that should be discarded; compare the various groups' methods; and decide which methods were more precise than others. All of these decisions require analysis of precision and accuracy. The concept of uncertainty should also be part of the lab investigation that can be addressed prelab and/or postlab. For example, in *AP Physics 1 Investigation #9: Resistor Circuits* some students may automatically conclude that two potential differences are the same across branches in parallel if they are within 5–10 percent of each other. Other students may conclude they are different. This can lead to a discussion of the uncertainty in the meter measurements and the possible effects of the resistance of connecting wires. For lab problems on exams, discussion of accuracy, precision, and error analysis will primarily be

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qualitative. However, quantitative treatment of these is expected for college course work, so you should also ensure that students understand standard deviation as a measure of precision and percent error as a measure of accuracy, and that repetition makes for more robust data that enhances the physicists' ability to draw conclusions and answer questions. You could choose to delve further into statistical analysis with your students, addressing topics such as confidence intervals and *p*-values, if desired. Knowing how to use statistics to analyze the quality of laboratory results is extremely important in higher-level courses and an introduction to these concepts will thus benefit students.

Analysis of uncertainty (error analysis)

A third quantitative analysis task is analysis of uncertainty, or error analysis, which involves assessing likely sources of uncertainty and their effects on measured and calculated values. For example, in part I of *AP Physics 1 Investigation #7: Rotational Motion*, students make the necessary measurements and calculations needed for a kinematic analysis. They are then required to do an analysis of uncertainty to decide whether observed differences in the speeds of two objects are in fact different or simply due to uncertainties in the measurements.

SYSTEMATIC UNCERTAINTY includes uncertainty or errors due to the calibration of instruments and uncertainty due to faulty procedures or assumptions. Even if an instrument has been properly calibrated, it can still be used in a fashion that leads to systematically wrong (always either high or low) results. If instruments are calibrated and used correctly, then you can expect accurate results, but even the most basic measurements might include things such as parallax errors in measuring length or reading an analog meter and human reaction-time errors with a stopwatch, creating inaccuracies in results. Another common example of a systematic error in the physics lab is the assumption that air resistance is not a factor for a falling body, which makes real results inaccurate.

When the systematic uncertainties in an experiment are small, the experiment is said to be *accurate*. Accuracy is a measure of how close you are to the accepted answer.

RANDOM UNCERTAINTY include errors of judgment in reading a meter or a scale and uncertainties due to fluctuating experimental conditions. Because no instrument is infinitely precise, even if measurement conditions are not fluctuating, careful measurements of the same quantity by the same person will not yield the same result over multiple trials. For many measurements, environmental fluctuations (e.g., the temperature of the laboratory or the value of the line voltage) or small variations in starting conditions will necessarily give different results each time.

When the random uncertainties in an experiment are small, the experiment is said to be *precise*. Precision tells you how well you know the answer you have determined; it is how sure you are of your measurement or, alternatively, how unsure you are of your measurement, regardless of whether the measurement is accurate or correctly made.

Expectations for error analysis on the AP Physics Exams

Experiment and data analysis questions on the AP Physics 1 and 2 Exams will not require students to calculate standard deviations, use formal methods to calculate the propagation of error, or carry out a calculated linear best-fit. However students should be able to:

- Discuss which measurement or variable in a procedure contributes most to overall uncertainty in the final result and on conclusions drawn from a given data set;
- Recognize that there may be no significant difference between two reported measurements if they differ by less than the smallest division on a scale;
- Reason in terms of percentage error;
- Report results of calculations to an appropriate number of significant digits;
- Construct an estimated best-fit line to data that they plot;
- Articulate the effects of error and error propagation on conclusions drawn from a given data set and how the results and conclusions would be affected by changing the number of measurements, measurement techniques, or precision of measurements; and
- Review and critique an experimental design or procedure and decide whether the conclusions can be justified based on the procedure and the evidence presented.

Expectations for error analysis in college

Some colleges and universities expect students to submit a laboratory notebook to receive credit for lab courses. Given the emphasis on time spent in the laboratory, students are expected to have been introduced to the formal methods of error analysis as presented in this chapter and to have carried out the procedures on at least some of the laboratory experiments they undertook, particularly since the use of computers and calculators have significantly reduced the computational burden of these procedures.

Resources

"AP Physics 1 and 2 Lab Investigations: Student Guide to Data Analysis." AP Physics 1 and AP Physics 2 Essential Course Resources. College Board. Accessed February 10, 2015. https://media.collegeboard.com/digitalServices/pdf/ap/physics-1-2-data-analysis-student-guide.pdf

"Averaging, Errors and Uncertainty." Department of Physics and Astronomy. University of Pennsylvania. Accessed October 14, 2014. https://www.physics.upenn.edu/sites/www.physics.upenn.edu/files/Error_Analysis.pdf.

"Intro to Excel." Department of Physics and Astronomy. University of Pennsylvania. https://www.physics.upenn.edu/sites/www.physics.upenn.edu/files/Introduction_to_Excel.pdf

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"Functions and Formulas." Google Help (for Google Sheets). Accessed November 17, 2014. https://support.google.com/docs/topic/1361471?hl=en&ref_topic=2811806

"Quantitative Skills and Analysis in AP Physics 1 and 2 Investigations: A Guide for Teachers." AP Physics 1 and AP Physics 2 Essential Course Resources. College Board. Accessed February 10, 2015. https://media.collegeboard.com/digitalServices/pdf/ap/physics-1-2-data-analysis-student-guide.pdf

"Special Focus: Graphical Analysis." AP Physics 2006–2007 Professional Development Workshop Materials. College Board. Accessed October 14, 2014. http://apcentral.collegeboard.com/apc/public/repository/AP_Physics_Graphical_Analysis.pdf.

"Training Courses for Excel 2013." Microsoft Office. Accessed October 14, 2014. http://office.microsoft.com/en-us/excel-help/training-courses-for-excel-2013-HA104032083.aspx.

"Useful Excel Commands for Lab." Department of Physics. Randolph College. Accessed October 14, 2014. http://physics.randolphcollege.edu/lab/IntroLab/Reference/exchint.html.

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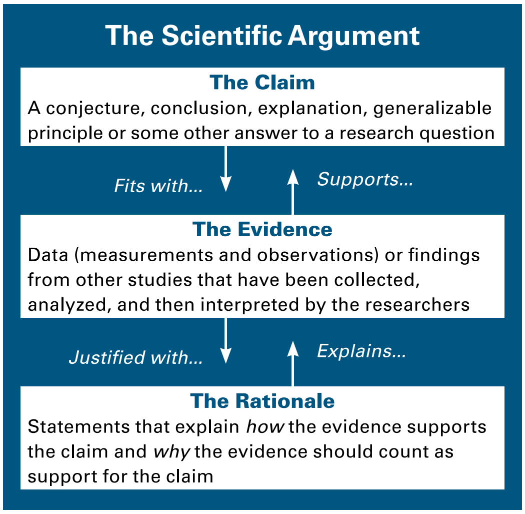
Chapter 7:
Written, Verbal, and Visual Communication

Engaging Students in Scientific Argumentation

Guide students to develop the mindset that there are no wrong answers to questions; instead, they should consider their responses to be steps toward developing the best explanation possible. Responses become valid only as they are supported by physics concepts and explanations. The physics concepts are in turn supported by evidence students collect during their investigations. To foster the inquiry process, cultivate a classroom environment in which students can be “wrong” without embarrassment, and can offer explanations with confidence that they will be taken seriously. Once explanations are proposed, guide students to final conclusions through a process of open scientific discussion and argumentation based on evidence.

The goal is to enable students to build skills in constructing arguments from evidence so that they can defend their conclusions. Laboratory experience, as distinguished from simple, everyday experience, must involve active engagement of students’ minds as well as their hands. Such experience is gained in investigations where students are required to articulate their observations, build mental models, draw conclusions from their observations, and make and test predictions based on their models. Students should then be able to construct claims based on their investigations that are supported by evidence, and to explain how that evidence supports what they claim about their observations.



The Scientific Argument

The Claim
A conjecture, conclusion, explanation, generalizable principle or some other answer to a research question

Fits with… ↓ ↑ *Supports…*

The Evidence
Data (measurements and observations) or findings from other studies that have been collected, analyzed, and then interpreted by the researchers

Justified with… ↓ ↑ *Explains…*

The Rationale
Statements that explain *how* the evidence supports the claim and *why* the evidence should count as support for the claim

Model developed by Sampson & Grooms, 2008; Sampson, Grooms, & Walker, 2009

Communicating Scientific Evidence from Investigations

Give students time to consider their explanations and the opportunity to discuss and respond, and allow the ensuing discussion to evolve as students develop their own understanding. Students should have opportunities to convey their evidence from investigations in the laboratory in several ways. Laboratory work should be recorded directly in written form (e.g., a bound journal or portfolio) in real time. You may choose to have the analysis of this work completed in the journal or developed in written form as a formal report. Reporting results can also be verbal, as individual students or student groups report their observations and conclusions to a larger group for discussion and feedback.

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Chapter 8:

Making AP Physics 1 and 2 Inclusive for All Learners

As a teacher, you should anticipate having students with special needs in your class, and plan to meet the individual needs of those students in order to support their endeavors to be successful in the course. This chapter provides guidance regarding issues that are particularly pertinent to special-needs students in the guided-inquiry physics laboratory.

Safety

The most important consideration for teachers is always the safety of students in the laboratory. You may need to make special efforts in order to ensure that students with special needs can work effectively and safely in the lab. Their inclusion can be successful when you have sufficient information about their particular needs, have the proper materials to assist them in the lab (as needed), and receive support from professionals who specialize in working with these students. In some cases, you will need to spend more time with special-needs students in the laboratory. Thus, the total number of students you can adequately supervise may be smaller, so teacher–studio ratio is particularly important. You may need to have additional professionals in the laboratory to be able to guide and manage all students safely. Some students may need specialized equipment or other aids to support their work in the lab. A team of professionals (counselors, science teachers, special-education teachers, and school administrators) should discuss class size, specialized equipment, and other issues pertinent to the requirements of the special-needs student prior to laboratory work, and you must ensure that recommendations are followed. You can help the team to identify risks that might arise in the specific context of the physics laboratory.

Accommodations

Both physical and nonphysical accommodations that enhance learning might be needed. The most common special needs relate to (1) vision, (2) mobility, (3) autism spectrum, (4) learning and attention, (5) hearing, and (6) health. Consultation with educational professionals who specialize in the particular special needs of a student is important. Awareness of organizations such as DO-IT (Disabilities, Opportunities, Internetworking, and Technology) can provide teachers with information about working in the laboratory/classroom with students with special needs. Many students with learning issues have individualized education programs (IEPs) that can guide the accommodations.

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Consider the following suggestions:

- **Students with vision impairments** might benefit greatly from enhanced verbal descriptions and demonstrations. Lab equipment can be purchased with Braille instructions, promoting independent participation for visually impaired students. Students with visual challenges might also benefit from preferential seating that allows them to see demonstrations more easily. If possible, provide students with raised-line drawings and tactile models for illustrations. You might also consider using technology to increase accessibility to the lab experience. For example, video cameras attached to a computer or television monitor can be used to enlarge images.
- **Students who have mobility challenges** may need a wheelchair-accessible laboratory. Keep the lab uncluttered and make sure that aisles are wide enough for wheelchair movement. Students can often see a demonstration better if a mirror is placed above the instructor. Lab adaptations are available for students with mobility problems to assist them in most lab activities. You will need to know a student's limitations before planning a successful lab experience.
- **Students with autism spectrum disorders** (including Asperger's syndrome and pervasive developmental disorder) may have a range of communication and impulsive behavior challenges requiring accommodations and close monitoring in the laboratory setting to ensure a safe and supportive learning environment. These students' particular challenges and needs are highly individualized. Guidance and support from appropriate professionals is particularly important in preparing you to meet such a student's needs. An educational aide or support staff member working with the student in the lab is sometimes helpful, as a lower student–educator ratio is often beneficial and may, in some cases, be called for in the student's IEP.
- **Students with hearing difficulty** might benefit from preferential seating near you when demonstrations are given. It is also helpful to provide hearing-impaired students with written instructions prior to the lab and use instructor captioning when showing videos and DVDs.
- **Students who have learning and attention special needs** may require a combination of oral, written, and pictorial instruction. Scaffolding instruction increases learning, and safety issues and procedural instructions may need to be repeated. Having audiotaped instructions may be helpful to allow students to hear them as often as needed for comprehension. Some students who have special needs related to attention need frequent breaks to allow them to move around and refocus. Providing a student with preferential seating to avoid distraction is also helpful. Students with reading and writing challenges often require more time to prepare for lessons and to complete the follow-up activities. Students with learning and attention challenges sometimes benefit greatly from the use of technology, such as scanning and speaking pens that help with reading. Other such students might benefit from using laptops to take notes during class.

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- **Students with health issues,** such as asthma, allergies, or insulin-dependent diabetes, may benefit from certain accommodations. Care should be taken to avoid risking a student's health because of exposure to chemicals or allergens such as noxious gases or vapors, latex gloves, or food components (e.g., milk or egg proteins, peanuts) while conducting laboratory investigations. Students with asthma or allergies may benefit from wearing a mask designed for physical laboratory use. You should be aware of any student requiring epinephrine administration (e.g., an EpiPen) in the case of an allergic reaction.

Universal Design

A laboratory environment that is universal in design is one that is accessible to students both with and without special needs. By creating such an environment, you will address most concerns and accommodations for students with special needs and, at the same time, improve learning opportunities for *all* students in the lab. Be proactive whenever possible in implementing accommodations, including the following:

- Provide both written and oral directions.
- Give students adequate time to prepare for labs and to complete follow-up activities.
- Make the aisles wide enough for wheelchairs.
- Install a mirror above the area where demonstrations are performed.
- Use tables that can be adjusted for height.

Supporting English Language Learner Students

All AP teachers should be prepared to accommodate English language learner (ELL) students in their courses. You can employ a number of strategies to support such students; many of these strategies will benefit all students, not just ELL students. Examples include:

- Using printed pictures and graphics (e.g., pictures of lab glassware) to support English text in curricular materials and lab handouts;
- Teacher demonstrations of basic procedures and techniques;
- Video clips showing laboratory techniques; and
- Multimedia simulations of chemical phenomena.

Another idea to consider is pairing students with less developed English language skills with another student who speaks their first language and has more developed English language skills; though of course this is not a substitute for teacher supervision and support. Close teacher monitoring and prompting in the lab will further help students who appear confused or on the wrong track during inquiry activities, and will prevent any potential safety hazards from arising.

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Developing a Community of Learners

Teachers must foster the creation of a learning environment that includes and respects *all* students. For example, creating cooperative learning groups provides students with the opportunity to share their knowledge and skills and to learn from each other. This is particularly advantageous for special-needs students. You may find it helpful to talk with students to discover firsthand what accommodations you need to implement in order to make students' lab experiences successful. By modeling attitudes and behaviors expected from students, you can develop activities that help *all* students build meaningful academic and personal relationships.

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References and Resources

AAPT Committee on Physics in High Schools. "Role of Labs in High School Physics." August, 1992. Accessed September 1, 2014. http://www.aapt.org/Resources/policy/roleoflabs.cfm.

American Association of Physics Teachers Apparatus Committee. "Safety in Physics Education." 2001. Accessed September 1, 2014. http://aapt.org/Resources/upload/safetypage1-11.pdf.

"America's Lab Report Investigations in High School Science." Edited by Susan R. Singer, Margaret L. Hilton, and Heidi A. Schweingruber. The National Academies Press. 2005. Accessed September 1. 2014. http://www.nap.edu/catalog.php?version=b&utm_expid=4418042-5.krRTDpXJQISoXLpdo-1Ynw.1&record_id=11311.

Arons, Arnold B. "Guiding Insight and Inquiry in the Introductory Physics Laboratories." *The Physics Teacher* 31, no. 5 (1993): 278–282.

Burgstahler, Sheryl. "Making Science Labs Accessible to Students with Disabilities." University of Washington. Accessed September 1, 2014. http://www.washington.edu/doit/Brochures/PDF/science_lab.pdf.

de Jong, Ton, Marcia C. Linn, and Zacharias C. Zacharia. "Physical and Virtual Laboratories in Science and Engineering Education." *Science* 340 (2013) 305–308.

Herr, Norman. *The Sourcebook for Teaching Science, Grades 6–12: Strategies, Activities, and Instructional Resources.* San Francisco: Jossey-Bass, 2008.

Herron, Marshall D. "The Nature of Scientific Enquiry." *The School Review* 79, no. 2 (1971): 171–212.

Interactive science simulations. PhET. University of Colorado Boulder. Accessed September 1, 2014. https://phet.colorado.edu.

Miner, Dorothy L., Ron Neiman, Anne B. Swanson, and Michael Woods, eds. "Teaching Chemistry to Students with Disabilities: A Manual for High Schools, Colleges, and Graduate Programs." American Chemical Society. Accessed September 1, 2014. https://www.acs.org/content/dam/acsorg/education/publications/teaching-chemistry-to-students-with-disabilities.pdf.

"Occupancy Loads in School Science Laboratories." National Science Education Leadership Association. Accessed September 1, 2014. http://www.nsela.org/about-nsela/position-statements/103-occupancy-loads-in-school-science-laboratories.

Rezba, Richard J., Teresa Auldridge, and Laura Rhea. *Teaching and Learning the Basic Science Skills*. Richmond, VA: Dept. of Education, Office of Elementary and Middle School Instructional Services, 1998. VHS.

Richard-Amato, Patricia A., and Marguerite Ann Snow. *Academic Success for English Language Learners: Strategies for K–12 Mainstream Teachers*. White Plains, NY: Longman, 2005.

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“Science and Safety: Making the Connection.” Council of State Science Supervisors. Accessed September 1, 2014. www.csss-science.org/downloads/scisafe.pdf.

“Science for English Language Learners.” National Science Teachers Association. Accessed September 1, 2014. http://www.nsta.org/about/positions/ell.aspx.

Sokoloff, David R., and Ronald K. Thornton. “Using Interactive Lecture Demonstrations to Create an Active Learning Environment.” *The Physics Teacher* 35, no. 6 (1997): 340–347.

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