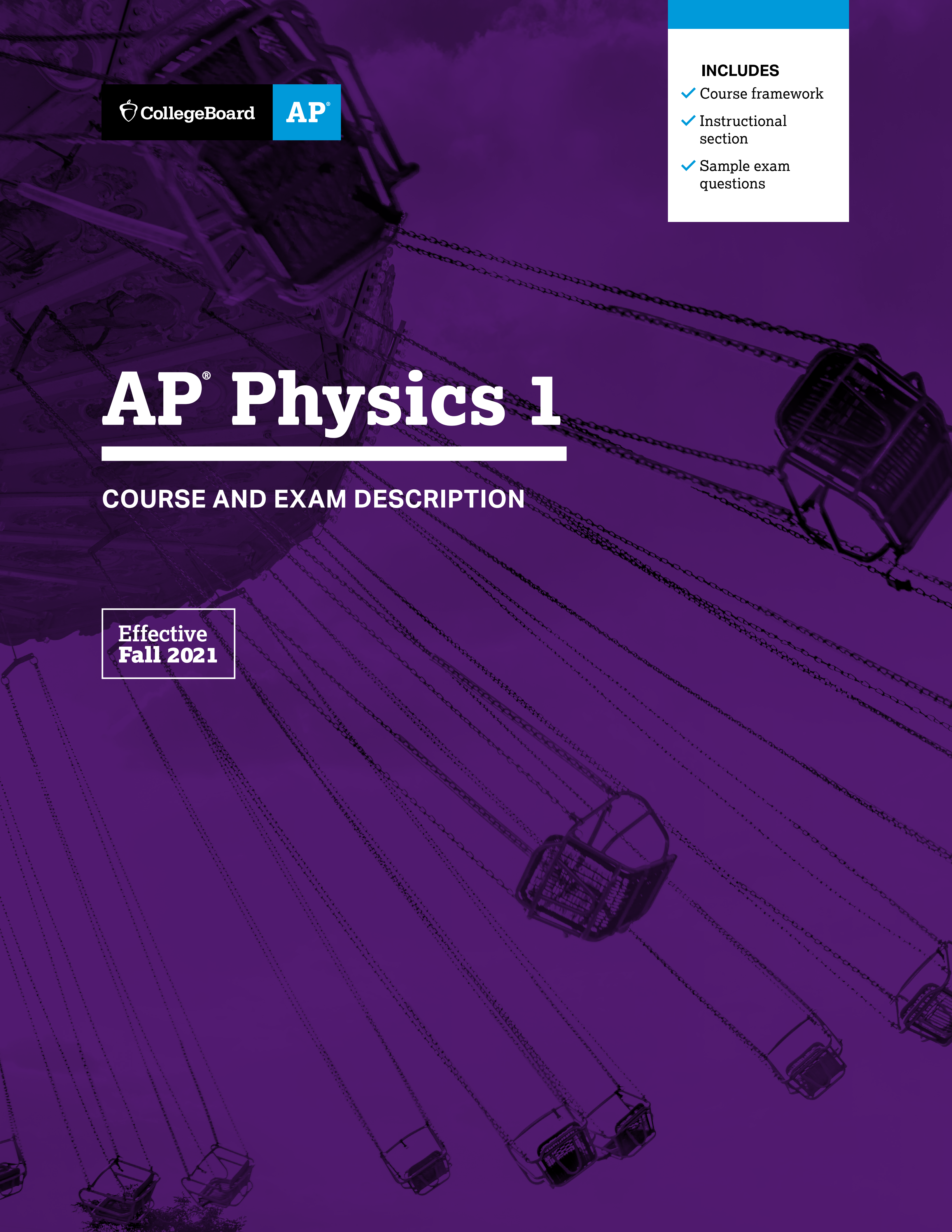

CollegeBoard AP®

INCLUDES
- Course framework
- Instructional section
- Sample exam questions

AP® Physics 1

COURSE AND EXAM DESCRIPTION

Effective
Fall 2021

AP® CollegeBoard

AP® Physics 1: Algebra-Based

COURSE AND EXAM DESCRIPTION

Effective
Fall 2021

AP COURSE AND EXAM DESCRIPTIONS ARE UPDATED PERIODICALLY

Please visit AP Central (apcentral.collegeboard.org) to determine whether a more recent course and exam description is available.

About College Board

College Board is a mission-driven not-for-profit organization that connects students to college success and opportunity. Founded in 1900, College Board was created to expand access to higher education. Today, the membership association is made up of over 6,000 of the world's leading educational institutions and is dedicated to promoting excellence and equity in education. Each year, College Board helps more than seven million students prepare for a successful transition to college through programs and services in college readiness and college success—including the SAT® and the Advanced Placement® Program. The organization also serves the education community through research and advocacy on behalf of students, educators, and schools.

For further information, visit **collegeboard.org**.

AP Equity and Access Policy

College Board strongly encourages educators to make equitable access a guiding principle for their AP programs by giving all willing and academically prepared students the opportunity to participate in AP. We encourage the elimination of barriers that restrict access to AP for students from ethnic, racial, and socioeconomic groups that have been traditionally underrepresented. Schools should make every effort to ensure their AP classes reflect the diversity of their student population. College Board also believes that all students should have access to academically challenging coursework before they enroll in AP classes, which can prepare them for AP success. It is only through a commitment to equitable preparation and access that true equity and excellence can be achieved.

Designers: Sonny Mui and Bill Tully

Visit College Board on the web: **collegeboard.org**.

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Acknowledgments

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About AP

College Board's Advanced Placement® Program (AP®) enables willing and academically prepared students to pursue college-level studies—with the opportunity to earn college credit, advanced placement, or both—while still in high school. Through AP courses in 38 subjects, each culminating in a challenging exam, students learn to think critically, construct solid arguments, and see many sides of an issue—skills that prepare them for college and beyond. Taking AP courses demonstrates to college admission officers that students have sought the most challenging curriculum available to them, and research indicates that students who score a 3 or higher on an AP Exam typically experience greater academic success in college and are more likely to earn a college degree than non-AP students. Each AP teacher's syllabus is evaluated and approved by faculty from some of the nation's leading colleges and universities, and AP Exams are developed and scored by college faculty and experienced AP teachers. Most four-year colleges and universities in the United States grant credit, advanced placement, or both on the basis of successful AP Exam scores; more than 3,300 institutions worldwide annually receive AP scores.

AP Course Development

In an ongoing effort to maintain alignment with best practices in college-level learning, AP courses and exams emphasize challenging, research-based curricula aligned with higher education expectations.

Individual teachers are responsible for designing their own curriculum for AP courses, selecting appropriate college-level readings, assignments, and resources. This course and exam description presents the content and science practices that are the focus of the corresponding college course and that appear on the AP Exam. It also organizes the content and science practices into a series of units that represent a sequence found in widely adopted college textbooks and that many AP teachers have told us they follow in order to focus their instruction. The intention of this publication is to respect teachers' time and expertise by providing a roadmap that they can modify and adapt to their local priorities and preferences. Moreover, by organizing the AP course content and science practices into units, the AP Program is able to provide teachers and students with free formative assessments—Personal Progress Checks—that teachers can assign throughout the year to measure student progress as they acquire content knowledge and develop science practices.

Enrolling Students: Equity and Access

College Board strongly encourages educators to make equitable access a guiding principle for their AP programs by giving all willing and academically prepared students the opportunity to participate in AP. We encourage the elimination of barriers that restrict access to AP for students from ethnic, racial, and socioeconomic groups that have been traditionally underserved. College Board also believes that all students should have access to academically challenging coursework before they enroll in AP classes, which can prepare them for AP success. It is only through a commitment to equitable preparation and access that true equity and excellence can be achieved.

Offering AP Courses: The AP Course Audit

The AP Program unequivocally supports the principle that each school implements its own curriculum that will enable students to develop the content understandings and science practices described in the course framework.

While the unit sequence represented in this publication is optional, the AP Program does have a short list of curricular and resource requirements that must be fulfilled before a school can label a course "Advanced Placement" or "AP." Schools wishing to offer AP courses must participate in the AP Course Audit, a process through which AP teachers' course materials are reviewed by college faculty. The AP Course Audit was created to provide teachers and administrators with clear guidelines on curricular and resource requirements for AP courses and to help colleges and universities validate courses marked "AP" on students' transcripts. This process ensures that AP teachers' courses meet or exceed the curricular and resource expectations that college and secondary school faculty have established for college-level courses.

The AP Course Audit form is submitted by the AP teacher and the school principal (or designated administrator) to confirm awareness and understanding of the curricular and resource requirements. A syllabus or course outline, detailing how course requirements are met, is submitted by the AP teacher for review by college faculty.

Please visit **collegeboard.org/apcourseaudit** for more information to support the preparation and submission of materials for the AP Course Audit.

How the AP Program Is Developed

The scope of content for an AP course and exam is derived from an analysis of hundreds of syllabi and course offerings of colleges and universities. Using this research and data, a committee of college faculty and expert AP teachers work within the scope of the corresponding college course to articulate what students should know and be able to do upon the completion of the AP course. The resulting course framework is the heart of this course and exam description and serves as a blueprint of the content and science practices that can appear on an AP Exam.

The AP Test Development Committees are responsible for developing each AP Exam, ensuring the exam questions are aligned to the course framework. The AP Exam development process is a multiyear endeavor; all AP Exams undergo extensive review, revision, piloting, and analysis to ensure that questions are accurate, fair, and valid and that there is an appropriate spread of difficulty across the questions.

Committee members are selected to represent a variety of perspectives and institutions (public and private, small and large schools and colleges) and a range of gender, racial/ethnic and regional groups. A list of each subject's current AP Test Development Committee members is available on **apcentral.collegeboard.org**.

Throughout AP course and exam development, College Board gathers feedback from various stakeholders in both secondary schools and higher education institutions. This feedback is carefully considered to ensure that AP courses and exams are able to provide students with a college-level learning experience and the opportunity to demonstrate their qualifications for advanced placement or college credit.

How AP Exams Are Scored

The exam scoring process, like the course and exam development process, relies on the expertise of both AP teachers and college faculty. While multiple-choice questions are scored by machine, the free-response questions and through-course performance assessments, as applicable, are scored by thousands of college faculty and expert AP teachers. Most are scored at the annual AP Reading, while a small portion is scored online. All AP Readers are thoroughly trained, and their work is monitored throughout the Reading for fairness and consistency. In each subject, a highly respected college faculty member serves as Chief Faculty Consultant and, with the help of AP Readers in leadership positions, maintains the accuracy of the scoring standards. Scores on the free-response questions and performance assessments are weighted and combined with the results of the computer-scored multiple-choice questions, and this raw score is converted into a composite AP score on a 1–5 scale.

AP Exams are **not** norm-referenced or graded on a curve. Instead, they are criterion-referenced, which means that every student who meets the criteria for an AP score of 2, 3, 4, or 5 will receive that score, no matter how many students that is. The criteria for the number of points students must earn on the AP Exam to receive scores of 3, 4, or 5—the scores that research consistently validates for credit and placement purposes—include:

- The number of points successful college students earn when their professors administer AP Exam questions to them.
- The number of points researchers have found to be predictive that an AP student will succeed when placed into a subsequent, higher-level college course.
- Achievement-level descriptions formulated by college faculty who review each AP Exam question.

Using and Interpreting AP Scores

The extensive work done by college faculty and AP teachers in the development of the course and exam and throughout the scoring process ensures that AP Exam scores accurately represent students' achievement in the equivalent college course. Frequent and regular research studies establish the validity of AP scores as follows:

AP Score	Credit Recommendation	College Grade Equivalent
5	Extremely well qualified	A
4	Well qualified	A-, B+, B
3	Qualified	B-, C+, C
2	Possibly qualified	n/a
1	No recommendation	n/a

While colleges and universities are responsible for setting their own credit and placement policies, most private colleges and universities award credit and/or advanced placement for AP scores of 3 or higher. Additionally, most states in the U.S. have adopted statewide credit policies that ensure college credit for scores of 3 or higher at public colleges and universities. To confirm a specific college's AP credit/placement policy, a search engine is available at **apstudent.org/creditpolicies**.

BECOMING AN AP READER

Each June, thousands of AP teachers and college faculty members from around the world gather for seven days in multiple locations to evaluate and score the free-response sections of the AP Exams. Ninety-eight percent of surveyed educators who took part in the AP Reading say it was a positive experience.

There are many reasons to consider becoming an AP Reader, including opportunities to:

- **Bring positive changes to the classroom:** Surveys show that the vast majority of returning AP Readers—both high school and college educators—make improvements to the way they teach or score because of their experience at the AP Reading.
- **Gain in-depth understanding of AP Exam and AP scoring standards:** AP Readers gain exposure to the quality and depth of the responses from the entire pool of AP Exam takers and thus are better able to assess their students' work in the classroom.
- **Receive compensation:** AP Readers are compensated for their work during the Reading. Expenses, lodging, and meals are covered for Readers who travel.
- **Score from home:** AP Readers have online distributed scoring opportunities for certain subjects. Check **collegeboard.org/apreading** for details.
- **Earn Continuing Education Units (CEUs):** AP Readers earn professional development hours and CEUs that can be applied to PD requirements by states, districts, and schools.

How to Apply

Visit **collegeboard.org/apreading** for eligibility requirements and to start the application process.

AP Resources and Supports

By completing a simple activation process at the start of the school year, teachers and students receive access to a robust set of classroom resources.

AP Classroom

AP Classroom is a dedicated online platform designed to support teachers and students throughout their AP experience. The platform provides a variety of powerful resources and tools to provide yearlong support to teachers and enable students to receive meaningful feedback on their progress.

UNIT GUIDES

Appearing in this publication and on AP Classroom, these planning guides outline all required course content and science practices, organized into commonly taught units. Each unit guide suggests a sequence and pacing of content, scaffolds skill instruction across units, organizes content into topics, and provides tips on taking the AP Exam.

PERSONAL PROGRESS CHECKS

Formative AP questions for every unit provide feedback to students on the areas where they need to focus. Available online, Personal Progress Checks measure knowledge and science practices through multiple-choice questions with rationales to explain correct and incorrect answers, and free-response questions with scoring information. Because the Personal Progress Checks are formative, the results of these assessments cannot be used to evaluate teacher effectiveness or assign letter grades to students, and any such misuses are grounds for losing school authorization to offer AP courses.*

PROGRESS DASHBOARD

This dashboard allows teachers to review class and individual student progress throughout the year. Teachers can view class trends and see where students struggle with content and science practices that will be assessed on the AP Exam. Students can view their own progress over time to improve their performance before the AP Exam.

AP QUESTION BANK

This online library of real AP Exam questions provides teachers with secure questions to use in their classrooms. Teachers can find questions indexed by course topics and science practices, create customized tests, and assign them online or on paper. These tests enable students to practice and get feedback on each question.

*To report misuses, please call, 877-274-6474 (International: +1-212-632-1781).

Digital Activation

In order to teach an AP class and make sure students are registered to take the AP Exam, teachers must first complete the digital activation process. Digital activation gives students and teachers access to resources and gathers students' exam registration information online, eliminating most of the answer sheet bubbling that has added to testing time and fatigue.

AP teachers and students begin by signing in to **My AP** and completing a simple activation process at the start of the school year, which provides access to all AP resources, including AP Classroom.

To complete digital activation:

- Teachers and students sign in to, or create, their College Board accounts.
- Teachers confirm that they have added the course they teach to their AP Course Audit account and have had it approved by their school's administrator.
- Teachers or AP Coordinators, depending on who the school has decided is responsible, set up class sections so students can access AP resources and have exams ordered on their behalf.
- Students join class sections with a join code provided by their teacher or AP coordinator.
- Students will be asked for additional registration information upon joining their first class section, which eliminates the need for extensive answer sheet bubbling on exam day.

While the digital activation process takes a short time for teachers, students, and AP coordinators to complete, overall it helps save time and provides the following additional benefits:

- **Access to AP resources and supports:** Teachers have access to resources specifically designed to support instruction and provide feedback to students throughout the school year as soon as activation is complete.
- **Streamlined exam ordering:** AP Coordinators can create exam orders from the same online class rosters that enable students to access resources. The coordinator reviews, updates, and submits this information as the school's exam order in the fall.
- **Student registration labels:** For each student included in an exam order, schools will receive a set of personalized AP ID registration labels, which replaces the AP student pack. The AP ID connects student's exam materials with the registration information they provided during digital activation, eliminating the need for pre-administration sessions and reducing time spent bubbling on exam day.
- **Targeted Instructional Planning Reports:** AP teachers will get Instructional Planning Reports (IPRs) that include data on each of their class sections automatically rather than relying on special codes optionally bubbled in on exam day.

Instructional Model

Integrating AP resources throughout the course can help students develop the course science practices and conceptual understandings. The instructional model outlined below shows possible ways to incorporate AP resources into the classroom.

Plan

Teachers may consider the following approaches as they plan their instruction before teaching each unit.

- Review the overview at the start of each **unit guide** to identify essential questions, conceptual understandings, and science practices for each unit.
- Use the **Unit at a Glance** table to identify related topics that build toward a common understanding, and then plan appropriate pacing for students.
- Identify useful strategies in the **Instructional Approaches** section to help teach the concepts and science practices.

Teach

When teaching, supporting resources can be used to build students' conceptual understanding and mastery of science practices.

- Use the topic pages in the **unit guides** to identify the required content.
- Integrate the content with a skill, considering any appropriate scaffolding.
- Employ any of the instructional strategies previously identified.
- Use the available resources on the topic pages to bring a variety of assets into the classroom.

Assess

Teachers can measure student understanding of the content and science practices covered in the unit and provide actionable feedback to students.

- At the end of each unit, use **AP Classroom** to assign students the online **Personal Progress Checks**, as homework or as an in-class task.
- Provide question-level feedback to students through answer rationales; provide unit- and skill-level feedback using the progress dashboard.
- Create additional practice opportunities using the **AP Question Bank** and assign them through **AP Classroom**.

About the AP Physics 1 Course

AP Physics 1 is an algebra-based, introductory college-level physics course. Students cultivate their understanding of physics through inquiry-based investigations as they explore these topics: kinematics, dynamics, circular motion and gravitation, energy, momentum, simple harmonic motion, torque and rotational motion, electric charge and electric force, DC circuits, and mechanical waves and sound.

College Course Equivalent

AP Physics 1 is a full-year course that is the equivalent of a first-semester introductory college course in algebra-based physics.

Prerequisites

There are no prerequisite courses. Students should have completed Geometry and be concurrently taking Algebra II or an equivalent course. Although the Physics 1 course includes basic use of trigonometric functions, this understanding can be gained either in the concurrent math course or in the AP Physics 1 course itself.

Laboratory Requirement

This course requires that twenty-five percent of instructional time will be spent in hands-on laboratory work, with an emphasis on inquiry-based investigations that provide students with opportunities to demonstrate the foundational physics principles and apply the science practices.

Inquiry-based laboratory experiences support the AP Physics 1 course and AP Course Audit 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.

Colleges may require students to present their laboratory materials from AP science courses before granting college credit for laboratory work, so students should be encouraged to retain their laboratory notebooks, reports, and other materials.

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AP PHYSICS 1

Course Framework

Introduction

The AP Physics 1 course outlined in this framework reflects a commitment to what physics teachers, professors, and researchers have agreed is the main goal of a college-level physics course: to help students develop a deep understanding of the foundational principles that shape classical mechanics. By confronting complex physical situations or scenarios, the course is designed to enable students to develop the ability to reason about physical phenomena using important science practices, such as explaining relationships, applying and justifying the use of mathematical routines, designing experiments, analyzing data, and making connections across multiple topics within the course.

To foster this deeper level of learning, the AP Physics 1 course defines concepts, science practices, and understandings required by representative colleges and universities for granting college credit and placement. Students will practice reasoning skills used by physicists by discussing and debating, with peers, the physical phenomena investigated in class, as well as by designing and conducting inquiry-based laboratory investigations to solve problems through first-hand observations, data collection, analysis, and interpretation.

This document is not a complete curriculum. Teachers create their own local curriculum by selecting, for each concept, content that enables students to explore the course learning objectives and meets state or local requirements. The result is a course that prepares students for college credit and placement.

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Course Framework Components

Overview

This course framework provides a clear and detailed description of the course requirements necessary for student success. The framework specifies what students must know, be able to do, and understand to qualify for college credit or placement.

The course framework includes two essential components:

1. **SCIENCE PRACTICES**
The science practices are central to the study and practice of physics. Students should develop and apply the described practices on a regular basis over the span of the course.

2. **COURSE CONTENT**
The course content is organized into commonly taught units of study that provide a suggested sequence for the course and detail required content and conceptual understandings that colleges and universities typically expect students to master to qualify for college credit and/or placement. This content is grounded in big ideas, which are cross-cutting concepts that build conceptual understanding and spiral throughout the course.

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AP PHYSICS 1

Science Practices

The table that follows presents the science practices that students should develop during the AP Physics 1 course. These practices form the basis of many tasks on the AP Physics 1 Exam.

The unit guides that follow embed and spiral these practices throughout the course, providing teachers with one way to integrate the practices into the course content with sufficient repetition to prepare students to transfer those science practices when taking the AP Physics 1 Exam.

More detailed information about teaching the science practices can be found in the Instructional Approaches section of this publication.

AP PHYSICS 1

Science Practices

Practice 1	Practice 2	Practice 3	Practice 4	Practice 5	Practice 6	Practice 7
Modeling 1 The student can use representations and models to communicate scientific phenomena and solve scientific problems.	***Mathematical Routines*** 2 The student can use mathematics appropriately.	***Scientific Questioning*** 3 The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course *(not assessed on the AP Exam).*	***Experimental Methods*** 4 The student can plan and implement data-collection strategies in relation to a particular scientific question.	***Data Analysis*** 5 The student can perform data analysis and evaluation of evidence.	***Argumentation*** 6 The student can work with scientific explanations and theories.	***Making Connections*** 7 The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.
1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain. **1.2** The student can describe representations and models of natural or man-made phenomena and systems in the domain. **1.3** The student can refine representations and models of natural or man-made phenomena and systems in the domain. **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain.	**2.1** The student can justify the selection of a mathematical routine to solve problems. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **2.3** The student can estimate quantities that describe natural phenomena.	**3.1** The student can pose scientific questions. **3.2** The student can refine scientific questions. **3.3** The student can evaluate scientific questions.	**4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question. **4.2** The student can design a plan for collecting data to answer a particular scientific question. **4.3** The student can collect data to answer a particular scientific question. **4.4** The student can evaluate sources of data to answer a particular scientific question.	**5.1** The student can analyze data to identify patterns or relationships. **5.2** The student can refine observations and measurements based on data analysis. **5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question.	**6.1** The student can justify claims with evidence. **6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices. **6.3** The student can articulate the reasons that scientific explanations and theories are refined or replaced. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **6.5** The student can evaluate alternative scientific explanations.	**7.1** The student can connect phenomena and models across spatial and temporal scales. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

2

AP PHYSICS 1

Course Content

Based on the Understanding by Design® (Wiggins and McTighe) model, this course framework provides a clear and detailed description of the course requirements necessary for student success. The framework specifies what students must know, be able to do, and understand, with a focus on six big ideas that encompass core principles, theories, and processes of physics. The framework also encourages instruction that prepares students to make connections across domains through a broader way of thinking about the physical world.

Big Ideas

The big ideas serve as the foundation of the course and allow students to create meaningful connections among concepts. They are often abstract concepts or themes that become threads that run throughout the course. Revisiting the big ideas and applying them in a variety of contexts allows students to develop deeper conceptual understanding. Below are the big ideas of the course and a brief description of each.

BIG IDEA 1: SYSTEMS (SYS)
Objects and systems have properties such as mass and charge. Systems may have internal structure.

BIG IDEA 2: FIELDS (FLD)
Fields existing in space can be used to explain interactions.

BIG IDEA 3: FORCE INTERACTIONS (INT)
The interactions of an object with other objects can be described by forces.

BIG IDEA 4: CHANGE (CHA)
Interactions between systems can result in changes in those systems.

BIG IDEA 5: CONSERVATION (CON)
Changes that occur as a result of interactions are constrained by conservation laws.

UNITS

The course content is organized into commonly taught units. The units have been arranged in a logical sequence frequently found in many college courses and textbooks.

The 7 units in AP Physics 1 and their relevant weightings on the multiple-choice section of AP Exam are listed below.

Pacing recommendations at the unit level and on the Course at Glance provide suggestions for how teachers can cover both the required course content and the Personal Progress Checks. The suggested class periods are based on a schedule in which the class meets five days a week for 45 minutes each day. While these recommendations have been made to aid in planning, teachers are free to adjust the pacing based on the needs of their students, alternate schedules (e.g., block scheduling), or their school's academic calendar.

TOPICS

Each unit is divided into teachable segments called topics. Visit the topic pages (starting on page 36) to see all required content for each topic.

Exam Weighting for the Multiple-Choice Section of the AP Exam

Units	Exam Weighting
Unit 1: *Kinematics*	**12–18%**
Unit 2: *Dynamics*	**16–20%**
Unit 3: *Circular Motion and Gravitation*	**6–8%**
Unit 4: *Energy*	**20–28%**
Unit 5: *Momentum*	**12–18%**
Unit 6: *Simple Harmonic Motion*	**4–6%**
Unit 7: *Torque and Rotational Motion*	**12–18%**

Spiraling the Big Ideas

The following table shows how the big ideas spiral across units by showing the units in which each big idea appears.

Big Ideas	Unit 1 *Kinematics*	Unit 2 *Dynamics*	Unit 3 *Circular Motion and Gravitation*	Unit 4 *Energy*	Unit 5 *Momentum*	Unit 6 *Simple Harmonic Motion*	Unit 7 *Torque and Rotational Motion*
1-Systems SYS		✓	✓				
2-Fields FLD		✓	✓				
3-Force Interactions INT	✓	✓	✓	✓	✓	✓	✓
4-Change CHA	✓	✓	✓	✓	✓		✓
5-Conservation CON				✓	✓	✓	✓

Course at a Glance

Plan

The Course at a Glance provides a useful visual organization of the AP Physics 1 course components, including:

- Sequence of units, along with approximate weighting and suggested pacing. Please note, pacing is based on 45-minute class periods, meeting five days each week for a full academic year.
- Progression of topics within each unit.
- Spiraling of the big ideas and science practices across units.

Teach

PRACTICES
Science practices spiral throughout the course.

1 Modeling
2 Mathematical Routines
3 Scientific Questioning
4 Experimental Methods
5 Data Analysis
6 Argumentation
7 Making Connections

+ Indicates 3 or more science pratices for a given topic. The individual topic page will show all the science practices.

BIG IDEAS
Big ideas spiral across topics and units.

SYS 1-Systems
FLD 2-Fields
INT 3-Force Interactions
CHA 4-Change
CON 5-Conservation

Assess

Assign the Personal Progress Checks—either as homework or in class—for each unit. Each Personal Progress Check contains formative multiple-choice and free-response questions. The feedback from these checks shows students the areas where they need to focus.

UNIT 1 Kinematics

~19-22 Class Periods | 12-18% AP Exam Weighting

Big Idea	Practices	Topic
INT	+	1.1 Position, Velocity, and Acceleration
CHA	+	1.2 Representations of Motion

Personal Progress Check 1

Multiple-choice: ~15 questions
Free-response: 2 questions
- Experimental Design
- Paragraph Argument Short Answer

UNIT 2 Dynamics

~21-24 Class Periods | 16-20% AP Exam Weighting

Big Idea	Practices	Topic
SYS	1, 7	2.1 Systems
FLD	2, 7	2.2 The Gravitational Field
INT	6	2.3 Contact Forces
SYS	4	2.4 Newton's First Law
INT	+	2.5 Newton's Third Law and Free-Body Diagrams
INT	+	2.6 Newton's Second Law
CHA	+	2.7 Applications of Newton's Second Law

Personal Progress Check 2

Multiple-choice: ~40 questions
Free-response: 2 questions
- Quantitative/Qualitative Translation
- Short Answer

UNIT 3 Circular Motion and Gravitation

~8-10 Class Periods | 6-8% AP Exam Weighting

- FLD — 3.1 Vector Fields
- INT, 7 — 3.2 Fundamental Forces
- INT, 2, 7 — 3.3 Gravitational and Electric Forces
- FLD, 2, 7 — 3.4 Gravitational Field/ Acceleration Due to Gravity on Different Planets
- SYS, 4 — 3.5 Inertial vs. Gravitational Mass
- CHA, 5 — 3.6 Centripetal Acceleration and Centripetal Force
- INT, + — 3.7 Free-Body Diagrams for Objects in Uniform Circular Motion
- INT, + — 3.8 Applications of Circular Motion and Gravitation

Personal Progress Check 3

Multiple-choice: ~40 questions
Free-response: 2 questions

- Experimental Design
- Paragraph Argument Short Answer

UNIT 4 Energy

~22-25 Class Periods | 20-28% AP Exam Weighting

- CON, 6, 7 — 4.1 Open and Closed Systems: Energy
- INT, CHA, + — 4.2 Work and Mechanical Energy
- CON, + — 4.3 Conservation of Energy, the Work-Energy Principle, and Power

Personal Progress Check 4

Multiple-choice: ~30 questions
Free-response: 2 questions

- Quantitative/Qualitative Translation
- Short Answer

UNIT 5 Momentum

~14-17 Class Periods | 12-18% AP Exam Weighting

- INT, + — 5.1 Momentum and Impulse
- CHA, + — 5.2 Representations of Changes in Momentum
- CON, 6, 7 — 5.3 Open and Closed Systems: Momentum
- CON, + — 5.4 Conservation of Linear Momentum

Personal Progress Check 5

Multiple-choice: ~35 questions
Free-response: 2 questions

- Experimental Design
- Paragraph Argument Short Answer

UNIT 6 Simple Harmonic Motion

~4-7 Class Periods | 4-6% AP Exam Weighting

INT +

6.1 Period of Simple Harmonic Oscillators

CON +

6.2 Energy of a Simple Harmonic Oscillator

Personal Progress Check 6

Multiple-choice: ~20 questions
Free-response: 2 questions
- Experimental Design
- Short Answer

UNIT 7 Torque and Rotational Motion

~14-19 Class Periods | 12-18% AP Exam Weighting

INT 1 2

7.1 Rotational Kinematics

INT +

7.2 Torque and Angular Acceleration

CHA +

7.3 Angular Momentum and Torque

CHA +

7.4 Conservation of Angular Momentum

Personal Progress Check 7

Multiple-choice: ~40 questions
Free-response: 2 questions
- Quantitative/Qualitative Translation
- Paragraph Argument Short Answer

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AP PHYSICS 1

Unit Guides

Introduction

Designed with input from the community of AP Physics 1 educators, the unit guides offer teachers helpful guidance in building students' skills and knowledge. The suggested sequence was identified through a thorough analysis of the syllabi of highly effective AP teachers and the organization of typical college textbooks.

This unit structure respects new AP teachers' time by providing one possible sequence they can adopt or modify rather than having to build from scratch. An additional benefit is that these units enable the AP Program to provide interested teachers with formative assessments—the Personal Progress Checks—that they can assign their students at the end of each unit to gauge progress toward success on the AP Exam. However, experienced AP teachers who are satisfied with their current course organization and exam results should feel no pressure to adopt these units, which comprise an optional sequence for this course.

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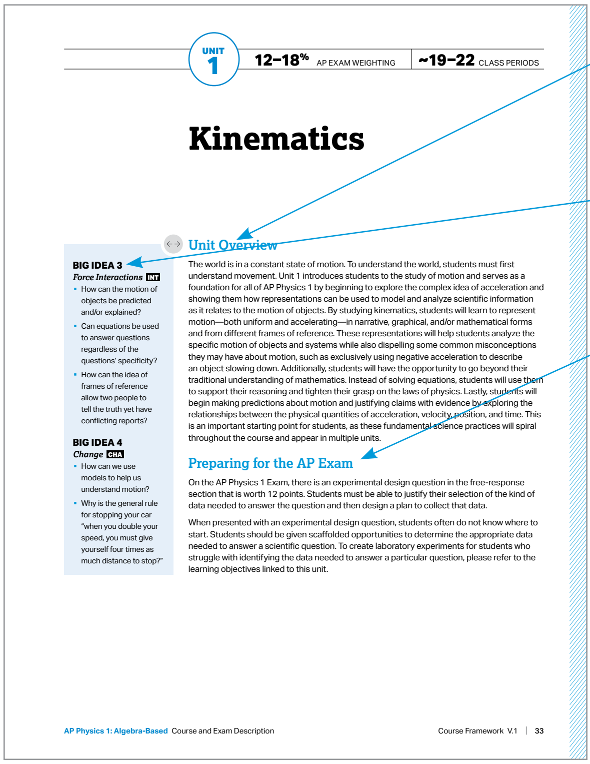
Using the Unit Guides



UNIT 1 | 12–18% AP EXAM WEIGHTING | ~19–22 CLASS PERIODS

Kinematics

BIG IDEA 3
Force Interactions INT
- How can the motion of objects be predicted and/or explained?
- Can equations be used to answer questions regardless of the questions' specificity?
- How can the idea of frames of reference allow two people to tell the truth yet have conflicting reports?

BIG IDEA 4
Change CHA
- How can we use models to help us understand motion?
- Why is the general rule for stopping your car "when you double your speed, you must give yourself four times as much distance to stop?"

Unit Overview

The world is in a constant state of motion. To understand the world, students must first understand movement. Unit 1 introduces students to the study of motion and serves as a foundation for all of AP Physics 1 by beginning to explore the complex idea of acceleration and showing them how representations can be used to model and analyze scientific information as it relates to the motion of objects. By studying kinematics, students will learn to represent motion—both uniform and accelerating—in narrative, graphical, and/or mathematical forms and from different frames of reference. These representations will help students analyze the specific motion of objects and systems while also dispelling some common misconceptions they may have about motion, such as exclusively using negative acceleration to describe an object slowing down. Additionally, students will have the opportunity to go beyond their traditional understanding of mathematics. Instead of solving equations, students will use them to support their reasoning and tighten their grasp on the laws of physics. Lastly, students will begin making predictions about motion and justifying claims with evidence by exploring the relationships between the physical quantities of acceleration, velocity, position, and time. This is an important starting point for students, as these fundamental science practices will spiral throughout the course and appear in multiple units.

Preparing for the AP Exam

On the AP Physics 1 Exam, there is an experimental design question in the free-response section that is worth 12 points. Students must be able to justify their selection of the kind of data needed to answer the question and then design a plan to collect that data.

When presented with an experimental design question, students often do not know where to start. Students should be given scaffolded opportunities to determine the appropriate data needed to answer a scientific question. To create laboratory experiments for students who struggle with identifying the data needed to answer a particular question, please refer to the learning objectives linked to this unit.

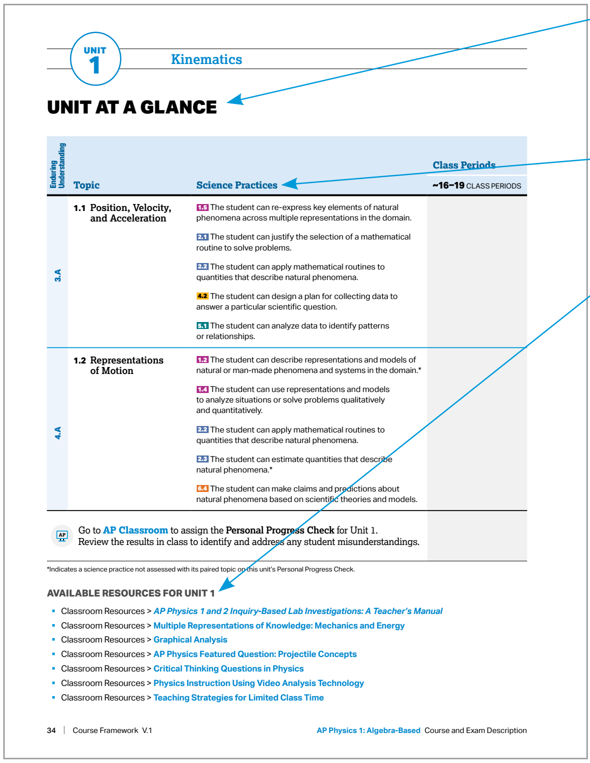
AP Physics 1: Algebra-Based Course and Exam Description — Course Framework V.1 | 33

UNIT OPENERS

The **Unit Overview** contextualizes and situates the key content of the unit within the scope of the course. It also describes specific aspects of the science practices that are appropriate to focus on in that unit.

Big ideas serve as the foundation of the course and develop understanding as they spiral throughout the course. The **essential questions** are thought-provoking questions that motivate students and inspire inquiry.

Preparing for the AP Exam provides helpful tips and common student misunderstandings identified from prior exam data.



UNIT 1 Kinematics

UNIT AT A GLANCE

Enduring Understanding	Topic	Science Practices	Class Periods ~16–19 CLASS PERIODS
3.A	1.1 Position, Velocity, and Acceleration	1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain. 2.1 The student can justify the selection of a mathematical routine to solve problems. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 4.2 The student can design a plan for collecting data to answer a particular scientific question. 5.1 The student can analyze data to identify patterns or relationships.	
4.A	1.2 Representations of Motion	1.2 The student can describe representations and models of natural or man-made phenomena and systems in the domain.* 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 2.3 The student can estimate quantities that describe natural phenomena.* 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 1. Review the results in class to identify and address any student misunderstandings.

*Indicates a science practice not assessed with its paired topic on this unit's Personal Progress Check.

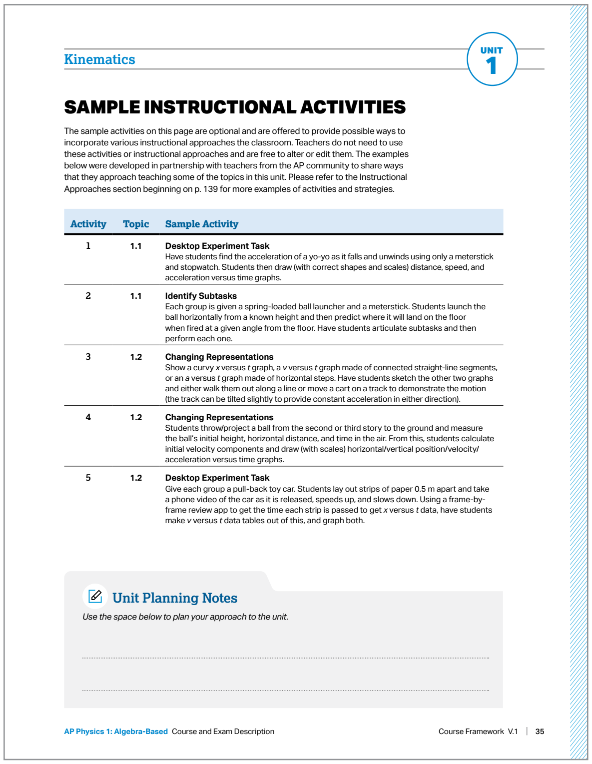
AVAILABLE RESOURCES FOR UNIT 1
- Classroom Resources > *AP Physics 1 and 2 Inquiry-Based Lab Investigations: A Teacher's Manual*
- Classroom Resources > Multiple Representations of Knowledge: Mechanics and Energy
- Classroom Resources > Graphical Analysis
- Classroom Resources > AP Physics Featured Question: Projectile Concepts
- Classroom Resources > Critical Thinking Questions in Physics
- Classroom Resources > Physics Instruction Using Video Analysis Technology
- Classroom Resources > Teaching Strategies for Limited Class Time

34 | Course Framework V.1 — AP Physics 1: Algebra-Based Course and Exam Description

The **Unit at a Glance** table shows the topics, related enduring understandings, and science practices. The "class periods" column has been left blank so teachers can customize the time they spend on each topic.

The **science practices** for each topic link the content in that topic to specific AP Physics 1 science practices. The questions on the Personal Progress Checks are based on these links.

Available resources might help teachers address a particular topic in their classroom.



Kinematics

UNIT 1

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 139 for more examples of activities and strategies.

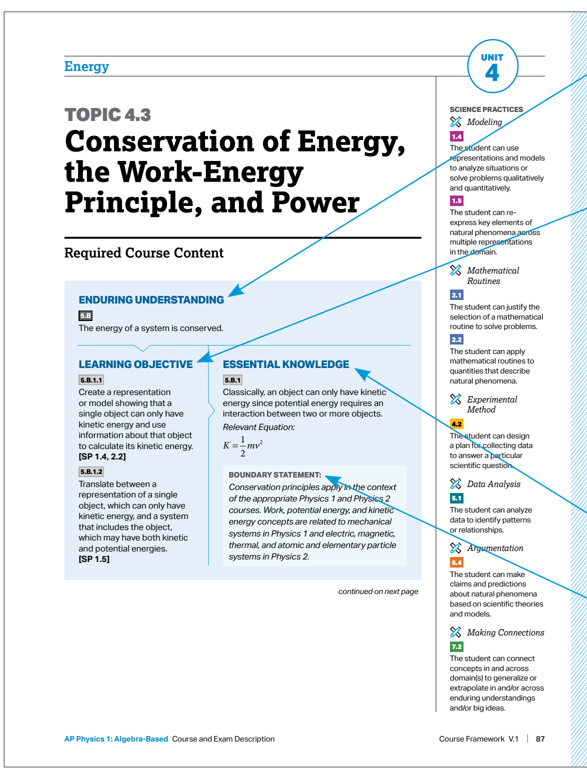
Activity	Topic	Sample Activity
1	1.1	**Desktop Experiment Task** Have students find the acceleration of a yo-yo as it falls and unwinds using only a meterstick and stopwatch. Students then draw (with correct shapes and scales) distance, speed, and acceleration versus time graphs.
2	1.1	**Identify Subtasks** Each group is given a spring-loaded ball launcher and a meterstick. Students launch the ball horizontally from a known height and then predict where it will land on the floor when fired at a given angle from the floor. Have students articulate subtasks and then perform each one.
3	1.2	**Changing Representations** Show a curvy *x* versus *t* graph, a *v* versus *t* graph made of connected straight-line segments, or an *a* versus *t* graph made of horizontal steps. Have students sketch the other two graphs and either walk them out along a line or move a cart on a track to demonstrate the motion (the track can be tilted slightly to provide constant acceleration in either direction).
4	1.2	**Changing Representations** Students throw/project a ball from the second or third story to the ground and measure the ball's initial height, horizontal distance, and time in the air. From this, students calculate initial velocity components and draw (with scales) horizontal/vertical position/velocity/acceleration versus time graphs.
5	1.2	**Desktop Experiment Task** Give each group a pull-back toy car. Students lay out strips of paper 0.5 m apart and take a phone video of the car as it is released, speeds up, and slows down. Using a frame-by-frame review app to get the time each strip is passed to get *x* versus *t* data, have students make *v* versus *t* data tables out of this, and graph both.

Unit Planning Notes

Use the space below to plan your approach to the unit.

AP Physics 1: Algebra-Based Course and Exam Description Course Framework V.1 | 35

The **Sample Instructional Activities** page includes optional activities that can help tie together the content and science practices of a particular topic.



Energy

UNIT 4

TOPIC 4.3

Conservation of Energy, the Work-Energy Principle, and Power

Required Course Content

ENDURING UNDERSTANDING

5.B

The energy of a system is conserved.

LEARNING OBJECTIVE

5.B.1.1

Create a representation or model showing that a single object can only have kinetic energy and use information about that object to calculate its kinetic energy. **[SP 1.4, 2.2]**

5.B.1.2

Translate between a representation of a single object, which can only have kinetic energy, and a system that includes the object, which may have both kinetic and potential energies. **[SP 1.5]**

ESSENTIAL KNOWLEDGE

5.B.1

Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects.

Relevant Equation:

$$K = \frac{1}{2}mv^2$$

BOUNDARY STATEMENT:

Conservation principles apply in the context of the appropriate Physics 1 and Physics 2 courses. Work, potential energy, and kinetic energy concepts are related to mechanical systems in Physics 1 and electric, magnetic, thermal, and atomic and elementary particle systems in Physics 2.

continued on next page

SCIENCE PRACTICES

Modeling

1.4

The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

1.5

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

Mathematical Routines

2.1

The student can justify the selection of a mathematical routine to solve problems.

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

Experimental Method

4.2

The student can design a plan for collecting data to answer a particular scientific question.

Data Analysis

5.1

The student can analyze data to identify patterns or relationships.

Argumentation

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

AP Physics 1: Algebra-Based Course and Exam Description Course Framework V.1 | 87

TOPIC PAGES

Enduring understandings are the long-term takeaways related to the big ideas that leave a lasting impression on students. Students build and earn these understandings over time by exploring and applying course content throughout the year.

Learning objectives provide clear and detailed articulation of what students should know and be able to do in order to progress toward the enduring understandings. Each learning objective is designed to help teachers integrate science practices **[SP]** with specific content and to provide them with clear information on how students will be expected to demonstrate their knowledge and science practices on the AP Physics 1 Exam. These learning objectives fully define what will be assessed on the exam. Questions that do not correspond to one or more learning objectives will not appear on the exam.

Essential knowledge statements describe the knowledge required to perform the learning objective.

Boundary statements provide guidance to teachers regarding the content boundaries of the AP Physics 1 and 2 courses. These statements help articulate the contextual differences of how the same big ideas and enduring understandings are applied in each course. Boundary statements appear at the end of essential knowledge statements where appropriate.

REQUIRED COURSE CONTENT LABELING SYSTEM

BIG IDEA 4
Change
CHA

ENDURING UNDERSTANDING

4.A

The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\sum \vec{F}}{m}$.

ESSENTIAL KNOWLEDGE

4.A.1

The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass.

a. The variables *x*, *v*, and *a* all refer to the center-of-mass quantities.

Relevant Equations:

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

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

$$v_x^{\ 2} = v_{x0}^2 + 2a_x(x - x_0)$$

LEARNING OBJECTIVE

4.A.1.1

Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively.
[SP 1.2, 1.4, 2.3, 6.4]

Note: Labels are used to distinguish each unique element of the required course content and are used throughout this course and exam description. Additionally, they are used in the AP Question Bank and other resources found in AP Classroom. Big ideas are labeled by number, with "1" referring to SYS, "2" referring to FLD, "3" referring to INT, "4" referring to CHA, "5" referring to CON, and "6" referring to WAV. The Course at a Glance on p. 20 contains more information on how the big ideas are numbered. Enduring understandings are labeled sequentially according to the big idea that they are related to. Essential knowledge statements are labeled to correspond with the enduring understanding they relate to. Finally, learning objectives are labeled to correspond with the essential knowledge statement they relate to.

AP PHYSICS 1

UNIT 1

Kinematics

12–18%
AP EXAM WEIGHTING

~19–22
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topics and science practices.

Personal Progress Check 1

Multiple-choice: ~15 questions
Free-response: 2 questions

- Experimental Design
- Paragraph Argument Short Answer

UNIT 1

12–18% AP EXAM WEIGHTING

~19–22 CLASS PERIODS

Kinematics

BIG IDEA 3

Force Interactions **INT**

- How can the motion of objects be predicted and/or explained?
- Can equations be used to answer questions regardless of the questions' specificity?
- How can the idea of frames of reference allow two people to tell the truth yet have conflicting reports?

BIG IDEA 4

Change **CHA**

- How can we use models to help us understand motion?
- Why is the general rule for stopping your car "when you double your speed, you must give yourself four times as much distance to stop?"

Unit Overview

The world is in a constant state of motion. To understand the world, students must first understand movement. Unit 1 introduces students to the study of motion and serves as a foundation for all of AP Physics 1 by beginning to explore the complex idea of acceleration and showing them how representations can be used to model and analyze scientific information as it relates to the motion of objects. By studying kinematics, students will learn to represent motion—both uniform and accelerating—in narrative, graphical, and/or mathematical forms and from different frames of reference. These representations will help students analyze the specific motion of objects and systems while also dispelling some common misconceptions they may have about motion, such as exclusively using negative acceleration to describe an object slowing down. Additionally, students will have the opportunity to go beyond their traditional understanding of mathematics. Instead of solving equations, students will use them to support their reasoning and tighten their grasp on the laws of physics. Lastly, students will begin making predictions about motion and justifying claims with evidence by exploring the relationships between the physical quantities of acceleration, velocity, position, and time. This is an important starting point for students, as these fundamental science practices will spiral throughout the course and appear in multiple units.

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- Classroom Resources > **Critical Thinking Questions in Physics**
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Unit Planning Notes

Use the space below to plan your approach to the unit.

SCIENCE PRACTICES

Modeling

1.5

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

Mathematical Routines

2.1

The student can justify the selection of a mathematical routine to solve problems.

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

Experimental Method

4.2

The student can design a plan for collecting data to answer a particular scientific question.

Data Analysis

5.1

The student can analyze data to identify patterns or relationships.

TOPIC 1.1
Position, Velocity, and Acceleration

Required Course Content

ENDURING UNDERSTANDING

3.A

All forces share certain common characteristics when considered by observers in inertial reference frames.

LEARNING OBJECTIVE

3.A.1.1

Express the motion of an object using narrative, mathematical, and graphical representations. **[SP 1.5, 2.1, 2.2]**

3.A.1.2

Design an experimental investigation of the motion of an object. **[SP 4.2]**

3.A.1.3

Analyze experimental data describing the motion of an object and be able to express the results of the analysis using narrative, mathematical, and graphical representations. **[SP 5.1]**

ESSENTIAL KNOWLEDGE

3.A.1

An observer in a reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.

a. Displacement, velocity, and acceleration are all vector quantities.

b. Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values.

Relevant Equations:

$$\vec{v}_{avg} = \frac{\Delta \vec{x}}{\Delta t}$$

$$\vec{a}_{avg} = \frac{\Delta \vec{v}}{\Delta t}$$

c. A choice of reference frame determines the direction and the magnitude of each of these quantities.

d. There are three fundamental interactions or forces in nature: the gravitational force, the electroweak force, and the strong force. The fundamental forces determine both the structure of objects and the motion of objects.

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LEARNING OBJECTIVE

3.A.1.1

Express the motion of an object using narrative, mathematical, and graphical representations. **[SP 1.5, 2.1, 2.2]**

3.A.1.2

Design an experimental investigation of the motion of an object. **[SP 4.2]**

3.A.1.3

Analyze experimental data describing the motion of an object and be able to express the results of the analysis using narrative, mathematical, and graphical representations. **[SP 5.1]**

ESSENTIAL KNOWLEDGE

e. In inertial reference frames, forces are detected by their influence on the motion (specifically the velocity) of an object. So force, like velocity, is a vector quantity. A force vector has magnitude and direction. When multiple forces are exerted on an object, the vector sum of these forces, referred to as the net force, causes a change in the motion of the object. The acceleration of the object is proportional to the net force.

f. The kinematic equations only apply to constant acceleration situations. Circular motion and projectile motion are both included. Circular motion is further covered in Unit 3. The three kinematic equations describing linear motion with constant acceleration in one and two dimensions are

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

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

$$v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$$

g. For rotational motion, there are analogous quantities such as angular position, angular velocity, and angular acceleration. The kinematic equations describing angular motion with constant angular acceleration are

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega = \omega_0 + \alpha t$$

$$\omega^2 = \omega_0^2 + 2\alpha_x(\theta - \theta_0)$$

h. This also includes situations where there is both a radial and tangential acceleration for an object moving in a circular path.

Relevant Equation:

$$a_c = \frac{v^2}{r}$$

For uniform circular motion of radius r, v is proportional to omega, ω (for a given r), and proportional to r (for a given omega, ω). Given a radius r and a period of rotation T, students derive and apply $v = (2\pi r)/T$.

BOUNDARY STATEMENT:

AP Physics 2 has learning objectives under Enduring Understanding 3.A that focus on electric and magnetic forces and other forces arising in the context of interactions introduced in Physics 2, rather than the mechanical systems introduced in Physics 1.

SCIENCE PRACTICES

Modeling

1.2

The student can describe representations and models of natural or man-made phenomena and systems in the domain.

1.4

The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

Mathematical Routines

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

2.3

The student can estimate quantities that describe natural phenomena.

Argumentation

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

TOPIC 1.2
Representations of Motion

Required Course Content

ENDURING UNDERSTANDING

4.A

The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\sum \vec{F}}{m}$.

LEARNING OBJECTIVE

4.A.1.1

Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively. **[SP 1.2, 1.4, 2.3, 6.4]**

ESSENTIAL KNOWLEDGE

4.A.1

The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass.

a. The variables *x*, *v*, and *a* all refer to the center-of-mass quantities.

Relevant Equations:

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

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

$$v_x^{\,2} = v_{x0}^2 + 2a_x(x - x_0)$$

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LEARNING OBJECTIVE

4.A.2.1

Make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time. **[SP 6.4]**

4.A.2.3

Create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system. **[SP 1.4, 2.2]**

ESSENTIAL KNOWLEDGE

4.A.2

The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time.

a. The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system.

b. Force and acceleration are both vectors, with acceleration in the same direction as the net force.

c. The acceleration of the center of mass of a system is equal to the rate of change of the center of mass velocity with time, and the center of mass velocity is equal to the rate of change of position of the center of mass with time.

d. The variables *x*, *v*, and *a* all refer to the center-of-mass quantities.

Relevant Equations:

$$\vec{a} = \frac{\sum \vec{F}}{m_{system}}$$

$$\vec{v}_{avg} = \frac{\Delta \vec{x}}{\Delta t}$$

$$\vec{a}_{avg} = \frac{\Delta \vec{v}}{\Delta t}$$

AP PHYSICS 1

UNIT 2

Dynamics

16–20%

AP EXAM WEIGHTING

~21–24

CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topics and science practices.

Personal Progress Check 2

Multiple-choice: ~40 questions
Free-response: 2 questions

- Quantitative/Qualitative Translation
- Short Answer

UNIT 2

16–20% AP EXAM WEIGHTING

~21–24 CLASS PERIODS

Dynamics

BIG IDEA 1
***Systems* SYS**
- How can the properties of internal and gravitational mass be experimentally verified to be the same?
- How do you decide what to believe about scientific claims?
- How does something we cannot see determine how an object behaves?

BIG IDEA 2
***Fields* FLD**
- How do objects with mass respond when placed in a gravitational field?
- Why is the acceleration due to gravity constant on Earth's surface?

BIG IDEA 3
***Force Interactions* INT**
- Are different kinds of forces *really* different?
- How can Newton's laws of motion be used to predict the behavior of objects?

BIG IDEA 4
***Change* CHA**
- Why does the same push change the motion of a shopping cart more than the motion of a car?

Unit Overview

In Unit 2, students are introduced to the term force, which is the interaction of an object with another object. Part of the larger study of dynamics, forces are used as the lens through which students analyze and come to understand a variety of physical phenomena. This is accomplished by revisiting and building upon the representations presented in Unit 1, specifically the introduction to the free-body diagram. Translation, however, is key in this unit: Students must be able to portray the same object–force interactions through different graphs, diagrams, and mathematical relationships. Students will continue to make meaning from models and representations that will help them further analyze systems, the interactions between systems, and how these interactions result in change.

Alongside mastering the use of specific force equations, Unit 2 also encourages students to derive new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts. The skill of making predictions will be nurtured throughout the course to help students craft sound scientific arguments.

Preparing for the AP Exam

The AP Physics 1 Exam requires students to be able to re-express key elements of natural phenomena across multiple representations in the domain. This skill appears in the Qualitative/Quantitative Translation (QQT), a long free-response question that requires students to go between words and mathematics in describing and analyzing a situation. A QQT question might ask students to work with multiple representations or to evaluate another student's words or representations. Representations include mathematical equations, narrative descriptions, graphs, diagrams, and data tables.

Students who have primarily been exposed to numerical problem solving often struggle with a QQT question because it requires students to have a more conceptual understanding of both content and representations. Opportunities to translate between different representations, including equations, diagrams, graphs, and written descriptions, will help students prepare for the QQT question.

UNIT AT A GLANCE

Enduring Understanding	Topic	Science Practices	Class Periods ~21-24 CLASS PERIODS
1.A	2.1 Systems	1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain.* 7.1 The student can connect phenomena and models across spatial and temporal scales.*	
2.B	2.2 The Gravitational Field	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.	
3.C	2.3 Contact Forces	6.1 The student can justify claims with evidence. 6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices.*	
1.C	2.4 Newton's First Law	4.2 The student can design a plan for collecting data to answer a particular scientific question.	
3.A	2.5 Newton's Third Law and Free-Body Diagrams	1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.1 The student can justify claims with evidence. 6.2 The student can construct explanations of phenomena based on evidence produced through scientific practices. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.	

*Indicates a science practice not assessed with its paired topic on this unit's Personal Progress Check.

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UNIT AT A GLANCE *(cont'd)*

Enduring Understanding	Topic	Science Practices	Class Periods ~21-24 CLASS PERIODS
3.B	**2.6** Newton's Second Law	**1.1** The student can create representations and models of natural or man-made phenomena and systems in the domain. **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **4.2** The student can design a plan for collecting data to answer a particular scientific question.* **5.1** The student can analyze data to identify patterns or relationships. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.	

*Indicates a science practice not assessed with its paired topic on this unit's Personal Progress Check.

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UNIT AT A GLANCE *(cont'd)*

Enduring Understanding	Topic	Science Practices	Class Periods ~21-24 CLASS PERIODS
4.A	**2.7 Applications of Newton's Second Law**	**1.2** The student can describe representations and models of natural or man-made phenomena and systems in the domain.* **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **2.3** The student can estimate quantities that describe natural phenomena.* **5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 2. Review the results in class to identify and address any student misunderstandings.

*Indicates a science practice not assessed with its paired topic on this unit's Personal Progress Check.

AVAILABLE RESOURCES FOR UNIT 2:

- Classroom Resources > ***AP Physics 1 and 2 Inquiry-Based Lab Investigations: A Teacher's Manual***
- Classroom Resources > **Multiple Representations of Knowledge: Mechanics and Energy**
- Classroom Resources > **Physics Instruction Using Video Analysis Technology**
- Classroom Resources > **Teaching Strategies for Limited Class Time**

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 139 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	2.1	**Changing Representations** Have students consider an accelerating two-object system from everyday life (e.g., person pushes a shopping cart, car pulls a trailer). Have them draw the forces on one object, then on the other, and then the external forces acting on the two-object system.
2	2.4	**Desktop Experiment Task** Have students measure the coefficient of static friction of their shoe on a wood plank or metal track. Level 1: Use a spring scale. Level 2: Use a pulley, a spring, a toy bucket, and an electronic balance. Level 3: Use a protractor.
3	2.5	**Desktop Experiment Task** Give students a yo-yo, a low mass, low friction pulley, 50 paper clips, and a scale. Have them find the acceleration of the falling, unrolling yo-yo and then determine the mass of the paper clips to attach to the free end of the string so that the paper clips stay at rest even as the yo-yo falls and the string passes over the pulley.
4	2.6	**Working Backward** Student A writes a Newton's second law equation either with symbols or plugged-in numbers including units. Student B must then describe a situation that the equation applies to, including the object's velocity direction and how velocity is changing, a diagram, and a free-body diagram.
5	2.7	**Troubleshooting** Students take some force-related problem from the homework or textbook (one that requires setting up Newton's second law and maybe more). Students write out a detailed solution that has exactly *one* mistake in it (not a calculation error). Post everyone's problems/ solutions, and then ask students to identify everyone else's errors. The last student to have his or her error found wins.

Unit Planning Notes

Use the space below to plan your approach to the unit.

SCIENCE PRACTICES

Modeling

1.1

The student can create representations and models of natural or man-made phenomena and systems in the domain.

Making Connections

7.1

The student can connect phenomena and models across spatial and temporal scales.

TOPIC 2.1
Systems

Required Course Content

ENDURING UNDERSTANDING

1.A

The internal structure of a system determines many properties of the system.

LEARNING OBJECTIVE

[While there is no specific learning objective for it, EK 1.A.1 serves as a foundation for other learning objectives in the course.]

1.A.5.1

Model verbally or visually the properties of a system based on its substructure and relate this to changes in the system properties over time as external variables are changed. **[SP 1.1, 7.1]**

ESSENTIAL KNOWLEDGE

1.A.1

A system is an object or a collection of objects. Objects are treated as having no internal structure.

a. A collection of particles in which internal interactions change little or not at all, or in which changes in these interactions are irrelevant to the question addressed, can be treated as an object.
b. Some elementary particles are fundamental particles, (e.g., electrons). Protons and neutrons are composed of fundamental particles (i.e., quarks) and might be treated as either systems or objects, depending on the question being addressed.
c. The electric charges on neutrons and protons result from their quark compositions.

1.A.5

Systems have properties that are determined by the properties and interactions of their constituent atomic and molecular substructures. In AP Physics, when the properties of the constituent parts are not important in modeling the behavior of the macroscopic system, the system itself may be referred to as an object.

TOPIC 2.2

The Gravitational Field

Required Course Content

ENDURING UNDERSTANDING

2.B

A gravitational field is caused by an object with mass.

LEARNING OBJECTIVE

2.B.1.1

Apply $\vec{F} = m\vec{g}$ to calculate the gravitational force on an object with mass m in a gravitational field of strength g in the context of the effects of a net force on objects and systems. **[SP 2.2, 7.2]**

ESSENTIAL KNOWLEDGE

2.B.1

A gravitational field $\vec{g}$ at the location of an object with mass m causes a gravitational force of magnitude mg to be exerted on the object in the direction of the field.

a. On Earth, this gravitational force is called weight.

b. The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force.

c. If the gravitational force is the only force exerted on the object, the observed free-fall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in Newtons/kilogram) at that location.

Relevant Equation:

$$\vec{g} = \frac{\vec{F}_g}{m}$$

SCIENCE PRACTICES

Mathematical Routines

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

SCIENCE PRACTICES

Argumentation

6.1

The student can justify claims with evidence.

6.2

The student can construct explanations of phenomena based on evidence produced through scientific practices.

TOPIC 2.3
Contact Forces

Required Course Content

ENDURING UNDERSTANDING

3.C

At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

LEARNING OBJECTIVE

3.C.4.1

Make claims about various contact forces between objects based on the microscopic cause of these forces. **[SP 6.1]**

3.C.4.2

Explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions. **[SP 6.2]**

ESSENTIAL KNOWLEDGE

3.C.4

Contact forces result from the interaction of one object touching another object, and they arise from interatomic electric forces. These forces include tension, friction, normal, spring (Physics 1), and buoyant (Physics 2).

Relevant Equations:

$$\left|\vec{F}_f\right| \leq \mu\left|\vec{F}_n\right|$$

$$\left|\vec{F}_s\right| = k\left|\vec{x}\right|$$

TOPIC 2.4

Newton's First Law

SCIENCE PRACTICE

Experimental Method

4.2

The student can design a plan for collecting data to answer a particular scientific question.

Required Course Content

ENDURING UNDERSTANDING

1.C

Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.

LEARNING OBJECTIVE

1.C.1.1

Design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration. **[SP 4.2]**

ESSENTIAL KNOWLEDGE

1.C.1

Inertial mass is the property of an object or system that determines how its motion changes when it interacts with other objects or systems.

a. $\vec{a} = \frac{\sum \vec{F}}{m}$

LEARNING OBJECTIVE

1.C.3.1

Design a plan for collecting data to measure gravitational mass and inertial mass and to distinguish between the two experiments. **[SP 4.2]**

ESSENTIAL KNOWLEDGE

1.C.3

Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.

SCIENCE PRACTICES

Modeling

1.1

The student can create representations and models of natural or man-made phenomena and systems in the domain.

1.4

The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

Argumentation

6.1

The student can justify claims with evidence.

6.2

The student can construct explanations of phenomena based on evidence produced through scientific practices.

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

TOPIC 2.5

Newton's Third Law and Free-Body Diagrams

Required Course Content

ENDURING UNDERSTANDING

3.A

All forces share certain common characteristics when considered by observers in inertial reference frames.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
3.A.2.1 Represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. **[SP 1.1]**	**3.A.2** Forces are described by vectors. a. Forces are detected by their influence on the motion of an object. b. Forces have magnitude and direction.
3.A.3.1 Analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. **[SP 6.4, 7.2]** **3.A.3.2** Challenge a claim that an object can exert a force on itself. **[SP 6.1]** **3.A.3.3** Describe a force as an interaction between two objects, and identify both objects for any force. **[SP 1.4]**	**3.A.3** A force exerted on an object is always due to the interaction of that object with another object. a. An object cannot exert a force on itself. b. Even though an object is at rest, there may be forces exerted on that object by other objects. c. The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object by other objects.

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LEARNING OBJECTIVE

3.A.4.1

Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. **[SP 1.4, 6.2]**

3.A.4.2

Use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. **[SP 6.4, 7.2]**

3.A.4.3

Analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. **[SP 1.4]**

ESSENTIAL KNOWLEDGE

3.A.4

If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.

SCIENCE PRACTICES

Modeling

1.1
The student can create representations and models of natural or man-made phenomena and systems in the domain.

1.4
The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

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

Mathematical Routines

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

Experimental Method

4.2
The student can design a plan for collecting data to answer a particular scientific question.

Data Analysis

5.1
The student can analyze data to identify patterns or relationships.

TOPIC 2.6
Newton's Second Law

Required Course Content

ENDURING UNDERSTANDING

3.B
Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\sum \vec{F}}{m}$.

LEARNING OBJECTIVE

3.B.1.1
Predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations, with acceleration in one dimension. **[SP 6.4, 7.2]**

3.B.1.2
Design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurement, and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces. **[SP 4.2, 5.1]**

3.B.1.3
Re-express a free-body diagram into a mathematical representation, and solve the mathematical representation for the acceleration of the object. **[SP 1.5, 2.2]**

ESSENTIAL KNOWLEDGE

3.B.1
If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. Projectile motion and circular motion are both included in AP Physics 1.

Relevant Equation:

$$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$$

BOUNDARY STATEMENT:
AP Physics 2 contains learning objectives for Enduring Understanding 3.B that focus on electric and magnetic forces and other forces arising in the context of interactions introduced in Physics 2, rather than the mechanical systems introduced in Physics 1.

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LEARNING OBJECTIVE

3.B.2.1

Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively.
[SP 1.1, 1.4, 2.2]

ESSENTIAL KNOWLEDGE

3.B.2

Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.

a. An object can be drawn as if it were extracted from its environment and the interactions with the environment were identified.
b. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force.
c. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free-body diagram to the algebraic representation.
d. Free-body or force diagrams may be depicted in one of two ways—one in which the forces exerted on an object are represented as arrows pointing outward from a dot, and the other in which the forces are specifically drawn at the point on the object at which each force is exerted.

SCIENCE PRACTICES ***(CONT'D)***

Argumentation

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

SCIENCE PRACTICES

Modeling

1.2

The student can describe representations and models of natural or man-made phenomena and systems in the domain.

1.4

The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

Mathematical Routines

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

2.3

The student can estimate quantities that describe natural phenomena.

Data Analysis

5.3

The student can evaluate the evidence provided by data sets in relation to a particular scientific question.

Argumentation

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

TOPIC 2.7

Applications of Newton's Second Law

Required Course Content

ENDURING UNDERSTANDING

4.A

The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\sum \vec{F}}{m}$.

LEARNING OBJECTIVE

4.A.1.1

Use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively. **[SP 1.2, 1.4, 2.3, 6.4]**

ESSENTIAL KNOWLEDGE

4.A.1

The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass. The variables *x*, *v*, and *a* all refer to the center-of-mass quantities.

Relevant Equations:

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

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

$$v_x^{\ 2} = v_{x0}^2 + 2a_x (x - x_0)$$

LEARNING OBJECTIVE

4.A.2.2

Evaluate, using given data, whether all the forces on a system or all the parts of a system have been identified. **[SP 5.3]**

ESSENTIAL KNOWLEDGE

4.A.2

The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time.

a. The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system.

b. Force and acceleration are both vectors, with acceleration in the same direction as the net force.

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LEARNING OBJECTIVE

4.A.2.2

Evaluate, using given data, whether all the forces on a system or all the parts of a system have been identified. **[SP 5.3]**

ESSENTIAL KNOWLEDGE

c. The acceleration of the center of mass of a system is equal to the rate of change of the center of mass velocity with time, and the center of mass velocity is equal to the rate of change of position of the center of mass with time.

d. The variables *x*, *v*, and *a* all refer to the center-of-mass quantities.

Relevant Equations:

$$\vec{a} = \frac{\sum \vec{F}}{m_{system}}$$

$$\vec{v}_{avg} = \frac{\Delta \vec{x}}{\Delta t}$$

$$\vec{a}_{avg} = \frac{\Delta \vec{v}}{\Delta t}$$

LEARNING OBJECTIVE

4.A.3.1

Apply Newton's second law to systems to calculate the change in the center-of-mass velocity when an external force is exerted on the system. **[SP 2.2]**

4.A.3.2

Use visual or mathematical representations of the forces between objects in a system to predict whether or not there will be a change in the center-of-mass velocity of that system. **[SP 1.4]**

ESSENTIAL KNOWLEDGE

4.A.3

Forces that the systems exert on each other are due to interactions between objects in the systems. If the interacting objects are parts of the same system, there will be no change in the center-of-mass velocity of that system.

Relevant Equation:

$$\vec{a} = \frac{\Sigma \vec{F}}{m_{system}} = \frac{\vec{F}_{net}}{m}$$

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AP PHYSICS 1

UNIT 3

Circular Motion and Gravitation

6–8%
AP EXAM WEIGHTING

~8–10
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topics and science practices.

Personal Progress Check 3

Multiple-choice: ~40 questions
Free-response: 2 questions

- Experimental Design
- Paragraph Argument Short Answer

UNIT 3

6–8% AP EXAM WEIGHTING

~8–10 CLASS PERIODS

Circular Motion and Gravitation

BIG IDEA 1
Systems **SYS**
- How does changing the mass of an object affect the gravitational force?
- Why is a refrigerator hard to push in space?

BIG IDEA 2
Fields **FLD**
- Why do we feel pulled toward Earth but not toward a pencil?
- How can the acceleration due to gravity be modified?

BIG IDEA 3
Force Interactions **INT**
- How can Newton's laws of motion be used to predict the behavior of objects?
- How can we use forces to predict the behavior of objects and keep us safe?

BIG IDEA 4
Change **CHA**
- How is the acceleration of the center of mass of a system related to the net force exerted on the system?
- Why is it more difficult to stop a fully loaded dump truck than a small passenger car?

Unit Overview

In Unit 3, students will continue to enhance their understanding of the physical world using models and representations to create a more complete and complex model of motion, particularly as it relates to gravitational mass and inertial mass. Again, translation and connections are essential—students must be able to use content and science practices from the previous two units and apply them in different ways.

While it's essential that students are able to calculate numerical answers to questions, it is more important that they can combine mathematical representations to make new representations that more accurately describe natural phenomena. For example, students should be comfortable combining equations for uniform circular motion with gravitational equations to describe the circular path of a satellite circling a planet.

It is also vital that students are given opportunities to think about and discuss the impact that changes or modifications have on physical scenarios. For example, students should be able to use mathematical and graphical representations to determine how doubling the distance of a satellite from a planet will change the period of orbit and then justify their answer with evidence and reasoning. Specific preconceptions will be addressed in this unit, such as the idea of a centrifugal force. Students will also have opportunities to wrestle with the idea of field models, which will be expanded upon in Unit 8.

Preparing for the AP Exam

Students will be asked to give a paragraph-length response to demonstrate their ability to communicate their understanding of a physical situation in a reasoned, expository analysis. For full credit, the response should be a coherent, organized, and sequential description of the analysis of a situation that draws from evidence, cites physical principles, and clearly presents the student's thinking. Full credit may not be earned if the response contains any of the following: principles not presented in a logical order, lengthy digressions within an argument, or a lack of linking prose between equations or diagrams.

Students will also be asked to explain phenomena based on evidence produced through scientific practices while using mathematical routines as evidence for claims. Students who are weak mathematically will need significant scaffolding to help them develop the conceptual mathematical understanding necessary to succeed on the AP Physics 1 Exam.

UNIT AT A GLANCE

Enduring Understanding	Topic	Science Practices	Class Periods ~8-10 CLASS PERIODS
2.A	**3.1 Vector Fields**	N/A	
3.G	**3.2 Fundamental Forces**	7.1 The student can connect phenomena and models across spatial and temporal scales.	
3.C	**3.3 Gravitational and Electric Forces**	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.*	
2.B	**3.4 Gravitational Field/Acceleration Due to Gravity on Different Planets**	2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.	
1.C	**3.5 Inertial vs. Gravitational Mass**	4.2 The student can design a plan for collecting data to answer a particular scientific question.	
4.A	**3.6 Centripetal Acceleration and Centripetal Force**	5.3 The students can evaluate the evidence provided by data sets in relation to a particular scientific question.	
3.B	**3.7 Free-Body Diagrams for Objects in Uniform Circular Motion**	1.1 The student can create representations and models of natural or man-made phenomena and systems in the domain. 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 4.2 The student can design a plan for collecting data to answer a particular scientific question. 5.1 The student can analyze data to identify patterns or relationships.*	

*Indicates a science practice not assessed with its paired topic on this unit's Personal Progress Check.

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UNIT AT A GLANCE *(cont'd)*

Enduring Understanding	Topic	Science Practices	Class Periods ~8-10 CLASS PERIODS
3.A	**3.8 Applications of Circular Motion and Gravitation**	**1.1** The student can create representations and models of natural or man-made phenomena and systems in the domain. **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain. **2.1** The student can justify the selection of a mathematical routine to solve problems. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **4.2** The student can design a plan for collecting data to answer a particular scientific question. **5.1** The student can analyze data to identify patterns or relationships. **6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 3. Review the results in class to identify and address any student misunderstandings.

AVAILABLE RESOURCES FOR UNIT 3:

- Classroom Resources > ***AP Physics 1 and 2 Inquiry-Based Lab Investigations: A Teacher's Manual***
- Classroom Resources > **Multiple Representations of Knowledge: Mechanics and Energy**

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 139 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	3.3	**Desktop Experiment Task** Have students use the "My Solar System" PhET applet to create circular orbits of varying radii around the central star and record radius, period, and planet mass for various trials. Next, have them calculate the speed using $v = 2\pi r/T$ and force using $F = mv^2/r$. Using the data, students show that gravitational force is directly proportional to mass and inversely proportional to radius.
2	3.6	**Construct an Argument** Ask students to consider two identical objects moving in circles (or parts of circles) of different radii. Ask them to think of a situation where the object with the smaller radius has a greater net force and another situation where the object with the larger radius has a greater net force.
3	3.7	**Changing Representations** Describe something a driver could be doing in a car (e.g., "turning the steering wheel to the right while pressing the brake"). Have students walk out the motion while holding out one arm representing the velocity vector and the other arm representing the acceleration vector.
4	3.8	**Create a Plan** Find a data table on stopping distance. Have students determine the coefficient of static friction of the car's tires from this data and then create a new table of different car speeds and minimum turning radii to not skid.
5	3.8	**Predict and Explain** Attach a pendulum of known weight (say, 2 N) to a force sensor and cause the bob to swing in a 180-degree arc. Ask students, "At the bottom, the bob is neither speeding up nor slowing down, so what force is registered at the bottom?" Expect students to (incorrectly) answer, "2 N."

Unit Planning Notes

Use the space below to plan your approach to the unit.

TOPIC 3.1

Vector Fields

Required Course Content

ENDURING UNDERSTANDING

2.A

A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces), as well as a variety of other physical phenomena.

LEARNING OBJECTIVE

[While there is no specific learning objective for it, EK 2.A.1 serves as a foundation for other learning objectives in the course.]

ESSENTIAL KNOWLEDGE

2.A.1

A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector.

a. Vector fields are represented by field vectors indicating direction and magnitude.
b. When more than one source object with mass or electric charge is present, the field value can be determined by vector addition.
c. Conversely, a known vector field can be used to make inferences about the number, relative size, and locations of sources.

BOUNDARY STATEMENT:

Physics 1 treats gravitational fields; Physics 2 treats electric and magnetic fields.

SCIENCE PRACTICE

Making Connections

7.1

The student can connect phenomena and models across spatial and temporal scales.

TOPIC 3.2

Fundamental Forces

Required Course Content

ENDURING UNDERSTANDING

3.G

Certain types of forces are considered fundamental.

LEARNING OBJECTIVE

3.G.1.1

Articulate situations when the gravitational force is the dominant force.
[SP 7.1]

ESSENTIAL KNOWLEDGE

3.G.1

Gravitational forces are exerted at all scales and dominate at the largest distances and mass scales.

TOPIC 3.3

Gravitational and Electric Forces

Required Course Content

ENDURING UNDERSTANDING

3.C

At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

LEARNING OBJECTIVE

3.C.1.1

Use Newton's law of gravitation to calculate the gravitational force that two objects exert on each other and use that force in contexts other than orbital motion. **[SP 2.2]**

3.C.1.2

Use Newton's law of gravitation to calculate the gravitational force between two objects and use that force in contexts involving orbital motion (for circular orbital motion only in Physics 1). **[SP 2.2]**

ESSENTIAL KNOWLEDGE

3.C.1

Gravitational force describes the interaction of one object with mass with another object with mass.

a. The gravitational force is always attractive.

b. The magnitude of force between two spherically symmetric objects of mass m_1 and m_2 is $G\frac{m_1 m_2}{r^2}$, where r is the center-to-center distance between the objects.

c. In a narrow range of heights above Earth's surface, the local gravitational field, g, is approximately constant.

Relevant Equations:

$$\left|F_g\right| = G\frac{m_1 m_2}{r^2}$$

$$\vec{g} = \frac{\vec{F}_g}{m}$$

SCIENCE PRACTICES

Mathematical Routines

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

SCIENCE PRACTICES

Mathematical Routines

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

Making Connections

7.2
The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

TOPIC 3.4

Gravitational Field/Acceleration Due to Gravity on Different Planets

Required Course Content

ENDURING UNDERSTANDING

2.B
A gravitational field is caused by an object with mass.

LEARNING OBJECTIVE

2.B.1.1
Apply $\vec{F} = m\vec{g}$ to calculate the gravitational force on an object with mass *m* in a gravitational field of strength *g* in the context of the effects of a net force on objects and systems. **[SP 2.2, 7.2]**

ESSENTIAL KNOWLEDGE

2.B.1
A gravitational field $\vec{g}$ at the location of an object with mass *m* causes a gravitational force of magnitude *mg* to be exerted on the object in the direction of the field.

a. On Earth, this gravitational force is called weight.
b. The gravitational field at a point in space is measured by dividing the gravitational force exerted by the field on a test object at that point by the mass of the test object and has the same direction as the force.
c. If the gravitational force is the only force exerted on the object, the observed free-fall acceleration of the object (in meters per second squared) is numerically equal to the magnitude of the gravitational field (in Newtons/kilogram) at that location.

Relevant Equation:

$$\vec{g} = \frac{\vec{F}_g}{m}$$

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LEARNING OBJECTIVE

2.B.2.1

Apply $g = G\frac{m}{r^2}$ to calculate the gravitational field due to an object with mass *m*, where the field is a vector directed toward the center of the object of mass *m*. **[SP 2.2]**

2.B.2.2

Approximate a numerical value of the gravitational field (*g*) near the surface of an object from its radius and mass relative to those of Earth or other reference objects. **[SP 2.2]**

ESSENTIAL KNOWLEDGE

2.B.2

The gravitational field caused by a spherically symmetric object with mass is radial and, outside the object, varies as the inverse square of the radial distance from the center of that object.

a. The gravitational field cause by a spherically symmetric object is a vector whose magnitude outside the object is equal to $G\frac{m}{r^2}$.

b. Only spherically symmetric objects will be considered as sources of the gravitational field.

Relevant Equation:

$$\vec{a} = \frac{\Sigma\vec{F}}{m_{system}} = \frac{\vec{F}_{net}}{m}$$

SCIENCE PRACTICE

Experimental Method

4.2

The student can design a plan for collecting data to answer a particular scientific question.

TOPIC 3.5

Inertial vs. Gravitational Mass

Required Course Content

ENDURING UNDERSTANDING

1.C

Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.

LEARNING OBJECTIVE

[While there is no specific learning objective for it, EK 1.C.2 serves as a foundation for other learning objectives in the course.]

ESSENTIAL KNOWLEDGE

1.C.2

Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems, or gravitational fields.

a. The gravitational mass of an object determines the amount of force exerted on the object by a gravitational field.

b. Near Earth's surface, all objects fall (in a vacuum) with the same acceleration, regardless of their inertial mass.

LEARNING OBJECTIVE

1.C.3.1

Design a plan for collecting data to measure gravitational mass and to measure inertial mass and to distinguish between the two experiments. **[SP 4.2]**

ESSENTIAL KNOWLEDGE

1.C.3

Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.

TOPIC 3.6

Centripetal Acceleration and Centripetal Force

Required Course Content

ENDURING UNDERSTANDING

4.A

The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\sum \vec{F}}{m}$.

LEARNING OBJECTIVE

4.A.2.2

Evaluate, using given data, whether all the forces on a system or whether all the parts of a system have been identified. **[SP 5.3]**

ESSENTIAL KNOWLEDGE

4.A.2

The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time.

a. The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system.

b. Force and acceleration are both vectors, with acceleration in the same direction as the net force.

c. The acceleration of the center of mass of a system is equal to the rate of change of the center of mass velocity with time, and the center of mass velocity is equal to the rate of change of position of the center of mass with time.

d. The variables x, v, and a all refer to the center-of-mass quantities.

Relevant Equations:

$$\vec{a} = \frac{\sum \vec{F}}{m_{system}}$$

$$\vec{v}_{avg} = \frac{\Delta \vec{x}}{\Delta t}$$

$$\vec{a}_{avg} = \frac{\Delta \vec{v}}{\Delta t}$$

SCIENCE PRACTICE

Data Analysis

5.3

The student can evaluate the evidence provided by data sets in relation to a particular scientific question.

SCIENCE PRACTICES

Modeling

1.1

The student can create representations and models of natural or man-made phenomena and systems in the domain.

1.4

The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

1.5

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

Mathematical Routines

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

Experimental Method

4.2

The student can design a plan for collecting data to answer a particular scientific question.

Data Analysis

5.1

The student can analyze data to identify patterns or relationships.

TOPIC 3.7

Free-Body Diagrams for Objects in Uniform Circular Motion

Required Course Content

ENDURING UNDERSTANDING

3.B

Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\Sigma \vec{F}}{m}$.

LEARNING OBJECTIVE

3.B.1.2

Design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements, and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces. **[SP 4.2, 5.1]**

3.B.1.3

Re-express a free-body diagram representation into a mathematical representation, and solve the mathematical representation for the acceleration of the object. **[SP1.5, 2.2]**

ESSENTIAL KNOWLEDGE

3.B.1

If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces. Projectile motion and circular motion are both included in AP Physics 1.

Relevant Equation:

$$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$$

BOUNDARY STATEMENT:

AP Physics 2 contains learning objectives for Enduring Understanding 3.B that focus on electric and magnetic forces and other forces arising in the context of interactions introduced in Physics 2, rather than the mechanical systems introduced in Physics 1.

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LEARNING OBJECTIVE

3.B.2.1

Create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively.
[SP 1.1, 1.4, 2.2]

ESSENTIAL KNOWLEDGE

3.B.2

Free-body diagrams are useful tools for visualizing forces being exerted on a single object and writing the equations that represent a physical situation.

a. An object can be drawn as if it were extracted from its environment and the interactions with the environment were identified.
b. A force exerted on an object can be represented as an arrow whose length represents the magnitude of the force and whose direction shows the direction of the force.
c. A coordinate system with one axis parallel to the direction of the acceleration simplifies the translation from the free-body diagram to the algebraic representation.
d. Free-body or force diagrams may be depicted in one of two ways—one in which the forces exerted on an object are represented as arrows pointing outward from a dot, and the other in which the forces are specifically drawn at the point on the object at which each force is exerted.

SCIENCE PRACTICES

Modeling

1.1
The student can create representations and models of natural or man-made phenomena and systems in the domain.

1.4
The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

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

Mathematical Routines

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

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

Experimental Method

4.2
The student can design a plan for collecting data to answer a particular scientific question.

Data Analysis

5.1
The student can analyze data to identify patterns or relationships.

TOPIC 3.8
Applications of Circular Motion and Gravitation

Required Course Content

ENDURING UNDERSTANDING

3.A
All forces share certain common characteristics when considered by observers in inertial reference frames.

LEARNING OBJECTIVE

3.A.1.1
Express the motion of an object using narrative, mathematical, and graphical representations. **[SP 1.5, 2.1, 2.2]**

3.A.1.2
Design an experimental investigation of the motion of an object. **[SP 4.2]**

3.A.1.3
Analyze experimental data describing the motion of an object and express the results of the analysis using narrative, mathematical, and graphical representations. **[SP 5.1]**

ESSENTIAL KNOWLEDGE

3.A.1
An observer in a reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.

a. Displacement, velocity, and acceleration are all vector quantities.
b. Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values.

Relevant Equations:

$$\vec{v}_{avg} = \frac{\Delta \vec{x}}{\Delta t}$$

$$\vec{a}_{avg} = \frac{\Delta \vec{v}}{\Delta t}$$

c. A choice of reference frame determines the direction and the magnitude of each of these quantities.
d. There are three fundamental interactions or forces in nature: the gravitational force, the electroweak force, and the strong force. The fundamental forces determine both the structure of objects and the motion of objects.

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LEARNING OBJECTIVE

3.A.1.1

Express the motion of an object using narrative, mathematical, and graphical representations. **[SP 1.5, 2.1, 2.2]**

3.A.1.2

Design an experimental investigation of the motion of an object. **[SP 4.2]**

3.A.1.3

Analyze experimental data describing the motion of an object and express the results of the analysis using narrative, mathematical, and graphical representations. **[SP 5.1]**

ESSENTIAL KNOWLEDGE

e. In inertial reference frames, forces are detected by their influence on the motion (specifically the velocity) of an object. So force, like velocity, is a vector quantity. A force vector has magnitude and direction. When multiple forces are exerted on an object, the vector sum of these forces, referred to as the net force, causes a change in the motion of the object. The acceleration of the object is proportional to the net force.

f. The kinematic equations only apply to constant acceleration situations. Circular motion and projectile motion are both included. Circular motion is further covered in Unit 3. The three kinematic equations describing linear motion with constant acceleration in one and two dimensions are

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

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

$$v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$$

g. For rotational motion, there are analogous quantities such as angular position, angular velocity, and angular acceleration. The kinematic equations describing angular motion with constant angular acceleration are

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega = \omega_0 + \alpha t$$

$$\omega^2 = \omega_0^2 + 2\alpha_x(\theta - \theta_0)$$

h. This also includes situations where there is both a radial and tangential acceleration for an object moving in a circular path.

Relevant Equation:

$$a_c = \frac{v^2}{r}$$

For uniform circular motion of radius *r*, *v* is proportional to omega, *ω* (for a given *r*), and proportional to *r* (for a given omega, *ω*). Given a radius *r* and a period of rotation *T*, students derive and apply *v* = (2*πr*)/*T*.

BOUNDARY STATEMENT:

AP Physics 2 has learning objectives under Enduring Understanding 3.A that focus on electric and magnetic forces and other forces arising in the context of interactions introduced in Physics 2, rather than the mechanical systems introduced in Physics 1.

SCIENCE PRACTICES (CONT'D)

Argumentation

6.2

The student can construct explanations of phenomena based on evidence produced through scientific practices.

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
3.A.2.1 Represent forces in diagrams or mathematically, using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation. **[SP 1.1]**	**3.A.2** Forces are described by vectors. a. Forces are detected by their influence on the motion of an object. b. Forces have magnitude and direction.
3.A.3.1 Analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces. **[SP 6.4, 7.2]** **3.A.3.3** Describe a force as an interaction between two objects and identify both objects for any force. **[SP 1.4]**	**3.A.3** A force exerted on an object is always due to the interaction of that object with another object. a. An object cannot exert a force on itself. b. Even though an object is at rest, there may be forces exerted on that object by other objects. c. The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object by other objects.
3.A.4.1 Construct explanations of physical situations involving the interaction of bodies using Newton's third law and the representation of action-reaction pairs of forces. **[SP 1.4, 6.2]** **3.A.4.2** Use Newton's third law to make claims and predictions about the action-reaction pairs of forces when two objects interact. **[SP 6.4, 7.2]** **3.A.4.3** Analyze situations involving interactions among several objects by using free-body diagrams that include the application of Newton's third law to identify forces. **[SP 1.4]**	**3.A.4** If one object exerts a force on a second object, the second object always exerts a force of equal magnitude on the first object in the opposite direction.

AP PHYSICS 1

UNIT 4

Energy

20–28%
AP EXAM WEIGHTING

~22–25
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topics and science practices.

Personal Progress Check 4

Multiple-choice: ~30 questions
Free-response: 2 questions

- Quantitative/Qualitative Translation
- Short Answer

UNIT 4

20–28% AP EXAM WEIGHTING | **~22–25** CLASS PERIODS

Energy

BIG IDEA 3

Force Interactions **INT**

- How does pushing something give it energy?

BIG IDEA 4

Change **CHA**

- How is energy exchanged and transformed within or between systems?
- How does the choice of system influence how energy is stored or how work is done?
- How does energy conservation allow the riders in the back car of a rollercoaster to have a thrilling ride?

BIG IDEA 5

Conservation **CON**

- How can the idea of potential energy be used to describe the work done to move celestial bodies?
- How is energy transferred between objects or systems?
- How does the law of conservation of energy govern the interactions between objects and systems?

Unit Overview

In Unit 4, students will be introduced to the idea of conservation as a foundational model of physics, along with the concept of work as the agent of change for energy. As in earlier units, students will once again utilize both familiar and new models and representations to analyze physical situations, now with force or energy as major components. Students will be encouraged to call upon their knowledge of Units 1–4 to determine the most appropriate technique and will be challenged to understand the limiting factors of each. Describing, creating, and using these representations will also help students grapple with common misconceptions that they may have about energy, such as whether or not a single object can "have" potential energy. A thorough understanding of these energy models will support students' ability to make predications—and ultimately justify claims with evidence—about physical situations. This is crucial, as the mathematical models and representations used in Unit 4 will mature throughout the course and appear in subsequent units.

As students' comprehension of energy (particularly kinetic, potential, and microscopic internal energy) evolves, they will begin to connect and relate knowledge across scales, concepts, and representations, as well as across disciplines, particularly physics, chemistry, and biology.

Preparing for the AP Exam

When students work with mathematical representations, it's crucial that they understand the connections between the mathematical description, physical phenomena, and the concepts represented in those mathematical descriptions. On the exam, students need to be able to justify why using a particular equation to analyze a situation is useful and be aware of the conditions under which equations/mathematical representations can be used. Familiarity with symbolic solutions is also necessary, because students will not often encounter a question that asks them to directly solve for a numerical answer. Finally, students need to be able to evaluate equations in terms of units and limiting case analysis. The exam asks students to translate between functional relationships in equations (proportionalities, inverse proportionalities, etc.) and cause-and-effect relationships in the physical world.

UNIT AT A GLANCE

Enduring Understanding	Topic	Science Practices	Class Periods ~22-25 CLASS PERIODS
5.A	**4.1 Open and Closed Systems: Energy**	**6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.	
3.E, 4.C	**4.2 Work and Mechanical Energy**	**1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **2.1** The student can justify the selection of a mathematical routine to solve problems. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.	
5.B	**4.3 Conservation of Energy, the Work-Energy Principle, and Power**	**1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **1.5** The student can re-express key elements of natural phenomena across multiple representations in the domain. **2.1** The student can justify the selection of a mathematical routine to solve problems. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **4.2** The student can design a plan for collecting data to answer a particular scientific question. **5.1** The student can analyze data to identify patterns or relationships. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 4.
Review the results in class to identify and address any student misunderstandings.

continued on next page

UNIT AT A GLANCE *(cont'd)*

AVAILABLE RESOURCES FOR UNIT 4:

- Classroom Resources > ***AP Physics 1 and 2 Inquiry-Based Lab Investigations: A Teacher's Manual***
- Classroom Resources > **Conservation Concepts**
- Classroom Resources > **Multiple Representations of Knowledge: Mechanics and Energy**

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 139 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	4.2	**Concept-Oriented Demonstration** Release a low-friction cart (mass m) from the top of a ramp, have students time (t) how long it takes to reach the bottom, and measure the release height h and track length L. Have students calculate velocity using $v = L/t$, and then calculate mgh and $\frac{1}{2}mv^2$. The two energies are different; explain what incorrect assumptions lead to the difference in energies.
2	4.2	**Desktop Experiment Task** Give each group a spring-loaded ball launcher, scale, and meterstick. Ask them to determine the spring constant of the spring in the launcher.
3	4.2	**Four-Square Problem Solving** First square: Describe an everyday situation (e.g., "a car goes downhill, speeding up even as the brakes are pressed") along with a diagram. Second square: Free-body diagram with an arrow off to the side representing the object's displacement. Third square: Energy bar charts (initial and final). Fourth square: For each force on the free-body diagram, state whether that force performs positive or negative work and what energy transformation that force is responsible for.
4	4.3	**Construct an Argument** Ask students to consider a cart that rolls from rest down a ramp and then around a vertical loop. For the cart to complete the loop without falling out, the cart must be released at a height higher than the top of the loop. Have students explain why this is the case using energy and circular motion principles.
5	4.3	**Working Backward** Student A writes a conservation of energy equation (either symbolically or with numbers and units plugged in). Student B then describes a situation that the equation could apply to, draws a diagram, and draws energy bar charts.

Unit Planning Notes

Use the space below to plan your approach to the unit.

TOPIC 4.1

Open and Closed Systems: Energy

Required Course Content

ENDURING UNDERSTANDING

5.A

Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
[While there is no specific learning objective for it, EK 5.A.1 serves as a foundation for other learning objectives in the course.]	**5.A.1** A system is an object or a collection of objects. The objects are treated as having no internal structure.
5.A.2.1 Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. **[SP 6.4, 7.2]**	**5.A.2** For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.
[While there is no specific learning objective for it, EK 5.A.3 serves as a foundation for other learning objectives in the course.]	**5.A.3** An interaction can be either a force exerted by objects outside the system or the transfer of some quantity with objects outside the system.
[While there is no specific learning objective for it, EK 5.A.4 serves as a foundation for other learning objectives in the course.]	**5.A.4** The placement of a boundary between a system and its environment is a decision made by the person considering the situation in order to simplify or otherwise assist in analysis.

SCIENCE PRACTICES

Argumentation

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

SCIENCE PRACTICES

Modeling

1.4
The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

Mathematical Routines

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

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

Argumentation

6.4
The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

7.2
The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

TOPIC 4.2
Work and Mechanical Energy

Required Course Content

ENDURING UNDERSTANDING

3.E
A force exerted on an object can change the kinetic energy of the object.

LEARNING OBJECTIVE

3.E.1.1
Make predictions about the changes in kinetic energy of an object based on considerations of the direction of the net force on the object as the object moves. **[SP 6.4, 7.2]**

3.E.1.2
Use net force and velocity vectors to determine qualitatively whether the kinetic energy of an object would increase, decrease, or remain unchanged. **[SP 1.4]**

3.E.1.3
Use force and velocity vectors to determine qualitatively or quantitatively the net force exerted on an object and qualitatively whether the kinetic energy of that object would increase, decrease, or remain unchanged. **[SP 1.4, 2.2]**

ESSENTIAL KNOWLEDGE

3.E.1
The change in the kinetic energy of an object depends on the force exerted on the object and on the displacement of the object during the interval that the force is exerted.

a. Only the component of the net force exerted on an object parallel or antiparallel to the displacement of the object will increase (parallel) or decrease (antiparallel) the kinetic energy of the object.
b. The magnitude of the change in the kinetic energy is the product of the magnitude of the displacement and of the magnitude of the component of force parallel or antiparallel to the displacement.

Relevant Equation:
$\Delta E = W = F_{\parallel} d$

c. The component of the net force exerted on an object perpendicular to the direction of the displacement of the object can change the direction of the motion of the object without changing the kinetic energy of the object. This should include uniform circular motion and projectile motion.

continued on next page

LEARNING OBJECTIVE

3.E.1.4

Apply mathematical routines to determine the change in kinetic energy of an object given the forces on the object and the displacement of the object. **[SP 2.2]**

ESSENTIAL KNOWLEDGE

d. The kinetic energy of a rigid system may be translational, rotational, or a combination of both. The change in the rotational kinetic energy of a rigid system is the product of the angular displacement and the net torque.

Relevant Equations:

$$K = \frac{1}{2}mv^2$$

$$\Delta E = W = F_{\parallel}d = Fd\cos\theta$$

ENDURING UNDERSTANDING

4.C

Interactions with other objects or systems can change the total energy of a system.

LEARNING OBJECTIVE

4.C.1.1

Calculate the total energy of a system and justify the mathematical routines used in the calculation of component types of energy within the system whose sum is the total energy. **[SP 1.4, 2.1, 2.2]**

4.C.1.2

Predict changes in the total energy of a system due to changes in position and speed of objects or frictional interactions within the system. **[SP 6.4]**

ESSENTIAL KNOWLEDGE

4.C.1

The energy of a system includes its kinetic energy, potential energy, and microscopic internal energy. Examples include gravitational potential energy, elastic potential energy, and kinetic energy.

a. A rotating, rigid body may be considered to be a system and may have both translational and rotational kinetic energy.

b. Although thermodynamics is not part of Physics 1, included is the idea that, during an inelastic collision, some of the mechanical energy dissipates as (converts to) thermal energy.

Relevant Equations:

$$K = \frac{1}{2}mv^2$$

$$K = \frac{1}{2}I\omega^2$$

$$\Delta U_g = mg\Delta y$$

$$U_G = -\frac{Gm_1m_2}{r}$$

$$U_s = \frac{1}{2}kx^2$$

continued on next page

LEARNING OBJECTIVE

4.C.2.1

Make predictions about the changes in the mechanical energy of a system when a component of an external force acts parallel or antiparallel to the direction of the displacement of the center of mass. **[SP 6.4]**

4.C.2.2

Apply the concepts of conservation of energy and the work-energy theorem to determine qualitatively and/or quantitatively that work done on a two-object system in linear motion will change the kinetic energy of the center of mass of the system, the potential energy of the systems, and/or the internal energy of the system. **[SP 1.4, 2.2, 7.2]**

ESSENTIAL KNOWLEDGE

4.C.2

Mechanical energy (the sum of kinetic and potential energy) is transferred into or out of a system when an external force is exerted on a system such that a component of the forces is parallel to its displacement. The process through which the energy is transferred is called work.

a. If the force is constant during a given displacement, then the work done is the product of the displacement and the component of the force parallel or antiparallel to the displacement.

Relevant Equation:

$W = F_{\parallel} d$

b. Work (change in energy) can be found from the area under a graph of the magnitude of the force component parallel to the displacement versus displacement.

Relevant Equation:

$\Delta E = W = F_{\parallel} d = Fd\cos\theta$

TOPIC 4.3

Conservation of Energy, the Work-Energy Principle, and Power

Required Course Content

ENDURING UNDERSTANDING

5.B

The energy of a system is conserved.

LEARNING OBJECTIVE

5.B.1.1

Create a representation or model showing that a single object can only have kinetic energy and use information about that object to calculate its kinetic energy. **[SP 1.4, 2.2]**

5.B.1.2

Translate between a representation of a single object, which can only have kinetic energy, and a system that includes the object, which may have both kinetic and potential energies. **[SP 1.5]**

ESSENTIAL KNOWLEDGE

5.B.1

Classically, an object can only have kinetic energy since potential energy requires an interaction between two or more objects.

Relevant Equation:

$$K = \frac{1}{2}mv^2$$

BOUNDARY STATEMENT:

Conservation principles apply in the context of the appropriate Physics 1 and Physics 2 courses. Work, potential energy, and kinetic energy concepts are related to mechanical systems in Physics 1 and electric, magnetic, thermal, and atomic and elementary particle systems in Physics 2.

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SCIENCE PRACTICES

Modeling

1.4

The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

1.5

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

Mathematical Routines

2.1

The student can justify the selection of a mathematical routine to solve problems.

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

Experimental Method

4.2

The student can design a plan for collecting data to answer a particular scientific question.

Data Analysis

5.1

The student can analyze data to identify patterns or relationships.

Argumentation

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
5.B.2.1 Calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. **[SP 1.4, 2.1]**	**5.B.2** A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. [Physics 1 includes mass-spring oscillators and simple pendulums. Physics 2 includes charged objects in electric fields and examining changes in internal energy with changes in configuration.]
5.B.3.1 Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. **[SP 2.2, 6.4, 7.2]** **5.B.3.2** Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. **[SP 1.4, 2.2]** **5.B.3.3** Apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system. **[SP 1.4, 2.2]**	**5.B.3** A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces. a. The work done by a conservative force is independent of the path taken. The work description is used for forces external to the system. Potential energy is used when the forces are internal interactions between parts of the system. b. Changes in the internal structure can result in changes in potential energy. Examples include mass-spring oscillators and objects falling in a gravitational field. c. The change in electric potential in a circuit is the change in potential energy per unit charge. [In Physics 1, only in the context of circuits] *Relevant Equations:* $T_p = 2\pi\sqrt{\frac{l}{g}}$ $T_s = 2\pi\sqrt{\frac{m}{k}}$ $U_s = \frac{1}{2}kx^2$ $\Delta U_g = mg\Delta y$

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LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
5.B.4.1 Describe and make predictions about the internal energy of systems. **[SP 6.4, 7.2]** **5.B.4.2** Calculate changes in kinetic energy and potential energy of a system using information from representations of that system. **[SP 1.4, 2.1, 2.2]**	**5.B.4** The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system. a. Since energy is constant in a closed system, changes in a system's potential energy can result in changes to the system's kinetic energy. b. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system.
5.B.5.1 Design an experiment and analyze data to determine how a force exerted on an object or system does work on the object or system as it moves through a distance. **[SP 4.2, 5.1]** **5.B.5.2** Design an experiment and analyze graphical data in which interpretations of the area under a force-distance curve are needed to determine the work done on or by the object or system. **[SP 4.2, 5.1]** **5.B.5.3** Predict and calculate from graphical data the energy transfer to or work done on an object or system from information about a force exerted on the object or system through a distance. **[SP 1.4, 2.2, 6.4]**	**5.B.5** Energy can be transferred by an external force exerted on an object or a system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A piston filled with gas getting compressed or expanded is treated in Physics 2 as part of thermodynamics.] *Relevant Equations:* $\Delta E = W = F_{\parallel} d = Fd\cos\theta$ $P = \dfrac{\Delta E}{\Delta t}$

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LEARNING OBJECTIVE

5.B.5.4

Make claims about the interaction between a system and its environment in which the environment exerts a force on the system, thus doing work on the system and changing the energy of the system (kinetic energy plus potential energy). **[SP 6.4, 7.2]**

5.B.5.5

Predict and calculate the energy transfer to (i.e., the work done on) an object or system from information about a force exerted on the object or system through a distance. **[SP 2.2, 6.4]**

ESSENTIAL KNOWLEDGE

5.B.5

Energy can be transferred by an external force exerted on an object or a system that moves the object or system through a distance; this energy transfer is called work. Energy transfer in mechanical or electrical systems may occur at different rates. Power is defined as the rate of energy transfer into, out of, or within a system. [A piston filled with gas getting compressed or expanded is treated in Physics 2 as part of thermodynamics.]

Relevant Equations:

$$\Delta E = W = F_{\parallel} d = Fd\cos\theta$$

$$P = \frac{\Delta E}{\Delta t}$$

AP PHYSICS 1

UNIT 5

Momentum

12–18%
AP EXAM WEIGHTING

~14–17
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topics and science practices.

Personal Progress Check 5

Multiple-choice: ~35 questions
Free-response: 2 questions

- Experimental Design
- Paragraph Argument Short Answer

UNIT 5

12–18% AP EXAM WEIGHTING

~14–17 CLASS PERIODS

Momentum

BIG IDEA 3
Force Interactions **INT**
- How does pushing an object change its momentum?

BIG IDEA 4
Change **CHA**
- How do interactions with other objects or systems change the linear momentum of a system?
- How is the physics definition of momentum different from how momentum is used to describe things in everyday life?

BIG IDEA 5
Conservation **CON**
- How does the law of the conservation of momentum govern interactions between objects or systems?
- How can momentum be used to determine fault in car crashes?

Unit Overview

Unit 5 introduces students to the relationship between force, time, and momentum via calculations, data analysis, designing experiments, and making predictions. Students will learn how to use new models and representations to illustrate the law of the conservation of momentum of objects and systems while simultaneously building on their knowledge of previously studied representations. Using the law of the conservation of momentum to analyze physical situations gives students a more complete picture of forces and leads them to revisit their misconceptions surrounding Newton's third law. Students will also have the opportunity to make connections between the conserved quantities of momentum and energy to determine under what conditions each quantity is conserved. It's essential that students are not only comfortable solving numerical equations (such as the speed of a system after an inelastic collision) but also confident in their ability to discuss when momentum is conserved and how the type of collision affects the outcome. Threading such connections between physical quantities is fundamental to understanding the broader relationship between this unit and the rest of the course.

Students will have more opportunities to apply conservation laws to make predictions and justify claims in Unit 7 when they are introduced to rotational quantities.

Preparing for the AP Exam

Physicists often use models and representations to show the design or workings of a system, an object, or a concept. Representations and models include, but are not limited to, sketching the physical situation, free-body diagrams, graphs, mathematical equations, and narratives. Unit 5 focuses on the creation/use and re-representation of models and representations. Students should be presented with multiple opportunities to create, use, and re-represent models and representations, including non-traditional representations. For example, while it is important that students be able to create a force versus time graph and explain that the area under the curve is equal to the momentum, they also need to feel comfortable with sketching or analyzing a graph of momentum versus time where the slope of the line is the net external force. In every situation, students need to be able to think about possible re-representations and how the new representation would change the model and/or introduce new data for analysis.

UNIT AT A GLANCE

Enduring Understanding	Topic	Science Practices	Class Periods ~14-17 CLASS PERIODS
3.D	**5.1 Momentum and Impulse**	2.1 The student can justify the selection of a mathematical routine to solve problems. 4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question. 4.2 The student can design a plan for collecting data to answer a particular scientific question. 5.1 The student can analyze data to identify patterns or relationships. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.	
4.B	**5.2 Representations of Changes in Momentum**	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 5.1 The student can analyze data to identify patterns or relationships.	
5.A	**5.3 Open and Closed Systems: Momentum**	6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.*	

*Indicates a science practice not assessed with its paired topic on this unit's Personal Progress Check.

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UNIT AT A GLANCE *(cont'd)*

Enduring Understanding	Topic	Science Practices	Class Periods ~14-17 CLASS PERIODS
5.D	**5.4** Conservation of Linear Momentum	**2.1** The student can justify the selection of a mathematical routine to solve problems. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **3.2** The student can refine scientific questions. **4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question. **4.2** The student can design a plan for collecting data to answer a particular scientific question. **4.4** The student can evaluate sources of data to answer a particular scientific question.* **5.1** The student can analyze data to identify patterns or relationships. **5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 5.
Review the results in class to identify and address any student misunderstandings.

*Indicates a science practice not assessed with its paired topic on this unit's Personal Progress Check.

AVAILABLE RESOURCES FOR UNIT 5:

- Classroom Resources > ***AP Physics 1 and 2 Inquiry-Based Lab Investigations: A Teacher's Manual***
- Classroom Resources > **Conservation Concepts**

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 139 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	5.1	**Conflicting Contentions** Ask students to imagine a pitcher throwing a baseball and a catcher catching it. Students will debate who exerted more force on the ball (no way to know), who applied greater impulse (same for both), and who did a greater magnitude of net work on the ball (same). Repeat for a pitcher throwing the baseball and a batter hitting it back at the same speed.
2	5.1	**Desktop Experiment Task** Connect a spring-loaded lanyard between a cart and force sensor, with a motion sensor on the other side of the cart. Have students take force and motion versus time data as the lanyard contracts and pulls, accelerating the cart. Show that impulse applied to the cart equals the cart's change in momentum.
3	5.2	**Bar Chart/Construct an Argument** Have students use momentum bar charts to explain why a dart bouncing off a cart makes the cart move faster than if the dart sticks to the cart, passes through the cart, or stops and drops after colliding with the cart.
4	5.2	**Predict and Explain/Concept-Oriented Demonstration** Have a cart crash into a force sensor set to its highest setting in three different ways: cart sticks to sensor, cart bounces off the sensor on its hard side, and cart bounces off the sensor with its spring side. Have students predict in which case more force is registered, and explain why after each experiment is done.
5	5.4	**Desktop Experiment Task** Have two carts with different masses collide in a non-stick collision. Film the carts with a phone camera from above, with a meterstick next to the track. Have students use a frame-by-frame review app to determine the cart's initial/final speeds, whether momentum was conserved, and whether the collision was elastic.

Unit Planning Notes

Use the space below to plan your approach to the unit.

TOPIC 5.1

Momentum and Impulse

Required Course Content

ENDURING UNDERSTANDING

3.D

A force exerted on an object can change the momentum of the object.

LEARNING OBJECTIVE

3.D.1.1

Justify the selection of data needed to determine the relationship between the direction of the force acting on an object and the change in momentum caused by that force. **[SP 4.1]**

ESSENTIAL KNOWLEDGE

3.D.1

The change in momentum of an object is a vector in the direction of the net force exerted on the object.

Relevant Equation:

$\vec{p} = m\vec{v}$

LEARNING OBJECTIVE

3.D.2.1

Justify the selection of routines for the calculation of the relationships between changes in momentum of an object, average force, impulse, and time of interaction. **[SP 2.1]**

3.D.2.2

Predict the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. **[SP 6.4]**

ESSENTIAL KNOWLEDGE

3.D.2

The change in momentum of an object occurs over a time interval.

a. The force that one object exerts on a second object changes the momentum of the second object (in the absence of other forces on the second object).
b. The change in momentum of that object depends on the impulse, which is the product of the average force and the time interval during which the interaction occurred.

Relevant Equation:

$\vec{p} = m\vec{v}$

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SCIENCE PRACTICES

Mathematical Routines

2.1

The student can justify the selection of a mathematical routine to solve problems.

Experimental Method

4.1

The student can justify the selection of the kind of data needed to answer a particular scientific question.

4.2

The student can design a plan for collecting data to answer a particular scientific question.

Data Analysis

5.1

The student can analyze data to identify patterns or relationships.

Argumentation

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

LEARNING OBJECTIVE

3.D.2.3

Analyze data to characterize the change in momentum of an object from the average force exerted on the object and the interval of time during which the force is exerted. **[SP 5.1]**

3.D.2.4

Design a plan for collecting data to investigate the relationship between changes in momentum and the average force exerted on an object over time. **[SP 4.2]**

ESSENTIAL KNOWLEDGE

3.D.2

The change in momentum of an object occurs over a time interval.

a. The force that one object exerts on a second object changes the momentum of the second object (in the absence of other forces on the second object).

b. The change in momentum of that object depends on the impulse, which is the product of the average force and the time interval during which the interaction occurred.

Relevant Equation:

$\vec{p} = m\vec{v}$

TOPIC 5.2

Representations of Changes in Momentum

Required Course Content

ENDURING UNDERSTANDING

4.B

Interactions with other objects or systems can change the total linear momentum of a system.

LEARNING OBJECTIVE

4.B.1.1

Calculate the change in linear momentum of a two-object system with constant mass in linear motion from a representation of the system (data, graphs, etc.). **[SP 1.4, 2.2]**

4.B.1.2

Analyze data to find the change in linear momentum for a constant-mass system using the product of the mass and the change in velocity of the center of mass. **[SP 5.1]**

ESSENTIAL KNOWLEDGE

4.B.1

The change in linear momentum for a constant-mass system is the product of the mass of the system and the change in velocity of the center of mass.

Relevant Equation:

$\vec{p} = m\vec{v}$

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SCIENCE PRACTICES

Modeling

1.4

The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

Mathematical Routines

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

Data Analysis

5.1

The student can analyze data to identify patterns or relationships.

LEARNING OBJECTIVE

4.B.2.1

Apply mathematical routines to calculate the change in momentum of a system by analyzing the average force exerted over a certain time on the system. **[SP 2.2]**

4.B.2.2

Perform an analysis on data presented as a force-time graph and predict the change in momentum of a system. **[SP 5.1]**

ESSENTIAL KNOWLEDGE

4.B.2

The change in linear momentum of the system is given by the product of the average force on that system and the time interval during which the force is exerted.

a. The units for momentum are the same as the units of the area under the curve of a force versus time graph.
b. The change in linear momentum and force are both vectors in the same direction.

Relevant Equations:

$$\vec{p} = m\vec{v}$$

$$\vec{p} = \vec{F}\Delta t$$

TOPIC 5.3

Open and Closed Systems: Momentum

Required Course Content

ENDURING UNDERSTANDING

5.A

Certain quantities are conserved, in the sense that the changes of those quantities in a given system are always equal to the transfer of that quantity to or from the system by all possible interactions with other systems.

LEARNING OBJECTIVE

5.A.2.1

Define open and closed systems for everyday situations and apply conservation concepts for energy, charge, and linear momentum to those situations. **[SP 6.4, 7.2]**

ESSENTIAL KNOWLEDGE

5.A.2

For all systems under all circumstances, energy, charge, linear momentum, and angular momentum are conserved. For an isolated or a closed system, conserved quantities are constant. An open system is one that exchanges any conserved quantity with its surroundings.

SCIENCE PRACTICES

Argumentation

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

SCIENCE PRACTICES

Mathematical Routines

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

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

Scientific Questioning

3.2
The student can refine scientific questions.

Experimental Method

4.1
The student can justify the selection of the kind of data needed to answer a particular scientific question.

4.2
The student can design a plan for collecting data to answer a particular scientific question.

4.4
The student can evaluate sources of data to answer a particular scientific question.

Data Analysis

5.1
The student can analyze data to identify patterns or relationships.

5.3
The student can evaluate the evidence provided by data sets in relation to a particular scientific question.

TOPIC 5.4
Conservation of Linear Momentum

Required Course Content

ENDURING UNDERSTANDING

5.D
The linear momentum of a system is conserved.

LEARNING OBJECTIVE

5.D.1.1
Make qualitative predictions about natural phenomena based on conservation of linear momentum and restoration of kinetic energy in elastic collisions. **[SP 6.4, 7.2]**

5.D.1.2
Apply the principles of conservation of momentum and restoration of kinetic energy to reconcile a situation that appears to be isolated and elastic, but in which data indicate that linear momentum and kinetic energy are not the same after the interaction, by refining a scientific question to identify interactions that have not been considered. Students will be expected to solve qualitatively and/or quantitatively for one-dimensional situations and qualitatively in two-dimensional situations. **[SP 2.2, 3.2, 5.1, 5.3]**

ESSENTIAL KNOWLEDGE

5.D.1
In a collision between objects, linear momentum is conserved. In an elastic collision, kinetic energy is the same before and after.

a. In a closed system, the linear momentum is constant throughout the collision.
b. In a closed system, the kinetic energy after an elastic collision is the same as the kinetic energy before the collision.

Relevant Equations:

$$\vec{p} = m\vec{v}$$

$$K = \frac{1}{2}mv^2$$

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LEARNING OBJECTIVE

5.D.1.3

Apply mathematical routines appropriately to problems involving elastic collisions in one dimension and justify the selection of those mathematical routines based on conservation of momentum and restoration of kinetic energy. **[SP 2.1, 2.2]**

5.D.1.4

Design an experimental test of an application of the principle of the conservation of linear momentum, predict an outcome of the experiment using the principle, analyze data generated by that experiment whose uncertainties are expressed numerically, and evaluate the match between the prediction and the outcome. **[SP 4.2, 5.1, 5.3, 6.4]**

5.D.1.5

Classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum and restoration of kinetic energy as the appropriate principles for analyzing an elastic collision, solve for missing variables, and calculate their values. **[SP 2.1, 2.2]**

ESSENTIAL KNOWLEDGE

BOUNDARY STATEMENT:

Physics 1 includes a quantitative and qualitative treatment of conservation of momentum in one dimension and a semiquantitative treatment of conservation of momentum in two dimensions. Test items involving solution of simultaneous equations are not included in Physics 1, but items testing whether students can set up the equations properly and can reason about how changing a given mass, speed, or angle would affect other quantities are included.

Physics 1 includes only conceptual understanding of the center of mass motion of a system without the need for calculation of center of mass.

The Physics 1 course includes topics from Enduring Understanding 5.D in the context of mechanical systems.

LEARNING OBJECTIVE

5.D.2.1

Qualitatively predict, in terms of linear momentum and kinetic energy, how the outcome of a collision between two objects changes depending on whether the collision is elastic or inelastic. **[SP 6.4, 7.2]**

ESSENTIAL KNOWLEDGE

5.D.2

In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.

a. In a closed system, the linear momentum is constant throughout the collision.

b. In a closed system, the kinetic energy after an inelastic collision is different from the kinetic energy before the collision.

Relevant Equations:

$$\vec{p} = m\vec{v}$$

$$K = \frac{1}{2}mv^2$$

SCIENCE PRACTICES *(CONT'D)*

Argumentation

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

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LEARNING OBJECTIVE

5.D.2.2

Plan data-collection strategies to test the law of conservation of momentum in a two-object collision that is elastic or inelastic and analyze the resulting data graphically. **[SP 4.1, 4.2, 5.1]**

5.D.2.3

Apply the conservation of linear momentum to a closed system of objects involved in an inelastic collision to predict the change in kinetic energy. **[SP 6.4, 7.2]**

5.D.2.4

Analyze data that verify conservation of momentum in collisions with and without an external frictional force. **[SP 4.1, 4.2, 4.4, 5.1, 5.3]**

5.D.2.5

Classify a given collision situation as elastic or inelastic, justify the selection of conservation of linear momentum as the appropriate solution method for an inelastic collision, recognize that there is a common final velocity for the colliding objects in the totally inelastic case, solve for missing variables, and calculate their values. **[SP 2.1, 2.2]**

ESSENTIAL KNOWLEDGE

5.D.2

In a collision between objects, linear momentum is conserved. In an inelastic collision, kinetic energy is not the same before and after the collision.

a. In a closed system, the linear momentum is constant throughout the collision.

b. In a closed system, the kinetic energy after an inelastic collision is different from the kinetic energy before the collision.

Relevant Equations:

$\vec{p} = m\vec{v}$

$K = \frac{1}{2}mv^2$

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LEARNING OBJECTIVE

5.D.3.1

Predict the velocity of the center of mass of a system when there is no interaction outside of the system but there is an interaction within the system (i.e., the student simply recognizes that interactions within a system do not affect the center-of-mass motion of the system and is able to determine that there is no external force). **[SP 6.4]**

ESSENTIAL KNOWLEDGE

5.D.3

The velocity of the center of mass of the system cannot be changed by an interaction within the system. [Physics 1 includes no calculations of centers of mass; the equation is not provided until Physics 2. However, without doing calculations, Physics 1 students are expected to be able to locate the center of mass of highly symmetric mass distributions, such as a uniform rod or cube of uniform density, or two spheres of equal mass.]

a. The center of mass of a system depends on the masses and positions of the objects in the system. In an isolated system (a system with no external forces), the velocity of the center of mass does not change.

b. When objects in a system collide, the velocity of the center of mass of the system will not change unless an external force is exerted on the system.

c. Included in Physics 1 is the idea that, where there is both a heavier and lighter mass, the center of mass is closer to the heavier mass. Only a qualitative understanding of this concept is required.

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AP PHYSICS 1

UNIT 6

Simple Harmonic Motion

4–6%
AP EXAM WEIGHTING

~4–7
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topics and science practices.

Personal Progress Check 6

Multiple-choice: ~20 questions
Free-response: 2 questions

- Experimental Design
- Short Answer

UNIT 6

4–6% AP EXAM WEIGHTING

~4–7 CLASS PERIODS

Simple Harmonic Motion

BIG IDEA 3

***Force Interactions* INT**

- How does a restoring force differ from a "regular" force?
- How does the presence of restoring forces predict and lead to harmonic motion?
- How does a spring cause an object to oscillate?
- How can oscillations be used to make our lives easier?

BIG IDEA 5

***Conservation* CON**

- How does the law of conservation of energy govern the interactions between objects and systems?
- How can energy stored in a spring be used to create motion?

Unit Overview

In Unit 6, students will continue to use the same tools, techniques, and models that they have been using throughout this course. However, they will now use them to analyze a new type of motion: simple harmonic motion. Although simple harmonic motion is unique, students will learn that even in new situations, the fundamental laws of physics remain the same. Energy bar charts, as well as free-body diagrams, become increasingly important as students work toward determining which model is most appropriate for a given physical situation. Preconceptions—such as the relationship between the amplitude and period of oscillation—will also be addressed to provide students with a more nuanced awareness of simple harmonic motion.

Students are expected to use the content knowledge they gained in the first five units to make and defend claims while also making connections in and across the content topics and big ideas. Because Unit 6 is the first unit in which students possess all the tools of force, energy, and momentum conservation, it's important that teachers scaffold lessons to help them develop a better understanding of each fundamental physics principles as well as its limitations. Throughout this unit, students will be asked to create force, energy, momentum, and position versus time graphs for a single scenario and to make predictions based on their representations. Students will enhance their study of motion when they learn about oscillatory motion in Unit 10.

Preparing for the AP Exam

Some questions on AP Physics 1 Exam require students to identify more than one correct answer. Because these multiple-select questions can easily intimidate students, we highly recommend that they take the time to read the entire prompt. Students who jump right to the answers could be frustrated to find answer choices that are factually correct but do not complete the task. Remember: Students will only get credit if they choose *all* the correct answers.

UNIT AT A GLANCE

Enduring Understanding	Topic	Science Practices	Class Periods ~4-7 CLASS PERIODS
3.B	**6.1** Period of Simple Harmonic Oscillators	**2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **4.2** The student can design a plan for collecting data to answer a particular scientific question. **5.1** The student can analyze data to identify patterns or relationships. **6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.	
5.B	**6.2** Energy of a Simple Harmonic Oscillator	**1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **2.1** The student can justify the selection of a mathematical routine to solve problems. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 6.
Review the results in class to identify and address any student misunderstandings.

AVAILABLE RESOURCES FOR UNIT 6:

- Classroom Resources > *AP Physics 1 and 2 Inquiry-Based Lab Investigations: A Teacher's Manual*

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 139 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	6.1	**Desktop Experiment Task** Have students determine the spring constant of a spring using (1) known masses and meterstick only and then (2) known masses and stopwatch only.
2	6.1	**Desktop Experiment Task** Have students use a pendulum to measure the acceleration of gravity. Ask them to refine the experiment from single-trial calculation, to taking an average, to making a graph of linearized data.
3	6.1	**Predict and Explain** Make a pendulum bob oscillate with the other end of the string "clamped" between your fingers. While the bob oscillates, pull the string through your fingers so that the string length is shortened. Before doing this, ask students what will happen to the period of the oscillation and the amplitude (measured in degrees), and then explain why the period decreases and the amplitude angle increases.
4	6.2	**Construct an Argument** A cart wiggles on a horizontal spring. A blob of clay is dropped on the cart and sticks (could be when the cart is at the center or at one end). Ask students to explain what happened to the period, total energy, amplitude of motion, and maximum speed?
5	6.2	**Create a Plan** Students choose a song and find its tempo (beats per minute). Students then must build a pendulum so that it swings back and forth on each beat. Students are then given a spring. They must find the spring's constant and then find the amount of mass necessary to make the spring-mass oscillate on each beat.

Unit Planning Notes

Use the space below to plan your approach to the unit.

SCIENCE PRACTICES

Mathematical Routines

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

Experimental Method

4.2

The student can design a plan for collecting data to answer a particular scientific question.

Data Analysis

5.1

The student can analyze data to identify patterns or relationships.

Argumentation

6.2

The student can construct explanations of phenomena based on evidence produced through scientific practices.

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

TOPIC 6.1

Period of Simple Harmonic Oscillators

Required Course Content

ENDURING UNDERSTANDING

3.B

Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\sum \vec{F}}{m}$.

LEARNING OBJECTIVE

3.B.3.1

Predict which properties determine the motion of a simple harmonic oscillator and what the dependence of the motion is on those properties. **[SP 6.4, 7.2]**

3.B.3.2

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. **[SP 4.2]**

3.B.3.3

Analyze data to identify qualitative and quantitative relationships between given values and variables (i.e., force, displacement, acceleration, velocity, period of motion, frequency, spring constant, string length, mass) associated with objects in oscillatory motion and use those data to determine the value of an unknown. **[SP 2.2, 5.1]**

ESSENTIAL KNOWLEDGE

3.B.3

Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples include gravitational force exerted by Earth on a simple pendulum and mass-spring oscillator.

a. For a spring that exerts a linear restoring force, the period of a mass-spring oscillator increases with mass and decreases with spring stiffness.

b. For a simple pendulum, the period increases with the length of the pendulum and decreases with the magnitude of the gravitational field.

c. Minima, maxima, and zeros of position, velocity, and acceleration are features of harmonic motion. Students should be able to calculate force and acceleration for any given displacement for an object oscillating on a spring.

Relevant Equations:

$$T_p = 2\pi\sqrt{\frac{l}{g}}$$

$$T_s = 2\pi\sqrt{\frac{m}{k}}$$

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LEARNING OBJECTIVE

3.B.3.4

Construct a qualitative and/or quantitative explanation of oscillatory behavior given evidence of a restoring force. **[SP 2.2, 6.2]**

ESSENTIAL KNOWLEDGE

3.B.3

Restoring forces can result in oscillatory motion. When a linear restoring force is exerted on an object displaced from an equilibrium position, the object will undergo a special type of motion called simple harmonic motion. Examples include gravitational force exerted by Earth on a simple pendulum and mass-spring oscillator.

a. For a spring that exerts a linear restoring force, the period of a mass-spring oscillator increases with mass and decreases with spring stiffness.

b. For a simple pendulum, the period increases with the length of the pendulum and decreases with the magnitude of the gravitational field.

c. Minima, maxima, and zeros of position, velocity, and acceleration are features of harmonic motion. Students should be able to calculate force and acceleration for any given displacement for an object oscillating on a spring.

Relevant Equations:

$$T_p = 2\pi\sqrt{\frac{l}{g}}$$

$$T_s = 2\pi\sqrt{\frac{m}{k}}$$

SCIENCE PRACTICES

Modeling

1.4

The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

Mathematical Routines

2.1

The student can justify the selection of a mathematical routine to solve problems.

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

Argumentation

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

TOPIC 6.2

Energy of a Simple Harmonic Oscillator

Required Course Content

ENDURING UNDERSTANDING

5.B

The energy of a system is conserved.

LEARNING OBJECTIVE

5.B.2.1

Calculate the expected behavior of a system using the object model (i.e., by ignoring changes in internal structure) to analyze a situation. Then, when the model fails, the student can justify the use of conservation of energy principles to calculate the change in internal energy due to changes in internal structure because the object is actually a system. **[SP 1.4, 2.1]**

ESSENTIAL KNOWLEDGE

5.B.2

A system with internal structure can have internal energy, and changes in a system's internal structure can result in changes in internal energy. [Physics 1 includes mass-spring oscillators and simple pendulums. Physics 2 includes charged objects in electric fields and examining changes in internal energy with changes in configuration.]

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LEARNING OBJECTIVE

5.B.3.1

Describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy. **[SP 2.2, 6.4, 7.2]**

5.B.3.2

Make quantitative calculations of the internal potential energy of a system from a description or diagram of that system. **[SP 1.4, 2.2]**

5.B.3.3

Apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system. **[SP 1.4, 2.2]**

ESSENTIAL KNOWLEDGE

5.B.3

A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces.

a. The work done by a conservative force is independent of the path taken. The work description is used for forces external to the system. Potential energy is used when the forces are internal interactions between parts of the system.
b. Changes in the internal structure can result in changes in potential energy. Examples include mass-spring oscillators and objects falling in a gravitational field.
c. The change in electric potential in a circuit is the change in potential energy per unit charge. [In Physics 1, only in the context of circuits]

Relevant Equations:

$$T_p = 2\pi\sqrt{\frac{l}{g}}$$

$$T_s = 2\pi\sqrt{\frac{m}{k}}$$

$$U_s = \frac{1}{2}kx^2$$

$$\Delta U_g = mg\Delta y$$

5.B.4.1

Describe and make predictions about the internal energy of systems. **[SP 6.4, 7.2]**

5.B.4.2

Calculate changes in kinetic energy and potential energy of a system using information from representations of that system. **[SP 1.4, 2.1, 2.2]**

5.B.4

The internal energy of a system includes the kinetic energy of the objects that make up the system and the potential energy of the configuration of the objects that make up the system.

a. Since energy is constant in a closed system, changes in a system's potential energy can result in changes to the system's kinetic energy.
b. The changes in potential and kinetic energies in a system may be further constrained by the construction of the system.

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AP PHYSICS 1

UNIT 7

Torque and Rotational Motion

12–18%
AP EXAM WEIGHTING

~14–19
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topics and science practices.

Personal Progress Check 7

Multiple-choice: ~40 questions
Free-response: 2 questions

- Quantitative/Qualitative Translation
- Paragraph Argument Short Answer

Torque and Rotational Motion

BIG IDEA 3
***Force Interactions* INT**
- How does a system at rotational equilibrium compare to a system in translational equilibrium?
- How does the choice of system and rotation point affect the forces that can cause a torque on an object or a system?
- How can balanced forces cause rotation?
- Why does it matter where the door handle is placed?
- Why are long wrenches more effective?

BIG IDEA 4
***Change* CHA**
- How can an external net torque change the angular momentum of a system?
- Why is a rotating bicycle wheel more stable than a stationary one?

BIG IDEA 5
***Conservation* CON**
- How does the conservation of angular momentum govern interactions between objects and systems?
- Why do planets move faster when they travel closer to the sun?

Unit Overview

Unit 7 completes the study of mechanical physics by introducing students to torque and rotational motion. Although these topics present more complex scenarios, the tools of analysis remain the same: The content and models explored in the first six units of AP Physics 1 set the foundation for Unit 7.

During their study of torque and rotational motion, students will be confronted with different ways of thinking about and modeling forces. As in previous units, it's critical that students are given opportunities to create and use representations and models to make predictions and justify claims. It's equally important that students are comfortable deriving new expressions from fundamental principles to help them make predictions in unfamiliar, applied contexts.

Unit 7 also focuses on the mathematical practice of estimating quantities that can describe natural phenomena. For example, students need to be able to estimate the torque on an object caused by various forces in comparison to other situations. Although this particular science practice doesn't appear often in AP Physics 1, it nonetheless is an important conceptual skill for students to be able to compare estimated values of physical quantities.

Throughout this unit, students will have opportunities to compare and connect their understanding of linear and rotational motion, dynamics, energy, and momentum to make meaning of these concepts as a whole, rather than as distinct and separate units.

Preparing for the AP Exam

Students must be familiar with identifying and analyzing functional relationships, especially with equations that are not found on the equation sheet. It is likely that students will be asked to explain why a new equation—one that they have never seen before—does or does not support a claim. They may also have to briefly address functional dependence in questions. Students will be more prepared for the type of mathematical reasoning required on the AP Physics 1 Exam if they understand and practice making logical mathematical derivations while showing their starting principle and annotating their steps.

UNIT AT A GLANCE

Enduring Understanding	Topic	Science Practices	Class Periods ~14-19 CLASS PERIODS
3.A	7.1 Rotational Kinematics	1.5 The student can re-express key elements of natural phenomena across multiple representations in the domain. 2.1 The student can justify the selection of a mathematical routine to solve problems. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.	
3.F	7.2 Torque and Angular Acceleration	1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.1 The student can justify the selection of a mathematical routine to solve problems. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.* 2.3 The student can estimate quantities that describe natural phenomena. 4.1 The student can justify the selection of the kind of data needed to answer a particular scientific question. 4.2 The student can design a plan for collecting data to answer a particular scientific question. 5.1 The student can analyze data to identify patterns or relationships. 5.3 The student can evaluate the evidence provided by data sets in relation to a particular scientific question. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.	

*Indicates a science practice not assessed with its paired topic on this unit's Personal Progress Check.

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UNIT AT A GLANCE *(cont'd)*

Enduring Understanding	Topic	Science Practices	Class Periods ~14-19 CLASS PERIODS
4.D	**7.3 Angular Momentum and Torque**	**1.2** The student can describe representations and models of natural or man-made phenomena and systems in the domain.* **1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **3.2** The student can refine scientific questions.* **4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question. **4.2** The student can design a plan for collecting data to answer a particular scientific question. **5.1** The student can analyze data to identify patterns or relationships. **5.3** The student can evaluate the evidence provided by data sets in relation to a particular scientific question.	
5.E	**7.4 Conservation of Angular Momentum**	**2.1** The student can justify the selection of a mathematical routine to solve problems. **2.2** The student can apply mathematical routines to quantities that describe natural phenomena. **6.4** The student can make claims and predictions about natural phenomena based on scientific theories and models. **7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 7.
Review the results in class to identify and address any student misunderstandings.

*Indicates a science practice not assessed with its paired topic on this unit's Personal Progress Check.

AVAILABLE RESOURCES FOR UNIT 7:

- Classroom Resources > ***AP Physics 1 and 2 Inquiry-Based Lab Investigations: A Teacher's Manual***
- Classroom Resources > **Conservation Concepts**
- Classroom Resources > **Rotational Motion**

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 139 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	7.1	**Predict and Explain** Spin a bike wheel (preferably with the tire removed so that it will roll on its metal rims), and release it from rest on a floor or long table. Have students predict what will happen to the wheel's linear velocity (will increase) and its angular velocity (will decrease) as the wheel "peels out." Then explain why this happens using a force diagram.
2	7.2	**Desktop Experiment Task** Have students release a yo-yo from rest, calculate its acceleration from distance and time measurements, and then determine the yo-yo's rotational inertia (requires the yo-yo's mass and the radius at which the string connects to the yo-yo). Next, have them roll the yo-yo down a ramp and use distance and time data to construct a conservation of energy equation that can be solved for the yo-yo's rotational inertia.
3	7.3	**Concept-Oriented Demonstration** Obtain a ring and a disk of equal mass and radius, and load up a low-friction cart with weights to make it the same mass. "Race" the three objects from rest down identical inclines to show students the cart wins, then the disk, and then the ring. Have students explain why, with forces and then with energy.
4	7.3	**Ranking** A wheel rolls down an incline from rest and across a flat surface. Case 1: Tracks are rough enough that there is no slipping. Case 2: Tracks have some friction, but there is slipping. Case 3: Tracks have negligible friction. Have students rank translational kinetic energies at the end, rotational kinetic energies at the end, and total mechanical energies of the wheel at the end as three separate tasks. ($K_{T3} > K_{T2} > K_{T1}$), ($K_{R1} > K_{R2} > K_{R3}$), and ($E_1 = E_3 > E_2$).

Unit Planning Notes

Use the space below to plan your approach to the unit.

TOPIC 7.1

Rotational Kinematics

Required Course Content

ENDURING UNDERSTANDING

3.A

All forces share certain common characteristics when considered by observers in inertial reference frames.

LEARNING OBJECTIVE

3.A.1.1

Express the motion of an object using narrative, mathematical, and graphical representations. **[SP 1.5, 2.1, 2.2]**

ESSENTIAL KNOWLEDGE

3.A.1

An observer in a reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.

a. Displacement, velocity, and acceleration are all vector quantities.

b. Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values.

Relevant Equations:

$$\vec{v}_{avg} = \frac{\Delta \vec{x}}{\Delta t}$$

$$\vec{a}_{avg} = \frac{\Delta \vec{v}}{\Delta t}$$

c. A choice of reference frame determines the direction and the magnitude of each of these quantities.

d. There are three fundamental interactions or forces in nature: the gravitational force, the electroweak force, and the strong force. The fundamental forces determine both the structure of objects and the motion of objects.

SCIENCE PRACTICES

Modeling

1.5

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

Mathematical Routines

2.1

The student can justify the selection of a mathematical routine to solve problems.

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

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LEARNING OBJECTIVE

3.A.1.1

Express the motion of an object using narrative, mathematical, and graphical representations. **[SP 1.5, 2.1, 2.2]**

ESSENTIAL KNOWLEDGE

e. In inertial reference frames, forces are detected by their influence on the motion (specifically the velocity) of an object. So force, like velocity, is a vector quantity. A force vector has magnitude and direction. When multiple forces are exerted on an object, the vector sum of these forces, referred to as the net force, causes a change in the motion of the object. The acceleration of the object is proportional to the net force.

f. The kinematic equations only apply to constant acceleration situations. Circular motion and projectile motion are both included. Circular motion is further covered in Unit 3. The three kinematic equations describing linear motion with constant acceleration in one and two dimensions are

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

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

$$v_x^2 = v_{x0}^2 + 2a_x(x - x_0)$$

g. For rotational motion, there are analogous quantities such as angular position, angular velocity, and angular acceleration. The kinematic equations describing angular motion with constant angular acceleration are

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega = \omega_0 + \alpha t$$

$$\omega^2 = \omega_0^2 + 2\alpha_x(\theta - \theta_0)$$

h. This also includes situations where there is both a radial and tangential acceleration for an object moving in a circular path.

Relevant Equation:

$$a_c = \frac{v^2}{r}$$

For uniform circular motion of radius *r*, *v* is proportional to omega, *ω* (for a given *r*), and proportional to *r* (for a given omega, *ω*). Given a radius *r* and a period of rotation *T*, students derive and apply $v = (2\pi r)/T$.

BOUNDARY STATEMENT:

AP Physics 2 has learning objectives under Enduring Understanding 3.A that focus on electric and magnetic forces and other forces arising in the context of interactions introduced in Physics 2, rather than the mechanical systems introduced in Physics 1.

TOPIC 7.2

Torque and Angular Acceleration

Required Course Content

ENDURING UNDERSTANDING

3.F

A force exerted on an object can cause a torque on that object.

LEARNING OBJECTIVE

3.F.1.1

Use representations of the relationship between force and torque. **[SP 1.4]**

3.F.1.2

Compare the torques on an object caused by various forces. **[SP 1.4]**

3.F.1.3

Estimate the torque on an object caused by various forces in comparison with other situations. **[SP 2.3]**

3.F.1.4

Design an experiment and analyze data testing a question about torques in a balanced rigid system. **[SP 4.1, 4.2, 5.1]**

3.F.1.5

Calculate torques on a two-dimensional system in static equilibrium by examining a representation or model (such as a diagram or physical construction). **[SP 1.4, 2.2]**

ESSENTIAL KNOWLEDGE

3.F.1

Only the force component perpendicular to the line connecting the axis of rotation and the point of application of the force results in a torque about that axis.

a. The lever arm is the perpendicular distance from the axis of rotation or revolution to the line of application of the force.

b. The magnitude of the torque is the product of the magnitude of the lever arm and the magnitude of the force.

c. The net torque on a balanced system is zero.

Relevant Equations:

$$\tau = r_{\perp} F = rF \sin\theta$$

BOUNDARY STATEMENT:

Quantities such as angular acceleration, velocity, and momentum are defined as vector quantities, but in Physics 1 the determination of "direction" is limited to clockwise and counterclockwise with respect to a given axis of rotation.

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SCIENCE PRACTICES

Modeling

1.4

The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

Mathematical Routines

2.1

The student can justify the selection of a mathematical routine to solve problems.

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

2.3

The student can estimate quantities that describe natural phenomena.

Experimental Method

4.1

The student can justify the selection of the kind of data needed to answer a particular scientific question.

4.2

The student can design a plan for collecting data to answer a particular scientific question.

Data Analysis

5.1

The student can analyze data to identify patterns or relationships.

5.3

The student can evaluate the evidence provided by data sets in relation to a particular scientific question.

SCIENCE PRACTICES
(CONT'D)

Argumentation

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

LEARNING OBJECTIVE

3.F.2.1

Make predictions about the change in the angular velocity about an axis for an object when forces exerted on the object cause a torque about that axis. **[SP 6.4]**

3.F.2.2

Plan data-collection and analysis strategies designed to test the relationship between a torque exerted on an object and the change in angular velocity of that object about an axis. **[SP 4.1, 4.2, 5.1]**

ESSENTIAL KNOWLEDGE

3.F.2

The presence of a net torque along any axis will cause a rigid system to change its rotational motion or an object to change its rotational motion about that axis.

a. Rotational motion can be described in terms of angular displacement, angular velocity, and angular acceleration about a fixed axis.

b. Rotational motion of a point can be related to linear motion of the point using the distance of the point from the axis of rotation.

c. The angular acceleration of an object or a rigid system can be calculated from the net torque and the rotational inertia of the object or rigid system.

Relevant Equations:

$$\tau = r_{\perp}F = rF\sin\theta$$

$$\alpha = \frac{\sum \tau}{I}$$

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega = \omega_0 + \alpha t$$

$$\omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0)$$

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LEARNING OBJECTIVE

3.F.3.1

Predict the behavior of rotational collision situations by the same processes that are used to analyze linear collision situations using an analogy between impulse and change of linear momentum and angular impulse and change of angular momentum. **[SP 6.4, 7.2]**

3.F.3.2

In an unfamiliar context or using representations beyond equations, justify the selection of a mathematical routine to solve for the change in angular momentum of an object caused by torques exerted on the object. **[SP 2.1]**

3.F.3.3

Plan data-collection and analysis strategies designed to test the relationship between torques exerted on an object and the change in angular momentum of that object. **[SP 4.1, 4.2, 5.1, 5.3]**

ESSENTIAL KNOWLEDGE

3.F.3

A torque exerted on an object can change the angular momentum of an object.

a. Angular momentum is a vector quantity, with its direction determined by a right-hand rule.
b. The magnitude of angular momentum of a point object about an axis can be calculated by multiplying the perpendicular distance from the axis of rotation to the line of motion by the magnitude of linear momentum.
c. The magnitude of angular momentum of an extended object can also be found by multiplying the rotational inertia by the angular velocity. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense of what factors affect rotational inertia—for example, why a hoop has more rotational inertia than a puck of the same mass and radius.
d. The change in angular momentum of an object is given by the product of the average torque and the time the torque is exerted.

Relevant Equations:

$L = I\omega$

$\Delta L = \tau \Delta t$

$L = mvr$

SCIENCE PRACTICES

Modeling

1.2
The student can describe representations and models of natural or man-made phenomena and systems in the domain.

1.4
The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

Mathematical Routines

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

Scientific Questioning

3.2
The student can refine scientific questions.

Experimental Method

4.1
The student can justify the selection of the kind of data needed to answer a particular scientific question.

4.2
The student can design a plan for collecting data to answer a particular scientific question.

Data Analysis

5.1
The student can analyze data to identify patterns or relationships.

5.3
The student can evaluate the evidence provided by data sets in relation to a particular scientific question.

TOPIC 7.3
Angular Momentum and Torque

Required Course Content

ENDURING UNDERSTANDING

4.D
A net torque exerted on a system by other objects or systems will change the angular momentum of the system.

LEARNING OBJECTIVE

4.D.1.1
Describe a representation and use it to analyze a situation in which several forces exerted on a rotating system of rigidly connected objects change the angular velocity and angular momentum of the system.
[SP 1.2, 1.4]

4.D.1.2
Plan data-collection strategies designed to establish that torque, angular velocity, angular acceleration, and angular momentum can be predicted accurately when the variables are treated as being clockwise or counterclockwise with respect to a well-defined axis of rotation, and refine the research question based on the examination of data.
[SP 3.2, 4.1, 4.2, 5.1, 5.3]

ESSENTIAL KNOWLEDGE

4.D.1
Torque, angular velocity, angular acceleration, and angular momentum are vectors and can be characterized as positive or negative depending on whether they give rise to or correspond to counterclockwise or clockwise rotation with respect to an axis.

Relevant Equations:

$$\tau = r_{\perp}F = rF\sin\theta$$

$$\alpha = \frac{\sum \tau}{I}$$

$$L = I\omega$$

$$\Delta L = \tau\Delta t$$

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega = \omega_0 + \alpha t$$

$$\omega^2 = \omega_0^2 + 2\alpha(\theta - \theta_0)$$

BOUNDARY STATEMENT:
Students do not need to know the right-hand rule. A full dynamic treatment of rolling without slipping—for instance, using forces and torques to find the linear and angular acceleration of a cylinder rolling down a ramp—is not included in Physics 1.

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LEARNING OBJECTIVE

4.D.2.1

Describe a model of a rotational system and use that model to analyze a situation in which angular momentum changes due to interaction with other objects or systems. **[SP 1.2, 1.4]**

4.D.2.2

Plan a data-collection and analysis strategy to determine the change in angular momentum of a system and relate it to interactions with other objects and systems. **[SP 4.2]**

ESSENTIAL KNOWLEDGE

4.D.2

The angular momentum of a system may change due to interactions with other objects or systems.

a. The angular momentum of a system with respect to an axis of rotation is the sum of the angular momenta, with respect to that axis, of the objects that make up the system.

b. The angular momentum of an object about a fixed axis can be found by multiplying the momentum of the particle by the perpendicular distance from the axis to the line of motion of the object.

c. Alternatively, the angular momentum of a system can be found from the product of the system's rotational inertia and its angular velocity. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation.

Relevant Equations:

$$L = I\omega$$

$$\Delta L = \tau \Delta t$$

$$\tau = r_{\perp} F = rF\sin\theta$$

Alternatively, the angular momentum of a system can be found from the product of the system's rotational inertia and its angular velocity. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation.

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LEARNING OBJECTIVE

4.D.3.1

Use appropriate mathematical routines to calculate values for initial or final angular momentum, or change in angular momentum of a system, or average torque or time during which the torque is exerted in analyzing a situation involving torque and angular momentum. **[SP 2.2]**

4.D.3.2

Plan a data-collection strategy designed to test the relationship between the change in angular momentum of a system and the product of the average torque applied to the system and the time interval during which the torque is exerted. **[SP 4.1, 4.2]**

ESSENTIAL KNOWLEDGE

4.D.3

The change in angular momentum is given by the product of the average torque and the time interval during which the torque is exerted.

Relevant Equations:

$L = I\omega$

$\Delta L = \tau\Delta t$

$\tau = r_{\perp}F = rF\sin\theta$

TOPIC 7.4
Conservation of Angular Momentum

Required Course Content

ENDURING UNDERSTANDING

5.E

The angular momentum of a system is conserved.

LEARNING OBJECTIVE

5.E.1.1

Make qualitative predictions about the angular momentum of a system for a situation in which there is no net external torque. **[SP 6.4, 7.2]**

5.E.1.2

Make calculations of quantities related to the angular momentum of a system when the net external torque on the system is zero. **[SP 2.1, 2.2]**

ESSENTIAL KNOWLEDGE

5.E.1

If the net external torque exerted on the system is zero, the angular momentum of the system does not change.

Relevant Equations:

$L = I\omega$

$\Delta L = \tau \Delta t$

$\tau = r_{\perp} F = rF \sin\theta$

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SCIENCE PRACTICES

Mathematical Routines

2.1

The student can justify the selection of a mathematical routine to solve problems.

2.2

The student can apply mathematical routines to quantities that describe natural phenomena.

Argumentation

6.4

The student can make claims and predictions about natural phenomena based on scientific theories and models.

Making Connections

7.2

The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

LEARNING OBJECTIVE

5.E.2.1

Describe or calculate the angular momentum and rotational inertia of a system in terms of the locations and velocities of objects that make up the system. Use qualitative reasoning with compound objects and perform calculations with a fixed set of extended objects and point masses. **[SP 2.2]**

ESSENTIAL KNOWLEDGE

5.E.2

The angular momentum of a system is determined by the locations and velocities of the objects that make up the system. The rotational inertia of an object or a system depends on the distribution of mass within the object or system. Changes in the radius of a system or in the distribution of mass within the system result in changes in the system's rotational inertia, and hence in its angular velocity and linear speed for a given angular momentum. Examples include elliptical orbits in an Earth-satellite system. Mathematical expressions for the moments of inertia will be provided where needed. Students will not be expected to know the parallel axis theorem. Students do not need to know the equation for an object's rotational inertia, as it will be provided at the exam. They should have a qualitative sense that rotational inertia is larger when the mass is farther from the axis of rotation.

Relevant Equation:

$I = mr^2$

AP PHYSICS 1

Laboratory Investigations

Lab Experiments

Although laboratory work has often been separated from classroom work, research shows that experience and experiment are often more instructionally effective. Familiarity with concrete evidence leads to a deeper understanding and gives students a sense of ownership with the knowledge they have constructed.

AP Physics courses require students to engage with data in a variety of ways. The analysis, interpretation, and application of quantitative information are vital skills for students. Scientific inquiry experiences in AP Physics 1 should be designed and implemented with increasing student involvement to help enhance inquiry learning and develop critical thinking and problem-solving skills. Typically, the level of investigations in an AP Physics 1 classroom should focus primarily on the continuum between guided and open inquiry. However, depending on students' familiarity with the topic, a given laboratory experience might incorporate a sequence involving all four levels of inquiry (confirmation, structured inquiry, guided inquiry, and open inquiry).

Lab Manuals and Lab Notebooks

College Board publishes ***AP Physics 1 and 2 Inquiry-Based Lab Investigations: A Teacher's Manual*** to support the guided inquiry lab requirement for the course. It includes labs that teachers can choose from to satisfy the guided inquiry lab component for the course. Many publishers and science classroom material distributors offer affordable lab manuals with outlined experiments and activities as well as lab notebooks for recording lab data and observations. Students can use any type of notebook to fulfill the lab notebook requirement, even an online document. Consider the needs of the classroom when deciding what type of lab notebook to use.

Lab Materials

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, electronic balances, stopwatches, clamps, and ring stands, to items more specific to physics, such as tracks and carts. Successful guided inquiry student work can be accomplished with both simple, inexpensive materials and with more sophisticated physics equipment, such as air tracks and force sensors. Remember that the AP lab should provide experience for students equivalent to that of a college laboratory, so teachers are encouraged to make every effort to provide a range of experiences—from experiments students contrive from string, and duct tape to experiments in which students gather and analyze data using calculators or computer-interfaced equipment.

There are avenues that teachers can explore as a means of getting access to more expensive equipment, such as computers and probes. Probes can often be rented for short periods of time from instrument suppliers. Alternatively, local colleges or universities may allow high school students to complete a lab as a field trip on their campus, or they may allow teachers to borrow their equipment. They may even donate their old equipment. Some schools have partnerships with local businesses that can help with laboratory equipment and materials. Teachers can also utilize online donation sites such as Donors Choose and Adopt-A-Classroom.

Lab Time

For this AP Physics 1 to be comparable to a college physics course, it is critical that teachers make laboratory work an important part their curriculum. An analysis of data from AP Physics examinees, regarding the length of time they spent per week in the laboratory, shows that increased laboratory time correlates with higher AP scores. Flexible or modular scheduling must be implemented to meet the time requirements identified in the course outline. At minimum, one double period a week is needed. Furthermore, it is important that the AP Physics 1 laboratory program be adapted to local conditions and funding as it aims to offer the students a well-rounded experience with experimental physics. Adequate laboratory facilities should be provided so that each student has a work space where equipment and materials can be left overnight if necessary. Sufficient laboratory equipment for the anticipated enrollment and appropriate instruments should be provided. Students in AP Physics 1 should have access to computers with software appropriate for processing laboratory data and writing reports.

How to Set Up a Lab Program

Physics is not just a subject. Rather, it is a way of approaching scientific discovery that requires personal observation and physical experimentation. Being successful in this endeavor requires students to synthesize and use a broad spectrum of knowledge and skills, including mathematical, computational, experimental, and practical skills, and to develop habits of mind that might be characterized as thinking like a physicist. Student-directed, inquiry-based lab experience supports the AP Physics 1 course and AP Course Audit curricular requirements. It provides opportunities for students to design experiments, collect data, apply mathematical routines and methods, and refine testable explanations and predictions. Teachers are expected to devote a minimum of 25 percent of instructional time to lab investigations to support the learning objectives in the course framework.

The AP Physics 1 Exam directly assesses the learning objectives of the course framework, which means that the inclusion of appropriate experiments aligned with those learning objectives is important for student success. Teachers should select experiments that provide students with the broadest laboratory experience possible.

We encourage teachers to be creative in designing their lab program while ensuring that students explore and develop understandings of these core techniques. After completion, students should be able to describe how to construct knowledge, model (create an abstract representation of a real system), design experiments, analyze visual data, and communicate physics. Students should also develop an understanding of how changes in the design of the experiments would affect the outcome of their results. Many questions on the AP Exam are written in an experimental context, so these skills will prove invaluable for both concept comprehension and exam performance.

Getting Students Started

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. Teachers may choose to give students a list of materials they are allowed to use 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 course framework that relate to the subject under study and that may set forth specific tasks, in the form of "Design an experiment to . . . ."
- Rephrasing or refining the learning objectives that align to the unit of study to create an inquiry-based investigation for students.

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 to the class their basic design to elicit feedback on feasibility. Guided student groups can proceed through the experiment with the teacher allowing 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 have many opportunities for post-lab reporting so that groups can understand the successes and challenges of individual lab designs.

Communication, Group Collaboration, and the Laboratory Record

Laboratory work is an excellent means through which students can develop and practice communication skills. Success in subsequent work in physics depends heavily on an ability to communicate observations, ideas, and conclusions. Students must learn to recognize that an understanding of physics is relatively useless unless they can communicate their knowledge effectively to others. By working together in a truly collaborative manner to plan and carry out experiments, students learn oral communication skills and teamwork. Students must be encouraged to take full individual responsibility for the success, or failure, of the collaboration.

After students are given a question for investigation, they may present their findings in either a written or an oral report to the teacher and 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.

Laboratory Safety

Giving students the responsibility for design of their own laboratory experience involves special responsibilities for teachers. To ensure a safe working environment, teachers should first provide the limitations and safety precautions necessary for potential procedures and equipment students may use during their investigation. Teachers 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 designs 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 teachers may post:

- Before every lab, make sure you know and record the potential hazards involved in the investigation, as well as the precautions you will take to stay safe.
- Before using equipment, make sure you know the proper method of 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.

Teachers 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 teachers to keep the pulse of what students are doing and maintain a watchful eye for potential safety issues.

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AP PHYSICS 1

Instructional Approaches

Selecting and Using Course Materials

Teachers will benefit from a wide array of materials to help students become proficient with the science practices necessary to develop a conceptual understanding of the relationships, laws, and phenomena studied in AP Physics 1. In addition to using a college-level textbook that will provide required course content, students should have regular opportunities to create and use data, representations, and models. Rich, experimental investigation is the cornerstone of AP Physics 1, and diverse source material allows teachers more flexibility in designing the types of learning activities that will help develop the habits of thinking like a physicist.

Textbooks

While nearly all college-level physics textbooks address the 10 units of AP Physics 1, it's important for teachers to identify other types of secondary sources to supplement the chosen textbook accordingly, ensuring that each of the 7 topic areas, as well as the science practices, receives adequate attention.

AP Central provides an **example textbook list** to help determine whether a text is considered appropriate in meeting the AP Physics 1 Course Audit resource requirement. Teachers can also select textbooks locally.

AP Physics 1 Student Workbook

The AP Physics 1 Student Workbook is a resource published by College Board to help students further their understanding of the science practices and content needed to be successful on the AP Physics 1 Exam. The workbook is scaffolded within each unit and across the course to help students access the material. Students will be challenged to analyze scenarios that progress in difficulty. Each page is tagged to specific essential knowledge statements and science practices that students will use complete the assignment. The workbook also contains resources for both new and experienced AP teachers on how to prepare for, teach, and assess each page. Common student misconceptions are outlined in the beginning of each unit to help teachers understand what students struggle with most.

Guided Inquiry in AP Physics 1

The more active students are in their science education, the more scientifically literate they will become. Inquiry into authentic questions generated from student experiences should be one of the central strategies when teaching AP Physics 1. By posing questions, planning investigations, and reviewing what is already known in light of experimental evidence, students mirror how scientists analyze the natural world. Inquiry requires identifying assumptions, using critical and logical thinking, and considering alternative explanations. Having students probe for answers to scientific questions will lead to a deeper understanding of scientific concepts.

Science Practice	How to Scaffold Inquiry in the AP Classroom MORE ← AMOUNT OF DIRECTION FROM TEACHER → LESS			
3.1: The student can pose scientific questions.	The student works with a question developed by the teacher.	The student sharpens or clarifies a question provided by the teacher.	The student selects from a set of given questions or can modify a given question.	The student determines the question.
4.1: The student can justify the selection of the kind of data needed to answer a particular scientific question.	The student is given data and told how to analyze it.	The student is given data to analyze.	The student is told to collect and analyze certain data.	The student can determine what constitutes evidence and can collect it.
5.1: The student can analyze data to identify patterns or relationships.	[Science Practice 5.1 has only three levels of inquiry instruction.]	The student is given possible relationships or patterns.	The student is directed toward patterns or relationships.	The student can independently examine data and form links to explanations.
6.1: The student can justify claims with evidence.	The student is provided with evidence to support a claim.	The student is given possible ways to use evidence to create explanations.	The student is guided through the process of formulating explanations from evidence.	The student creates an explanation after summarizing the evidence.
6.4: The student can make claims and predictions about natural phenomena based on scientific theories and models.	The student is given steps and procedures to make claims and predictions.	The student is given broad guidelines to use in the sharpening of claims and predictions.	The student is coached in the development of claims and predictions.	The student can form reasonable and logical arguments to communicate explanations based on scientific theories and models.

Different types of lessons, and therefore different types of inquiry, are used throughout AP Physics 1. There is a continuum from more student-centered types of inquiry to more teacher-centered types. Understanding the different types of inquiry can help teachers scaffold the types of labs and activities to better meet the needs of their students.

Below are four suggestions to make labs and activities more student-centered and inquiry-based

- Start small: Take out the "data" or "results" section from traditional labs. If the procedure is thorough and simple enough, students can read and design the data and results sections on their own.
- Tackle the procedure: Eventually, teachers will want students to design their own experiments, but they may need some practice first. Remove the step numbers and shuffle the steps. Have the students work in pairs to put the steps into the correct order. Next, try having them write a procedure as a pre-lab homework assignment, and then work together as a class to develop it further, making sure that the question, variables, and safety are addressed.
- Try a goal-oriented task: Completely remove the procedure, and prompt students with a question that asks them to achieve something they want to do. At this point, it's best to choose a lab that students already understand conceptually and that uses simple, familiar equipment.
- Let them do the thinking: Students choose what they will investigate. Facilitate their thought process without telling them what to do. A pre-lab brainstorming session in small groups is helpful when having students develop a question to investigate. It is important to provide students with some guidelines at this step. For example, students need to think about a question, a hypothesis, and materials before beginning an open-ended lab. Seeing and approving this in the lab groups helps boost students' confidence.

Instructional Strategies

The AP Physics 1 course framework outlines the concepts and science practices students must master in order to be successful on the AP Exam. To address those concepts and science practices effectively, teachers should incorporate a variety of instructional approaches and best practices into their daily lessons and activities. Teachers can help students develop the science practices by engaging them in learning activities that allow them to apply their understanding of course concepts. Teachers may consider the following strategies as they plan instruction. Please note they are listed alphabetically and not by order of importance or instruction.

Strategy	Definition	Purpose	Example
Ask the Expert	Students are assigned as “experts” on problems they have mastered; groups rotate through the expert stations to learn about problems they have not yet mastered.	Provides opportunities for students to share their knowledge and learn from one another.	Assign students “experts” on conservation of linear momentum questions. Students rotate through stations in groups, working with the station expert to justify a set of claims with corresponding physical laws.
Bar Chart	Bar chart tasks have histograms for one or more quantities. Frequently, histograms are given before and after some physical process with one bar left off. Students are asked to complete the bar chart by supplying the value of the missing quantity. These are a new type of representation, requiring students to translate between whatever other representation they are using and this one. Bar chart tasks are usually quite productive in helping students make meaning.	Bar chart tasks help students make meaning by asking them to translate between before and after some physical process.	This strategy can be used with conservation laws. Have students define the system and then create bar charts for before and after some event. For example, students create an energy bar chart for a ball rolling down an incline. Students identify the system and then create one set of charts for the top of the incline and a separate set of charts for the bottom of the incline.

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Strategy	Definition	Purpose	Example
Changing Representations	These tasks require students to translate from one representation (e.g., an electric field diagram) to another (e.g., an equipotential curves or surfaces diagram). Students often learn how to cope with one representation without really learning the role and value of representations and their relationship to problem solving. Getting them to go back and forth between/among different representations for a concept forces them to develop a more robust understanding of each representation. Among the representations that will be employed at times are mathematical relationships, so this task can serve as a bridge between conceptual understanding and traditional problem solving.	Students create pictures, tables, graphs, lists, equations, models, and/or verbal expressions to interpret text or data. This helps organize information using multiple ways to present data and answer a question or show a problem's solution.	As students learn about energy conservation, ask them to move between different representations. For example, for a given situation involving energy conservation, students should be able to create a sketch of the identified system, a set of conservation of energy equations, sets of energy bar charts and graphs of potential energy, kinetic energy, total energy or combinations of the above representations.
Concept-Oriented Demonstration	These tasks involve an actual demonstration, but with the students doing as much of the description, prediction, and explanation as possible. Demonstrations should be ones where students feel comfortable making predictions about what will happen, yet will produce results they do not expect.	Involving an actual demonstration, students are asked to predict and explain.	In Unit 7, teachers can demonstrate the soup can race, where different soup cans with identical diameters reach the bottom of an incline at different times because of the contents of the can. Students will be challenged to explain the outcome of the race in terms of physical laws and theories.
Conflicting Contentions	Conflicting contentions tasks present students with two or three statements that disagree in some way. The students have to decide which contention they agree with and explain why. These tasks are very useful for contrasting statements of students' alternate conceptions with physically accepted statements. This process is facilitated in these tasks because they can be phrased as "which statement do you agree with and why" rather than asking which statement is correct or true. These tasks complement "What if Anything Is Wrong?" tasks.	These tasks help contrast statements of students' alternate conceptions with physically accepted statements.	This strategy is useful for helping students begin to understand how to write a full argument. By providing the arguments and having students identify good claims (and not-so-good claims) and good evidence and reasoning (and not-so-good evidence and reasoning), teachers can help scaffold the instruction of good argumentation for their students.

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Strategy	Definition	Purpose	Example
Construct an Argument	Students use mathematical reasoning to present assumptions about mathematical situations, support conjectures with mathematically relevant and accurate data, and provide a logical progression of ideals leading to a conclusion that makes sense.	Helps develop the process of evaluating mathematical information, developing reasoning skills, and enhancing communication skills in supporting conjectures and conclusions.	This strategy can be used with word problems that do not lend themselves to immediate application of a formula or mathematical process. Teachers can provide distance and velocity graphs that represent a motorist's behavior through several towns on a map and ask students to construct a mathematical argument either in defense of or against a police officer's charge of speeding, given a known speed limit.
Create a Plan	Students analyze the tasks in a problem and create a process for completing the tasks by finding the information needed, interpreting data, choosing how to solve a problem, communicating the results, and verifying accuracy.	Assists in breaking tasks into smaller parts and identifying the steps needed to complete the entire task.	When scaffolding for how to design an experiment, assigning small groups to analyze the tasks necessary to design the experiment is a good first step. Students identify the steps needed to answer the question by collecting and analyzing data. Included in this discussion is a plan for what to do with the collected data.
Debriefing	Students discuss the understanding of a concept to lead to a consensus on its meaning.	Helps clarify misconceptions and deepen understanding of context.	In order to discern the difference between average velocity and instantaneous velocity, have students roll a ball down a simple ramp and measure the distance the ball travels over time every second for 5 seconds. Plotting position versus time and sketching a curve of best fit, students discuss how they might determine the average velocity of the ball over the 5 seconds and then the instantaneous velocity of the ball at several points. A discussion in which students address the distinction between the ball's average velocity between two points and its velocity at a single point helps in clarifying the concept and mathematical process.

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Strategy	Definition	Purpose	Example
Desktop Experiments Tasks	These tasks involve students performing a demonstration at their desks (either in class or at home) using a predict-and-explain format but adding the step of doing it. This "doing it" step is followed by the reformulating step, where students reconsider their previous explanations in light of what happened. DETs are narrow in scope, usually qualitative in nature, and typically use simple equipment.	Students are presented with a small desktop experiment and asked to use the apparatus provided to answer a given question.	Direct Measurement Videos make excellent "desktop" experiments that students can work with either in class or as homework. DETs can include small experiments with toy cars, balances, or cell phone cameras.
Discussion Groups	Students work in groups to discuss content, create problem solutions, and explain and justify a solution.	Aids in understanding through the sharing of ideas, interpretation of concepts, and analysis of problem scenarios.	Once students learn all methods of problem solving and can select which is the most appropriate given a particular situation, have them discuss in small groups (no writing) why a specific method should be used over another.
Friends Without Pens	Students are given a free-response problem, quiz, or challenging problem. This task takes place in two rounds: The first round is the "friends without pens" round, where students are grouped together and can discuss the question but are not allowed to write down anything. This round is timed. At the end of the time, students return to their desks for the "pens without friends" round, where they tackle the assignment in the traditional, independent sense.	This can be a scaffolding tool if students are being introduced to a new type of assignment or a particularly difficult or challenging AP-level question.	After scaffolding argumentation, where students have been working on identifying good (and not-so-good) claims, evidence, and reasoning, assigning a friends without pens task will help scaffold one more step. Students will identify good claims, evidence, and reasoning with their peers, and then they must return to their desk, having discussed the ideas, to create the full argument.

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Strategy	Definition	Purpose	Example
Four-Square Problem Solving	Students are given some sort of situation, perhaps one that came from a traditional, plug-and-chug problem. Have them divide a sheet of paper into four quadrants. In each quadrant, the students are to put some representation of what is going on in the problem. Possible representations include motion maps or graphs, any other kinds of graphs, free-body diagrams, energy bar graphs, momentum bar graphs, mathematical models (equations with symbols), well-labeled diagrams, or written responses (two to three strong, clear sentences).	Re-expressing or re-representing data is a key skill for student success in AP Physics 1. Asking students to come up with four representations scaffolds the practice needed for them to get into the habit of creating and using representations to make claims and answer questions.	In unit 4, students can regularly and repeatedly do four-square problem solving with work and energy questions. They can sketch graphs or free-body diagrams, write paragraphs, and solve numerical and/or symbolic problems.
Graph and Switch	Students generate a graph (or a sketch of a graph) to model a certain function and then switch calculators (or papers) to review each other's solutions.	Allows students to practice creating different representations of functions as well as both giving and receiving feedback on each other's work.	As students learn about momentum diagrams, have them graph momentum versus time and force versus time and create a momentum diagram to diagram a single situation. Students individually graph and explain how their representations support claims. They then share their steps with a partner and receive feedback on their graphs, claims, evidence, and reasoning.

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Strategy	Definition	Purpose	Example
Graphic Organizer	Students arrange information into charts and diagrams.	Builds comprehension and facilitates discussion by representing information in visual form.	To organize the representations for three kinds of collisions (bounce, stick, and pass-through) have students create a graphic organizer to collect the representations (momentum versus time graph, force versus time graph, momentum diagram, free-body diagram, energy bar chart, and mathematical relationships) for each collision. Students can then write short paragraphs about the differences and similarities between the three types.
Identify Subtasks	Students break a problem into smaller pieces whose outcomes lead to a solution.	Helps organize the pieces of a complex problem and reach a complete solution.	Another scaffolding technique: When first exposing students to AP-level questions that involve several steps of reasoning and logic, additional questions can be added to help guide students to the final claim, evidence, and reasoning. For example, have students sketch a free-body diagram, discuss the system, and/or draw energy bar charts. After the first few units, students should be able to identify (first in groups and then individually) what the subtasks would be (free-body diagram, etc.) to start thinking about the claim, evidence, and reasoning.

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Strategy	Definition	Purpose	Example
Marking the Text	Students highlight, underline, and/or annotate text to focus on key information to help understand the text or solve the problem.	Helps the student identify important information in the text and make notes in the text about the concepts and interpretations of tasks required to reach a solution.	This strategy can be used with AP-level problems as well as problems from the text and sample laboratory procedures. Have students read through the question, experimental design, or another student's experimental design and underline the pronouns, equipment, and key information (i.e., the car begins at rest) to identify important information and be able to ask clarifying questions.
Meaningful, Meaningless Calculations	These tasks present the students with an unreduced expression for a calculation for a physical quantity for a physical situation. They must decide whether the calculation is meaningful (i.e., it gives a value that tells us something legitimate about the physical situation) or is meaningless (i.e., the expression is a totally inappropriate use of a relation). These calculations should not be what we might call trivially meaningless, such as substituting a wrong numerical value into the expression. These items are best when the quantity calculated fits with students' alternative conceptions.	Students are presented with an unreduced calculation for a physical calculation that involves a mathematical relationship, and students are asked if the calculation makes any sense.	These calculations can take many forms, but the most useful are those where the "meaningless" calculations illustrate common student misconceptions. Students could be asked to write an expression for the energy of a system. Students then have to decide which of the following expressions are meaningful (MgD, Mg/D, MD/g and 1/MgD). Students could also be asked about a situation where a cart with a fan is released from rest and moves across a flat tabletop 1 m long with negligible friction. Have students find the final speed of the cart by measuring the time it took to travel 1 m and dividing the displacement of the cart (1 m) by the time the cart took to travel the 1 m. Ask students if this a meaningful calculation for this situation.

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Strategy	Definition	Purpose	Example
Model Questions	Students answer items from released AP Physics Exams.	Provides rigorous practices and assesses students' ability to apply multiple physical practices on content in either a multiple-choice or a free-response question.	Model questions can be AP-released or AP-level questions. They can be given as is, or scaffolded for students earlier in the year to provide them with support.
Note Taking	Students create a record of information while reading a text or listening to a speaker.	Helps in organizing ideas and processing information.	Have students write down verbal descriptions of the steps needed to solve a problem so that a record of the processes can be referred to at a later point in time.
Predict and Explain	Predict and explain tasks describe a physical situation that is set up at a point where some event is about to occur. Students predict what will happen in the situation and explain why they think that will occur. These tasks must involve situations with which the students are familiar or have sufficient background information to enable them to understand the situation. This is important because otherwise they usually do not feel comfortable enough to attempt to answer.	Stimulates thinking by asking students to make, check, and correct predictions based on evidence from the outcome.	When a ballistic pendulum is set up, ask students what will happen to the maximum swing height when the mass of the dart is increased or decreased? What would happen if the dart were to bounce instead of stick into the block? What if the dart passed through the block?
Qualitative Reasoning	These tasks can take a variety of forms, with their common denominator being qualitative analysis. Frequently, students are presented with an initial and a final situation and asked how some quantity, or aspect, will change. Qualitative comparisons (e.g., the quantity increases, decreases, or stays the same) are often the appropriate answer. Qualitative reasoning tasks can frequently contain elements found in some of the other task formats (e.g., different qualitative representations and a prediction or an explanation).	Students are presented with a physical situation and asked to apply a principle to qualitatively reason what will happen. These questions are commonly found in other multiple-choice question subtypes.	Ask students what would happen to the angular momentum of an object in orbit around the Earth if the radius of orbit were increased, if the speed of orbit were decreased, or if the mass of the Earth were changed. Additional questions could include, "What happens to the energy of the system as the physical properties above are changed?"

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Strategy	Definition	Purpose	Example
Quickwrite	Students write for a short, specific amount of time about a designated topic.	Helps generate ideas in a short amount of time.	To help synthesize concepts after having learned about the conservation of mechanical energy, have students list as many ways as possible to change the total mechanical energy of a system and how each change affects the total mechanical energy.
Ranking	Ranking tasks present students with a set of variations, sometimes three or four but usually six to eight, on a basic physical situation. The variations differ in the values (numeric or symbolic) for the variables involved but also frequently include variables that are not important to the task. The students' task is to rank the variations on the basis of a specified physical quantity. Student must also explain the reasoning for their ranking scheme and rate their confidence in their ranking.	These tasks require students to engage in a comparison reasoning process that they seldom have opportunities to do in traditional problem solving.	Given six different arrows launched from the ground with different speeds at different angles, have students rank the arrows on the basis of the highest acceleration at the top, the longest time in the air, and the largest velocity at the top.
Sharing and Responding	Students communicate with another person or a small group of peers who respond to a proposed problem solution.	Gives students the opportunity to discuss their work with peers, make suggestions to improve the work of others, and/or receive appropriate and relevant feedback on their own work.	Group students to review individual work (graphs, derivations, problem solutions, experimental designs, etc.). Have the groups make any necessary corrections and build a single, complete solution together.
Simplify the Problem	Students use friendlier numbers or functions to help solve a problem.	Provides insight into the problem or the strategies needed to solve the problem.	Have students use the analogy of one-dimensional motion when initially analyzing rotational kinematics.

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Strategy	Definition	Purpose	Example
Troubleshooting	Troubleshooting tasks are variations on the "What if Anything Is Wrong?" tasks. Students are explicitly told that there is an error in the given situation. Their job is to determine what the error is and explain how to correct it. These tasks can often produce interesting insights into students' thinking, because they will, at times, identify some correct aspect of the situation as erroneous. This helps develop additional items.	Allows students to troubleshoot errors and misconceptions by focusing on problems that may arise when they do the same procedures themselves.	Give students a derivation or problem solution and ask them to find the incorrect step(s). Have them identify and explain the mistake or misunderstanding that led to the error. This can also be done with bar charts, diagrams, and other representations.
"What if Anything Is Wrong?"	Requires students to analyze a statement or diagrammed situation to determine if it is correct or not. If everything is correct, the student is asked to explain the situation/statement on and why it works as described. If something is incorrect, the student has to identify the error and explain how to correct it. These are open-ended exercises, so they provide insights into students' ideas, since they will often have interesting reasons for accepting incorrect situations and for rejecting legitimate situations. Often, students' responses provide ideas for other items.	Allows students to troubleshoot errors and focus on problems that may arise when they do the same procedures themselves.	Give students a free-body diagram or a force diagram that may or may not have incorrect forces drawn. This technique can also be used in derivations and problem solving, where students are given the "complete" solution and are asked to verify that it was done correctly.
Write and Switch	Like graph and switch, with writing. Students make observations or collect data or make a claim and then switch papers.	Allows students to practice writing and both give and receive feedback on each other's work.	As students learn about creating an argument, they can draft an initial argument themselves; share their claim, evidence, and reasoning with a partner; and receive feedback on their argument.

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Strategy	Definition	Purpose	Example
Working Backward	This task reverses the order of the problem steps. For example, the given information could be an equation with specific values for all, or all but one, of the variables. The students then have to construct a physical situation for which the given equation would apply. Such working backward tasks require students to take numerical values, including units, and translate them into physical variables. Working backward problems also require students to reason about these situations in an unusual way and often allow for more than one solution.	Provides another way to check possible answers for accuracy.	Students are given an equation such as $4m = 6\frac{m}{s} - 9\frac{m}{s^2}$ and are asked to create another representation from this equation, such as a written scenario that this equation could represent, a position versus time graph, a velocity versus time graph, a motion map, etc.

Developing the Science Practices

Throughout the course, students will develop science practices that are fundamental to the discipline of physics. Since these practices represent the complex skills that adept physicists demonstrate, students will benefit from multiple opportunities to develop them in a scaffolded manner. Through the use of guided questioning, discussion techniques, and other instructional strategies, teachers can help their students practice applying these science practices in new contexts, providing an important foundation for their college and career readiness.

Science Practice 1: Modeling

The student can use representations and models to communicate scientific phenomena and solve scientific problems.

The real world is extremely complex. When physicists describe and explain phenomena, they try to simplify real objects, systems, and processes to make the analysis manageable. These simplifications or models are used to predict how new phenomena will occur. A simple model may treat a system as an object, neglecting the system's internal structure and behavior. More complex models are models of a system of objects, such as a fireworks display or planets orbiting the sun. A process can be simplified, too. Models can be both conceptual and mathematical. Ohm's law is an example of a mathematical model, while the model of a current as a steady flow of charged particles is a conceptual model. To make a good model, one needs to identify a set of the most important characteristics of a phenomenon or system that may simplify analysis. Inherent in the construction of models that physicists invent is the use of representations. Examples of representations used to model introductory physics are pictures, force diagrams, graphs, energy bar charts, ray diagrams, and circuit diagrams. Representations help in analyzing phenomena and making predictions and communicating ideas. AP Physics 1 requires students to use, analyze, and/or re-express models and representations of natural or man-made systems.

The following table provides examples of questions and instructional strategies for implementing representation and modeling resources into the course:

Science Practice	Key Questions	Instructional Notes or Sample Activities	Instructional Strategies
1.1 *The student can create representations and models of natural or man-made phenomena and systems in the domain.*	▪ What kind of model or representation would be appropriate for this physical system? ▪ What physical characteristics can be modeled or represented for this physical situation?	Have students divide their paper into four quarters. In each quarter of the paper, students create a representation of the physical situation. Representations can include equations, sentences (or paragraphs), bar charts, circuit diagrams, or sketches of physical situations.	▪ Four-Square Problem Solving ▪ "What if Anything Is Wrong?" ▪ Graph and Switch ▪ Changing Representations

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Science Practice	Key Questions	Instructional Notes or Sample Activities	Instructional Strategies
1.2 *The student can describe representations and models of natural or man-made phenomena and systems in the domain.*	▪ What does the representation show?	Have students describe the physical features and meaning of figures and representations, including figures and representations from the textbook or other reference sources.	▪ "What if Anything Is Wrong?" ▪ Graph and Switch ▪ Discussion Groups
1.3 *The student can refine representations and models of natural or man-made phenomena and systems in the domain.*	▪ What assumptions are inherent in the representation or model? ▪ How can these assumptions be modified in the representation or model? ▪ What would the representation or model look like if these assumptions were modified?	Have students in groups create a representation for a certain physical situation. The groups then switch papers and discuss modifications that can be made to the representations or models based on assumptions that may have been made or could be made about the physical situation.	▪ Graph and Switch ▪ "What if Anything Is Wrong?"
1.4 *The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.*	▪ What does the representation show? ▪ What features of the representation provide information relevant to the question or problem?	Have students analyze slopes, areas under curves, and *y* and *x* intercepts to help them solve problems. Students should be able to analyze situations using graphs/models/representations as easily as they can with numbers and equations.	▪ "What if Anything Is Wrong?" ▪ Changing Representations ▪ Bar Chart
1.5 *The student can re-express key elements of natural phenomena across multiple representations in the domain.*	▪ What characteristic or physical quantity of the situation does each representation illustrate? ▪ How do the representations show consistency?	Have students divide their paper into four quarters and provide four different representations for a given physical situation. Representations can include an equation, a written sentence (or paragraph), a graph, a bar chart, or a sketch of the physical scenario.	▪ "What if Anything Is Wrong?" ▪ Changing Representations ▪ Four-Square Problem Solving

Science Practice 2: Mathematical Routines

The student can use mathematics appropriately.

Physicists commonly use mathematical representations to describe and explain phenomena, as well as to solve problems. When students work with these representations, we want them to understand the connections between the mathematical description, the physical phenomena, and the concepts represented in the mathematical descriptions. When using equations or mathematical representations, students need to be able to justify why using a particular equation to analyze a particular situation is useful and to be aware of the conditions under which the equations/mathematical representations can be used. Students tend to rely too much on mathematical representations. When solving a problem, they need to be able to describe the problem situation in multiple ways, including pictorial representations, force diagrams etc., and then choose an appropriate mathematical representation, instead of first choosing a formula whose variables seem to match the givens in the problem. Students should also be able to work with the algebraic form of the equation before substituting values. Students should be able to evaluate the equation(s) and the answer in terms of units and limiting case analysis. Students should be able to translate between functional relationships in equations (proportionalities, inverse proportionalities, etc.) and cause-and-effect relationships in the physical world. Students should be able to evaluate a numerical result in terms of whether it makes sense. In many physical situations, simple mathematical routines may be needed to arrive at a result even though they are not the focus of a learning objective.

The following table provides examples of questions and instructional strategies for implementing mathematical routines into the course:

Science Practice	Key Questions	Instructional Notes or Sample Activities	Instructional Strategies
2.1 *The student can justify the selection of a mathematical routine to solve problems.*	▪ What quantities are given? ▪ What quantity is needed to answer the question? ▪ What relationship(s) link the needed quantities with the given quantities?	Have students work backward from a given mathematical routine to a physical situation. For example, students can be given an equation such as $4m = 6\frac{m}{s} - 9\frac{m}{s^2}$ and then be asked to create another representation from this equation, such as a written scenario that this equation could represent, a position versus time graph, a velocity versus time graph, a motion map, etc.	▪ Working Backward ▪ Simplify the Problem ▪ Ask the Expert

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Science Practice	Key Questions	Instructional Notes or Sample Activities	Instructional Strategies
2.2 *The student can apply mathematical routines to quantities that describe natural phenomena.*	▪ What laws, definitions, or mathematical relationships exist that relate to the given problem? ▪ What are the rules, assumptions, or limitations surrounding the use of the chosen law, definition, or relationship? ▪ Did the calculation begin with an equation or a fundamental physics relationship, law, or definition? ▪ Are the steps clearly written out and annotated? ▪ Are any steps skipped? ▪ Is the unknown quantity clearly labeled as the final answer, complete with units?	Have students perform a task where the calculations (plugging and chugging) are already done—a task that will force the students to focus on making important distinctions that physicists consider critical. For example, have students determine whether a specified calculation is meaningful or meaningless—this is entirely different from plugging numerical values into an equation and turning the crank. Meaningful, meaningless calculation tasks are another tool to get students to process information about a concept or principle in a different way.	▪ Model Questions ▪ Discussion Groups ▪ Meaningful, Meaningless Calculations
2.3 *The student can estimate numerically quantities that describe natural phenomena.*	▪ How can the mathematical routine be simplified to give an estimated or order-of-magnitude calculation? ▪ How can this estimated value be used as a guide when calculating an unknown value?	Have students practice estimating numerical quantities. For example, have students practice determining the approximate center of mass for a system of discrete objects.	▪ Meaningful-Meaningless Calculations ▪ Simplify the Problem

Science Practice 3: Scientific Questioning

The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.

Research scientists pose and answer meaningful questions. Students may easily miss this point since, depending on how a science class is taught, it may seem that science is about compiling and passing down a large body of known facts (e.g., the acceleration of a free-falling object is 9.8 m/s^2). Helping students learn how to pose, refine, and evaluate scientific questions is an important but difficult instructional and cognitive goal. Students need to be guided away from asking "fuzzy" questions about queries that are measurable and testable. A first step in refining questions might be to guide students to consider all the ways one might measure relevant physical quantities, leading to further discussions about how one would evaluate questions by designing and carrying out experiments and then evaluating data and findings.

The following table provides examples of questions and instructional strategies for implementing scientific questioning into the course:

Science Practice	Key Questions	Instructional Notes or Sample Activities	Instructional Strategies
3.1 *The student can pose scientific questions.*	▪ What does it mean for a question to be "scientific?" ▪ How can questions be modified to make them testable?	Have students practice posing scientific questions by giving them opportunities to discuss what is scientifically measurable and determinable with certain laboratory equipment.	▪ Desktop Experiment Tasks ▪ Write and Switch
3.2 *The student can refine scientific questions.*	▪ How can scientific questions be modified to make them testable? ▪ How can a scientific question be refined concerning a proposed incorrect relationship between variables?	Have students practice engaging in scientific questioning. For example, have students start by asking questions about the relationships between linear momentum and kinetic energy before and after a collision. As a first step, students might consider in what ways one can measure physical quantities relevant to the collision, leading to a discussion of mass, velocity, momentum, and kinetic energy. Follow-up discussions can lead to how one goes about evaluating questions such as, "Does the conservation of momentum and/or kinetic energy depend on the type of collision?" by designing and carrying out experiments and then evaluating data and findings.	▪ Desktop Experiment Tasks ▪ Write and Switch ▪ Predict and Explain
3.3 *The student can evaluate scientific questions.*	▪ This science practice is not directly tested on the AP Physics 1 Exam.	N/A	N/A

Science Practice 4: Experimental Methods

The student can plan and implement data-collection strategies in relation to a particular scientific question.

Scientific questions can range in scope, from broad to narrow, as well as in specificity, from determining influencing factors and/or causes to determining mechanisms. The question posed will determine the type of data to be collected and will influence the plan for collecting data. Designing and improving experimental designs and/or data-collection strategies is a learned skill. Class discussion can reveal issues of measurement uncertainty and assumptions in data collection. Students need to understand that the results of collecting and using data to determine a numerical answer to a question are best thought of as an interval, not a single number. This interval, the experimental uncertainty, is due to a combination of uncertainty in the instruments used and the process of taking the measurement. Although detailed error analysis is not necessary to convey this pivotal idea, it is important that students make some reasoned estimate of the interval within which they know the value of a measured data point and can express their results in a way that makes this clear.

The following table provides examples of questions and instructional strategies for implementing data-collection resources into the course:

Science Practice	Key Questions	Instructional Notes or Sample Activities	Instructional Strategies
4.1 *The student can justify the selection of the kind of data needed to answer a particular scientific question.*	▪ What data is necessary to answer the scientific question? ▪ What physical law, equation, or relationship links the scientific question with the collected data?	Have students practice justifying the selection of the kind of data needed to answer a particular scientific question. For example, have students design an experiment and analyze data to determine the relationship between the change in angular momentum of a system and the product of the average torque applied to the system and the time interval during which the torque is exerted.	▪ Discussion Groups ▪ Create a Plan ▪ Write and Switch
4.2 *The student can design a plan for collecting data to answer a particular scientific question.*	▪ What information will be needed to answer the scientific question? ▪ What equipment is needed to collect the necessary data? ▪ How will each piece of equipment be used to collect the necessary data? ▪ What will be done with the data (data analysis) to answer the scientific question?	Have students practice designing plans for collecting data to answer scientific questions. Laboratory design procedures do not always have to be carried out. For example, have students design an experiment and analyze graphical data where the area under a velocity versus time graph is needed to determine the displacement of an object.	▪ Create a Plan ▪ Troubleshooting ▪ Desktop Experiment Tasks

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Science Practice	Key Questions	Instructional Notes or Sample Activities	Instructional Strategies
4.3 *The student can collect data to answer a particular scientific question.*	▪ What information will be needed to answer the scientific question? ▪ What equipment is needed to collect the necessary data? ▪ How will each piece of equipment be used to collect the necessary data? ▪ What will be done with the data (data analysis) to answer the scientific question?	Have students follow through with plans they have designed to collect data to answer a scientific question. Students can also be given a procedure to follow and can practice collecting careful data from a teacher's or classmate's written instructions.	▪ Write and Switch ▪ Desktop Experiment Tasks
4.4 *The student can evaluate sources of data to answer a particular scientific question.*	▪ Can the data set given or collected be trusted? ▪ Could there be anomalies in the data that need to be resolved?	Expose students to data that might have anomalies or might not be accurate. Students can discuss the possible reasons why a particular data set is or is not reliable. For example, students should be able to analyze data to verify conservation of momentum with and without an external frictional force.	▪ Troubleshooting ▪ Desktop Experiment Tasks

Science Practice 5: Data Analysis

The student can perform data analysis and evaluation of evidence.

Students often think that to make a graph, they need to connect the data points, or that the best-fit function is always linear. Thus, it is important that they can construct a best-fit curve even for data that do not fit a linear relationship. Students should be able to represent data points as intervals whose size depends on the experimental uncertainty. After students find a pattern in the data, they need to ask why this pattern is present and try to explain it using the knowledge that they have. When dealing with a new phenomenon, they should be able to devise a testable explanation of the pattern, if possible. It is important that students understand that instruments do not produce exact measurements and learn what steps they can take to decrease uncertainty. Students should be able to design a second experiment to determine the same quantity and then check for consistency across the two measurements, comparing two results by writing them both as intervals and not as single, absolute numbers. Finally, students should be able to revise their reasoning based on the new data, which for some may appear anomalous. The analysis, interpretation, and application of quantitative information are vital skills for students in AP Physics 1. Analysis skills can be taught using any type of data, but students will be more invested in the data analysis if it is data they have collected through their own investigations. Teachers are encouraged to provide opportunities for students to analyze data, draw conclusions, and apply their knowledge to the enduring understandings and learning objectives in the course.

The following table provides examples of questions and instructional strategies for implementing data analysis resources into the course:

Science Practice	Key Questions	Instructional Notes or Sample Activities	Instructional Strategies
5.1 *The student can analyze data to identify patterns or relationships.*	▪ How should the data be graphed so that the best-fit curve shows a relationship? ▪ How can data intervals be used to show experimental uncertainty? ▪ What do the data or graph show? ▪ What trends and patterns can you identify from the data? ▪ Why is the pattern present in the data? What does the pattern show about the relationship between quantities?	Have students practice analyzing data to find patterns and relationships. For example, have students analyze data (or a visual representation) describing the motion of an object and express the results of the analysis using narrative, mathematical, and graphical representations.	▪ Friends Without Pens ▪ Write and Switch ▪ Graph and Switch ▪ Predict and Explain
5.2 *The student can refine observations and measurements based on data analysis.*	▪ What changes can be made to observations and measurements to refine the data? ▪ How can a second experiment be designed to answer the same scientific question? ▪ What steps can be taken to decrease the uncertainty in the measurements and data?	Have students practice refining observations and measurements. For example, have students perform data analysis, evaluate evidence compared to the prediction, explain any discrepancy, and, if necessary, revise the relationship among variables responsible for the period of a pendulum.	▪ Desktop Experiment Tasks ▪ Write and Switch ▪ Graph and Switch

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Science Practice	Key Questions	Instructional Notes or Sample Activities	Instructional Strategies
5.3 *The student can evaluate the evidence provided by data sets in relation to a particular scientific question.*	▪ How does the presented evidence provide support for the claim or scientific question? ▪ Does the data set present clear and complete evidence in relation to the scientific question, or is the data flawed? ▪ If the data is flawed, what new data or procedure should be completed to obtain data in relation to the scientific question?	Have students refine and analyze a scientific question for an experiment relating the net work on an object to the forces exerted on that object over a distance.	▪ Sharing and Responding ▪ Conflicting Contentions

Science Practice 6: Argumentation

The student can work with scientific explanations and theories.

A scientific explanation, accounting for an observed phenomenon, needs to be experimentally testable. One should be able to use it to make predictions about new phenomena. A theory uses a unified approach to account for a large set of phenomena and gives accounts that are consistent with multiple experimental outcomes within the range of applicability of the theory. Examples of theories in physics include the kinetic molecular theory, quantum theory, and atomic theory. Students should understand the difference between explanations and theories.

Students should be prepared to offer evidence, construct reasoned arguments for their claim from the evidence, and use the claim or explanation to make predictions. A prediction states the expected outcome of a particular experimental design based on an explanation or a claim under scrutiny. Physicists examine data and evidence to develop claims about physical phenomena. As they articulate their claims, physicists use reasoning processes that rely on their awareness of different types of relationships, connections, and patterns within the data and evidence. They then formulate a claim and develop an argument that explains how the claim is supported by the available evidence. AP Physics 1 teachers should help students learn how to create persuasive and meaningful arguments by improving their proficiency with each of these practices.

The following table provides examples of strategies for implementing argumentation resources into the course:

Science Practice	Key Questions	Instructional Notes or Sample Activities	Instructional Strategies
6.1 *The student can justify claims with evidence.*	▪ What is evidence, and how does it differ from reasoning?	Have students identify and explain the evidence that supports their claim, with an emphasis on how the evidence supports the claim. Give students a question such as, "Which of the following is most responsible for . . . ?" Students should analyze possibilities and the evidence for and against each position. Have students choose a position and write a defensible claim or thesis that reflects their reasoning and evidence.	▪ Conflicting Contentions
6.2 *The student can construct explanations of phenomena based on evidence produced through scientific practices.*	▪ What possible claims could you make based on the question and the evidence? ▪ What is your purpose (to define, show causality, compare, or explain a process)? ▪ What evidence supports your claim? ▪ How does the evidence support your explanation?	Have students construct an explanation of physical phenomena based on evidence. For example, students can construct an explanation of the inverse square dependence of the gravitational field surrounding a spherically symmetric, massive object.	▪ Conflicting Contentions ▪ Concept-Oriented Demonstration ▪ Discussion Groups

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Science Practice	Key Questions	Instructional Notes or Sample Activities	Instructional Strategies
6.3 *The student can articulate the reasons that scientific explanations and theories are refined or replaced.*	▪ Not tested in AP Physics 1	N/A	N/A
6.4 *The student can make claims and predictions about natural phenomena based on scientific theories and models.*	▪ What reasoning (physical laws or theories) supports your claim? ▪ How does the reasoning support your claim? ▪ How does the evidence support your claim? Use transitions such as *because* or *therefore*.	Have students make claims about a physical situation that is set up at a point where some event is about to occur. Students have to predict what will happen in the situation and explain why they think that will occur. For example, students can make claims and predictions about the internal energy of systems.	▪ Predict and Explain ▪ Discussion Groups ▪ Conflicting Contentions
6.5 *The student can evaluate alternative scientific explanations.*	▪ Not tested in AP Physics 1	N/A	N/A

Science Practice 7: Making Connections

The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

Students should have the opportunity to transfer their learning across disciplinary boundaries so that they are able to link, synthesize, and apply the ideas they learn across the sciences and mathematics. Research on how people learn indicates that providing multiple contexts in which major ideas apply facilitates transfer; this allows students to bundle knowledge and memory together with the multiple contexts to which it applies. Students should also be able to recognize seemingly appropriate contexts to which major concepts and ideas do not apply.

The following table provides examples of questions and instructional strategies for making connections throughout the course:

Science Practice	Key Questions	Instructional Notes or Sample Activities	Instructional Strategies
7.1 *The student can connect phenomena and models across spatial and temporal scales.*	▪ What models and/or representations can help connect these phenomena with other phenomena? ▪ What important features of the models and/or representations connect the phenomena across spatial and temporal scales?	Have students practice connecting phenomena across spatial and temporal scales. Problem solving in isolation of one unit will not prepare students for the AP Physics 1 Exam. Have students connect representations between topics and big ideas. For example, students should be able to articulate situations when the gravitational force is the dominant force and when the electromagnetic, weak, and strong forces can be ignored.	▪ Meaningful, Meaningless Calculations ▪ Model Questions ▪ “What if Anything Is Wrong?”
7.2 *The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.*	▪ What big ideas can link these phenomena with other phenomena? ▪ How can the ideas used to explain this phenomenon be generalized to extrapolate across enduring understandings? ▪ How can the ideas used to explain this phenomenon be generalized to extrapolate across big ideas?	Have students practice connecting phenomena across domains and making generalizations across enduring understandings and big ideas. For example, have students apply conservation concepts for energy, charge, and linear momentum to everyday situations.	▪ Meaningful, Meaningless Calculations ▪ Model Questions ▪ “What if Anything Is Wrong?”

AP PHYSICS 1

Exam Information

Exam Overview

The AP Physics 1 Exam assesses student application of the science practices and understanding of the learning objectives outlined in the course framework. The exam is 3 hours long and includes 50 multiple-choice questions and 5 free-response questions. The 5 free-response questions may appear in any order on the AP Exam. A four-function, scientific, or graphing calculator is allowed on both sections of the exam. The details of the exam, including exam weighting and timing, can be found below:

Section	Question Type	Number of Questions	Weighting	Timing
IA	Single-select multiple-choice questions (discrete or in sets)	45	50%	90 minutes
IB	Multiple-select multiple-choice items (all discrete)	5		
II	Free-response questions	5	50%	90 minutes
	Question 1: Experimental Design (12 points)			
	Question 2: Qualitative/Quantitative Translation (12 points)			
	Question 3: Paragraph Argument Short Answer (7 points)			
	Questions 4 and 5: Short Answer (7 points each)			

The exam assesses content from each of five big ideas for the course:
Big Idea 1: Systems
Big Idea 2: Fields
Big Idea 3: Force Interactions
Big Idea 4: Change
Big Idea 5: Conservation

The exam also assesses each of the 10 units of instruction with the following exam weightings on the multiple-choice section of the AP Exam:

Exam Weighting for the Multiple-Choice Section of the AP Exam

Unit of Instruction	Exam Weighting
Unit 1: Kinematics	**12–18%**
Unit 2: Dynamics	**16–20%**
Unit 3: Circular Motion and Gravitation	**6–8%**
Unit 4: Energy	**20–28%**
Unit 5: Momentum	**12–18%**
Unit 6: Simple Harmonic Motion	**4–6%**
Unit 7: Torque and Rotational Motion	**12–18%**

How Student Learning Is Assessed on the AP Exam

Section I: Multiple-Choice

Science Practices 1, 2, 4, 5, 6, and 7 are all assessed in in the multiple-choice section with the following weighting (Science Practice 3 will not be assessed in the multiple-choice section):

Exam Weighting for the Multiple-Choice Section of the AP Exam

Science Practice	Exam Weighting
Science Practice 1: Modeling	**28–32%**
Science Practice 2: Mathematical Routines	**16–20%**
Science Practice 4: Experimental Method	**2–4%**
Science Practice 5: Data Analysis	**10–12%**
Science Practice 6: Argumentation	**24–28%**
Science Practice 7: Making Connections	**10–16%**

Section II: Free-Response

Science Practices 1, 2, 4, 5, 6, and 7 are all assessed in in the free-response section with the following weighting (Science Practice 3 will not be assessed in the free-response section):

Exam Weighting for the Free-Response Section of the AP Exam

Science Practice	Exam Weighting
Science Practice 1: Modeling	22–36%
Science Practice 2: Mathematical Routines	17–29%
Science Practice 4: Experimental Method	8–16%
Science Practice 5: Data Analysis	6–14%
Science Practice 6: Argumentation	17–29%
Science Practice 7: Making Connections	2–9%

The AP Physics 1 free-response section includes five free-response questions: two 12-point questions and three 7-point questions. Every exam includes one experimental design question, one quantitative/qualitative translation question, one paragraph short answer question, and two additional short answer questions. These questions may appear in any order on the AP Exam.

Experimental Design (12 points; 3–5 question parts)

This question type assesses student ability to design and describe a scientific investigation, analyze authentic laboratory data, and identify patterns or explain phenomena.

Qualitative/Quantitative Translation (12 points; 3–5 question parts)

This question type assesses student ability to translate between quantitative and qualitative justification and reasoning.

Paragraph Argument Short Answer Question (7 points; 1–3 question parts)

This question type assesses student ability to create a paragraph-length response, which consists of a coherent argument about a physics phenomenon that uses the information presented in the question and proceeds in a logical, expository fashion to arrive at a conclusion.

Short Answer Question (7 points; 1-3 question parts)

The two short answer questions focus on practices and learning objectives not focused on in the other question types.

Task Verbs Used in Free-Response Questions

The following task verbs are commonly used in the free-response questions.

Calculate: Perform mathematical steps to arrive at a final answer, including algebraic expressions, properly substituted numbers, and correct labeling of units and significant figures. Also phrased as "What is?"

Compare: Provide a description or explanation of similarities and/or differences.

Derive: Perform a series of mathematical steps using equations or laws to arrive at a final answer.

Describe: Provide the relevant characteristics of a specified topic.

Determine: Make a decision or arrive at a conclusion after reasoning, observation, or applying mathematical routines (calculations).

Evaluate: Roughly calculate numerical quantities, values (greater than, equal to, less than), or signs (negative, positive) of quantities based on experimental evidence or provided data. When making estimations, showing steps in calculations are not required.

Explain: Provide information about how or why a relationship, pattern, position, situation, or outcome occurs, using evidence and/or reasoning to support or qualify a claim. Explain "how" typically requires analyzing the relationship, process, pattern, position, situation, or outcome; whereas, explain "why" typically requires analysis of motivations or reasons for the relationship, process, pattern, position, situation, or outcome.

Justify: Provide evidence to support, qualify, or defend a claim, and/or provide reasoning to explain how that evidence supports or qualifies the claim.

Label: Provide labels indicating unit, scale, and/or components in a diagram, graph, model, or representation.

Plot: Draw data points in a graph using a given scale or indicating the scale and units, demonstrating consistency between different types of representations.

Sketch/Draw: Create a diagram, graph, representation, or model that illustrates or explains relationships or phenomena, demonstrating consistency between different types of representations. Labels may or may not be required.

State/Indicate/Circle: Indicate or provide information about a specified topic, without elaboration or explanation. Also phrased as "What…?" or "Would…?" interrogatory questions.

Verify: Confirm that the conditions of a scientific definition, law, theorem, or test are met in order to explain why it applies in a given situation. Also, use empirical data, observations, tests, or experiments to prove, confirm, and/or justify a hypothesis.

Sample Exam Questions

The sample exam questions that follow illustrate the relationship between the course framework and AP Physics 1 Exam and serve as examples of the types of questions that appear on the exam. After the sample questions, teachers will find a table that shows which science practice(s), learning objective(s), and unit each question relates to. The table also provides the answers to the multiple-choice questions.

Section I: Multiple-Choice Questions

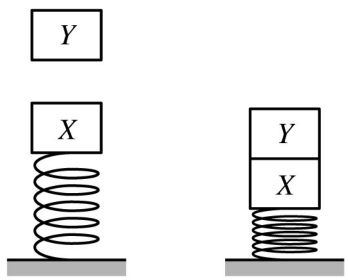


Figure 1 Figure 2

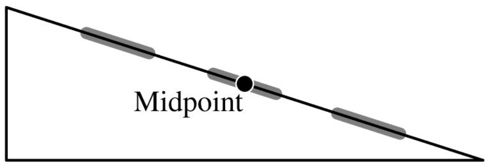
1. Block Y with mass m_Y falls onto and sticks to block X, which is attached to a vertical spring, as shown in Figure 1. A short time later, as shown in Figure 2, the blocks are momentarily at rest. At that moment, block Y exerts a force of magnitude F_{down} on block X, and block X exerts a force of magnitude F_{up} on block Y. Which of the following correctly relates F_{up}, F_{down}, and $m_Y g$ at the instant shown in Figure 2?

   (A) $\left(F_{up} = F_{down}\right) > m_Y g$

   (B) $\left(F_{up} = m_Y g\right) > F_{down}$

   (C) $m_Y g > F_{up} > F_{down}$

   (D) $F_{up} = F_{down} = m_Y g$



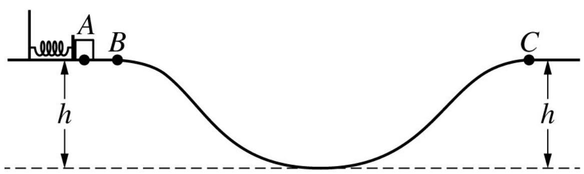
2. A block is released from rest and slides down a ramp. The surface of the ramp has three rough sections where the friction between the surface and the block is not negligible, as shown by the shaded regions above. Measuring which of the following will allow for the best estimate of the block's instantaneous acceleration when the block is at the midpoint of the ramp?

(A) The total distance traveled by the block and the total elapsed time

(B) The final speed of the block and the total elapsed time

(C) The distance between points just before and just after the midpoint and the time it takes the block to travel between them

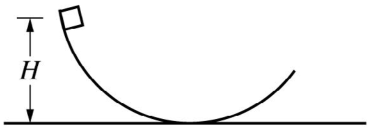
(D) The speed of the block at points just before and just after the midpoint and the time it takes the block to travel between them

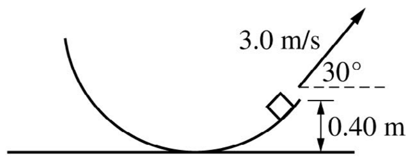


3. A block is held at rest against a compressed spring at point A at the top of a frictionless track of height h, as shown above. The block is released, loses contact with the spring at point B, and slides along the track until it passes point C, also at height h. How do the potential energy U of the block-Earth system and the kinetic energy K of the block at point C compare with those at point A?

	Potential Energy of Block-Earth System	Kinetic Energy of Block
(A)	$U_C = U_A$	$K_C = K_A$
(B)	$U_C = U_A$	$K_C > K_A$
(C)	$U_C > U_A$	$K_C = K_A$
(D)	$U_C > U_A$	$K_C > K_A$

Questions 4–6 refer to the following material.





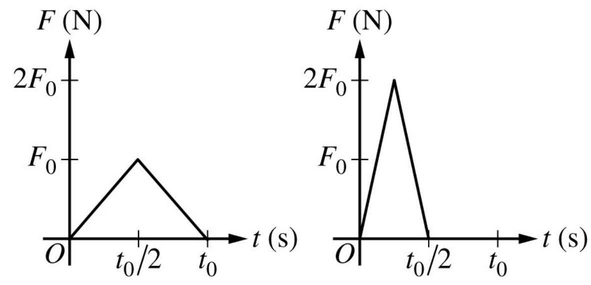
Note: Figures not drawn to scale.

The figures above show a small block of mass 0.20 kg on a track in the shape of a circular arc. The block is released from rest at a height H above the floor, as shown in Figure 1. The block slides along the track with negligible friction and leaves it at a height of 0.40 m above the floor and a speed of 3.0 m/s at a 30° angle, as shown in Figure 2.

4. The height H is most nearly
   (A) 0.45 m
   (B) 0.51 m
   (C) 0.86 m
   (D) 1.7 m

5. The magnitude of the gravitational force exerted on the block is F_g, and the magnitude of the normal force exerted by the track on the block is F_n. Which of the following correctly compares the magnitudes of these two forces when the block is at the lowest point on the track?
   (A) $F_n > F_g$
   (B) $F_n = F_g$
   (C) $F_n < F_g$
   (D) The magnitudes cannot be compared without knowing the radius of the arc of the track.

6. After the block leaves the track, what is the block's speed when it reaches the highest point of its motion?
   (A) 0
   (B) 1.5 m/s
   (C) 2.6 m/s
   (D) 3.0 m/s



Object X   Object Y

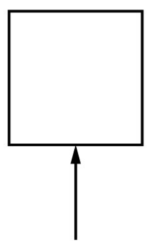
7. Objects X and Y are constrained to move along a straight line. The graphs above show the net force exerted along that line on each of the objects as functions of time. Which of the following correctly ranks the change in momentum Δp of the objects?

(A) $\Delta p_X < \Delta p_Y$

(B) $\Delta p_X = \Delta p_Y$

(C) $\Delta p_X > \Delta p_Y$

(D) The ranking cannot be determined without knowing the masses of the objects.

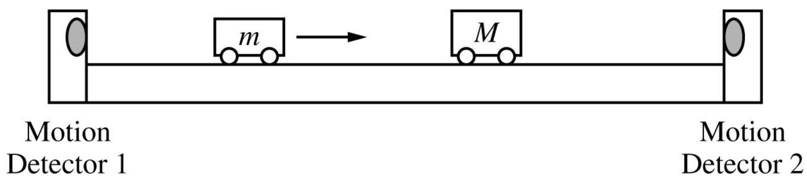


8. A person exerts an upward force on a box, as shown above. The box may be moving upward, downward, or not at all while the person exerts the upward force. For which of the following motions of the box is the work done by the person on the box correctly indicated?

	Motion of Box	Work Done by Person on Box
(A)	No motion	Positive
(B)	Upward with decreasing speed	Negative
(C)	Downward with constant speed	Zero
(D)	Downward with increasing speed	Negative

9. Two satellites are in circular orbits around Earth. Satellite 1 has mass m_0 and an orbital radius of $2R_E$, where R_E is the radius of Earth. Satellite 2 has mass $2m_0$ and an orbital radius of $3R_E$. Which of the following correctly compares the magnitude F of the force exerted by Earth on each satellite and the speed v of each satellite?

	Force	Speed
(A)	$F_1 > F_2$	$v_1 > v_2$
(B)	$F_1 > F_2$	$v_2 > v_1$
(C)	$F_2 > F_1$	$v_1 > v_2$
(D)	$F_2 > F_1$	$v_2 > v_1$



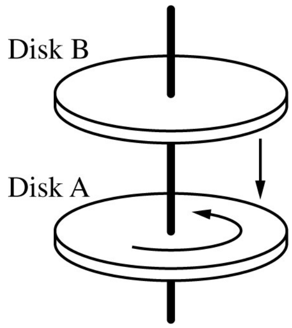
10. In the setup shown above, a student uses motion detector 1 to measure the speed v_i of a cart with mass m before it collides with and sticks to a stationary cart with mass M. Motion detector 2 measures the speed v_f of the carts after the collision. The student repeats the experiment several times using different values of v_i and creates a graph of v_f as a function of v_i. The slope of this graph is most nearly equal to

(A) $\dfrac{m}{M}$

(B) $\dfrac{m}{M+m}$

(C) $\dfrac{M-m}{M+m}$

(D) $\sqrt{\dfrac{m}{M+m}}$



11. Cylindrical disk *A* is rotating freely about an axis when an identical disk *B* that is not rotating is dropped directly on top of disk *A*. If the two disks stick together, how does the total angular momentum and total kinetic energy of the two-disk system after the disks are stuck together compare to that of the system before disk *B* was dropped?

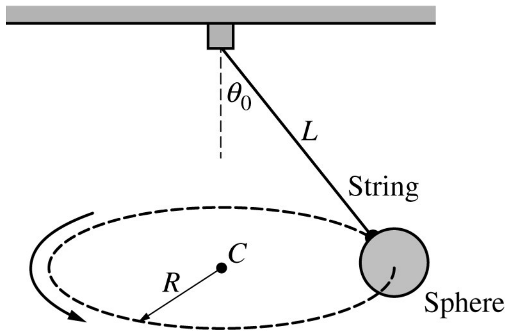
	Total Angular Momentum	Total Kinetic Energy
(A)	Remains the same	Is one-half its original value
(B)	Remains the same	Is one-fourth its original value
(C)	Is one-half its original value	Is one-half its original value
(D)	Is one-half its original value	Is one-fourth its original value

12. Which of the following statements about a satellite in an elliptical orbit around Earth are correct? Select two answers.
    (A) The satellite's kinetic energy is constant throughout the orbit.
    (B) The satellite's angular momentum about the center of mass of the satellite-Earth system is constant throughout the orbit.
    (C) The magnitude of the satellite's linear momentum is constant throughout the orbit.
    (D) The gravitational potential energy of the Earth-satellite system is greatest at the satellite's farthest point from Earth.

Section II: Free-Response Questions

The following are examples of the kinds of free-response questions found on the exam. Note that on the actual AP Exam, there will be one experimental design question, one quantitative/qualitative translation question, one paragraph argument short answer question, and two additional short answer questions.

FREE-RESPONSE QUESTION: QUANTITATIVE/QUALITATIVE TRANSLATION



1. A small sphere of mass M is suspended by a string of length L. The sphere is made to move in a horizontal circle of radius R at a constant speed, as shown above. The center of the circle is labeled point C, and the string makes an θ_0 with the vertical.

   (A) Two students are discussing the motion of the sphere and make the following statements.

   Student 1: None of the forces exerted on the sphere are in the direction of point C, the center of the circular path. Therefore, I don't see how there can be a centripetal force exerted on the sphere to make it move in a circle.

   Student 2: I see another problem. The tension force exerted by the string is at an angle from the vertical. Therefore, its vertical component must be less than the weight Mg of the sphere. That means the net force on the sphere has a downward vertical component, and the sphere should move downward as well as moving around in a circle.

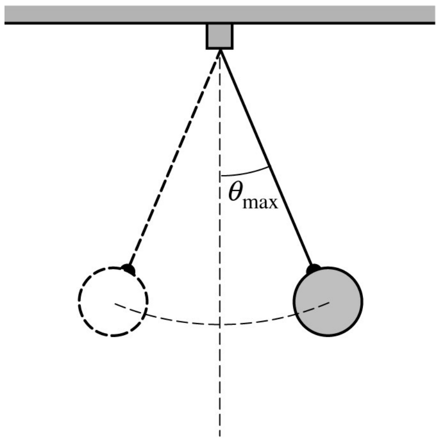
   i. What is one aspect of Student 1's reasoning that is incorrect?

   ii. What is one aspect of Student 2's reasoning that is incorrect?

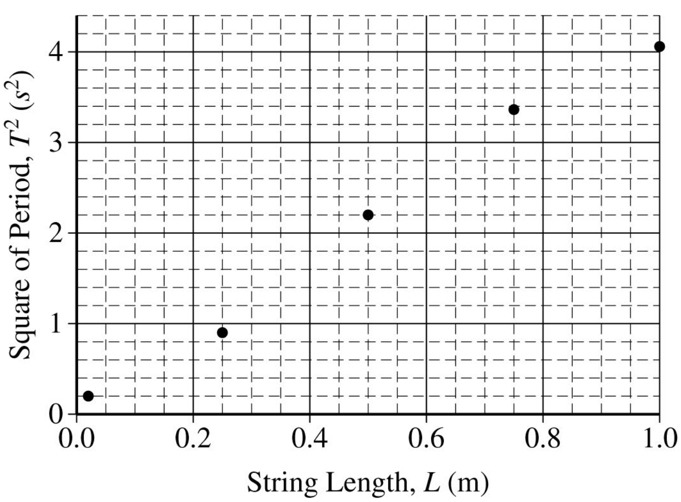
   (B)

   i. Derive an equation for the magnitude of the net force exerted on the sphere. Express your answer in terms of M, theta, and physical constants, as appropriate.

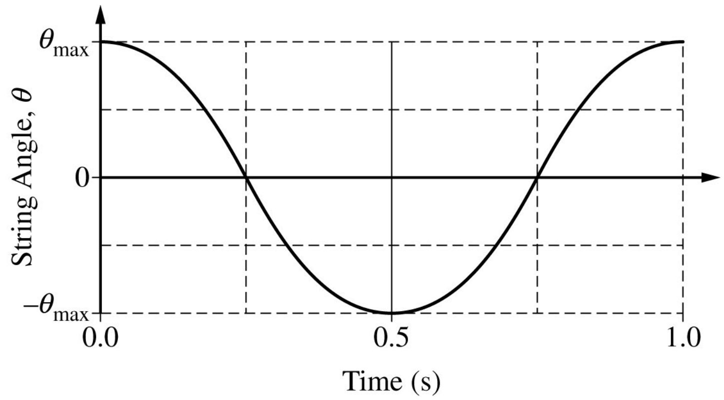
   ii. Describe one aspect or step in your derivation of part (b)(i) that can be correctly linked to your answer to either part (a)(i) or part (a)(ii).



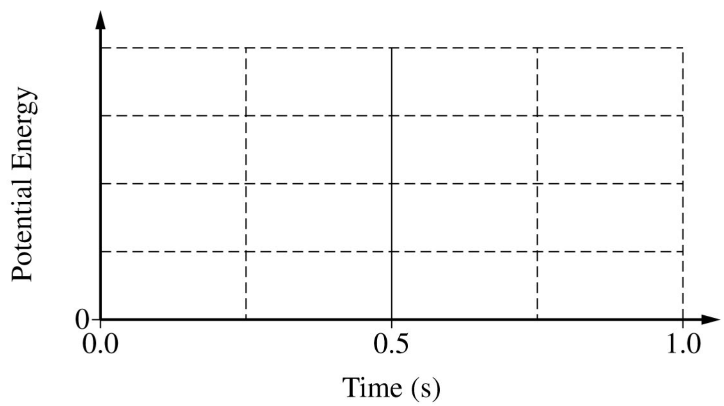
Instead of moving in a horizontal circle, the sphere now moves in a vertical plane so that it is a simple pendulum, as shown above. The maximum angle θ_{max} that the string makes from the vertical can be assumed to be small. The graph below shows data for the square of the pendulum period T as a function of string length L.



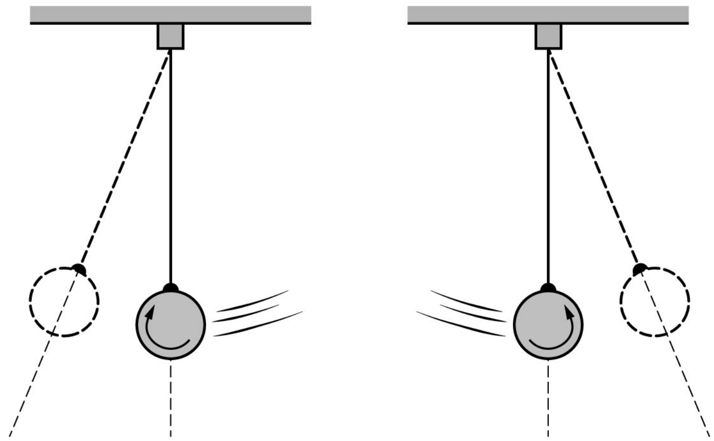
(C) On the graph above, draw a best-fit line for the data. Then use the line to calculate a numerical value for the gravitational acceleration g.



(D) The graph above shows the angle θ from the vertical as a function of time for the pendulum. On the axes below, sketch a graph of the gravitational potential energy of the sphere-Earth system for the same time interval. Take the zero of potential energy to be when the potential energy has its a minimum value.



(E) As the sphere swings back and forth, it must also rotate a small amount during each swing. The figures below indicate the direction that the sphere rotates as it is swinging in each direction.



In order for the sphere's rotation to change direction, a torque must be exerted on the sphere. When the sphere is at its maximum rightward displacement, what is the direction of the torque exerted on the sphere with respect to the point of attachment between the sphere and string?

____ Clockwise ____ Counterclockwise

Briefly state why the torque is in the direction you indicated.

FREE-RESPONSE QUESTION: PARAGRAPH ARGUMENT SHORT ANSWER

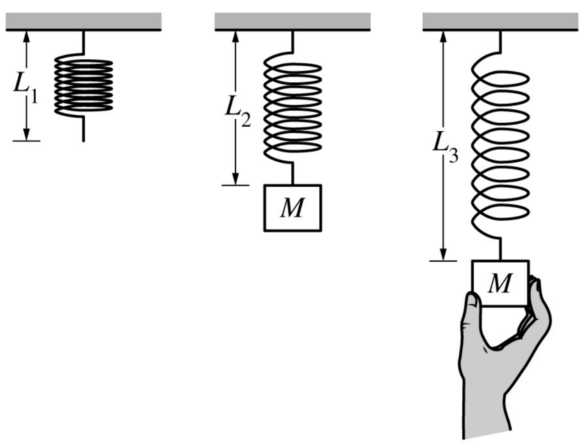
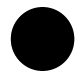


Figure 1 Figure 2 Figure 3

2. A spring with unstretched length L_1 is hung vertically, with the top end fixed in place, as shown in Figure 1 above. A block of mass M is attached to the bottom of the spring, as shown in Figure 2, and the spring has length $L_2 > L_1$ when the block hangs at rest. The block is then pulled downward and held in place so that the spring is stretched to a length $L_3 > L_2$, as shown in Figure 3.

   (A) On the dot below, which represents the block in Figure 3, draw and label the forces (not components) exerted on the block. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



(B) The student releases the block. Consider the time during which the block is moving upward toward its equilibrium position and the spring length is still longer than L_2.

In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, indicate why the total mechanical energy is increasing, decreasing, or constant for each of the systems listed below.

- System 1: The block
- System 2: The block and the spring
- System 3: The block, the spring, and Earth

Use E_1, E_2, and E_3 to denote the total mechanical energy of systems 1, 2, and 3, respectively.

Answer Key and Question Alignment to Course Framework

Multiple-Choice Question	Answer	Science Practice	Learning Objective	Unit
1	A	7.2	3.A.4.2	2
2	D	4.2	3.A.1.2	1
3	B	1.4	5.B.4.2	4
4	C	2.2	5.B.3.2	4
5	A	6.4	3.A.3.1	2
6	C	2.2	3.A.1.1	1
7	B	5.1	4.B.2.2	5
8	D	6.4	5.B.5.5	4
9	A	2.2	3.C.1.2	3
10	B	5.1	5.D.2.4	5
11	A	1.4	4.C.1.1	4
12	B, D	7.2	5.E.1.1	7

Free-Response Question	Question Type	Question Part	Science Practice	Learning Objective	Unit
1	Quantitative/ Qualitative Translation	(A)	6.4	3.A.3.1	3
		(B)	1.4, 2.2, 6.4	3.A.3.1, 3.B.2.1	2, 3
		(C)	2.2 5.1	3.B.3.3	6
		(D)	1.5	5.B.1.2	4
		(E)	1.4	4.D.2.1	7
2	Paragraph Argument Short Answer Question	(A)	1.1	3.B.2.1	2
		(B)	1.4, 2.1, 6.4	3.E.1.2, 4.C.1.1, 5.A.2.1, 5.B.4.1, 5.B.4.2	4

The scoring information for the questions within this course and exam description, along with further exam resources, can be found on the **AP Physics 1 Exam Page** on AP Central.

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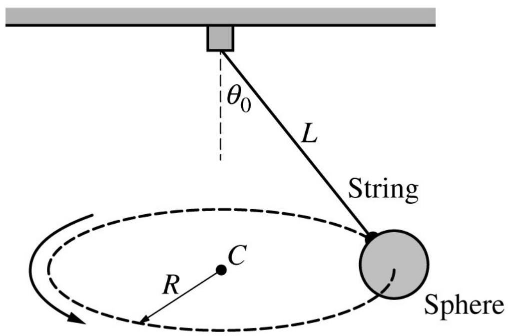
AP PHYSICS 1

Scoring Guidelines

Question 1: Quantitative/Qualitative Translation



1. A small sphere of mass M is suspended by a string of length L. The sphere is made to move in a horizontal circle of radius R at a constant speed, as shown above. The center of the circle is labeled point C, and the string makes an θ_0 with the vertical.

(A) Two students are discussing the motion of the sphere and make the following statements.

Student 1: None of the forces exerted on the sphere are in the direction of point C, the center of the circular path. Therefore, I don't see how there can be a centripetal force exerted on the sphere to make it move in a circle.

Student 2: I see another problem. The tension force exerted by the string is at an angle from the vertical. Therefore, its vertical component must be less than the weight Mg of the sphere. That means the net force on the sphere has a downward vertical component, and the sphere should move downward as well as moving around in a circle.

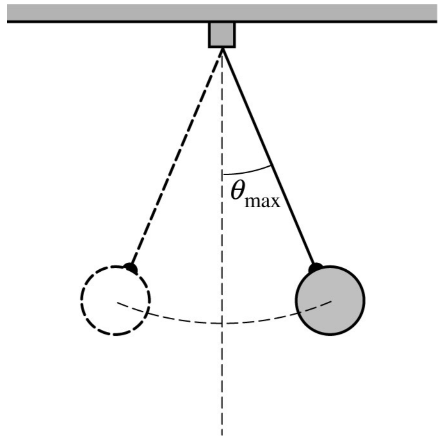
i. What is one aspect of Student 1's reasoning that is incorrect?

ii. What is one aspect of Student 2's reasoning that is incorrect?

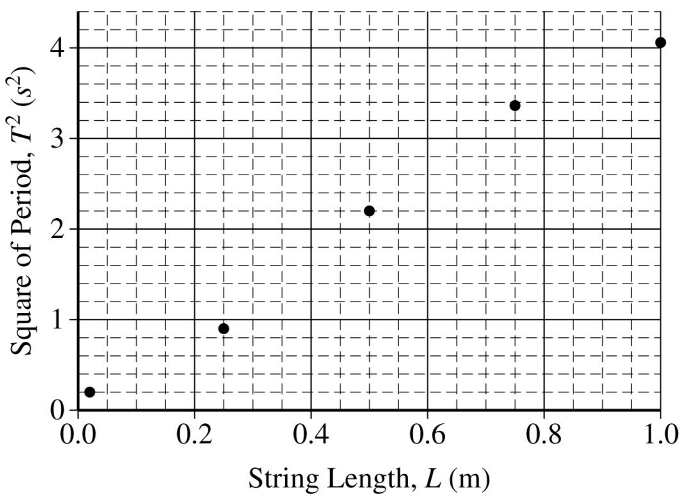
(B)

i. Derive an equation for the magnitude of the net force exerted on the sphere. Express your answer in terms of M, theta, and physical constants, as appropriate.

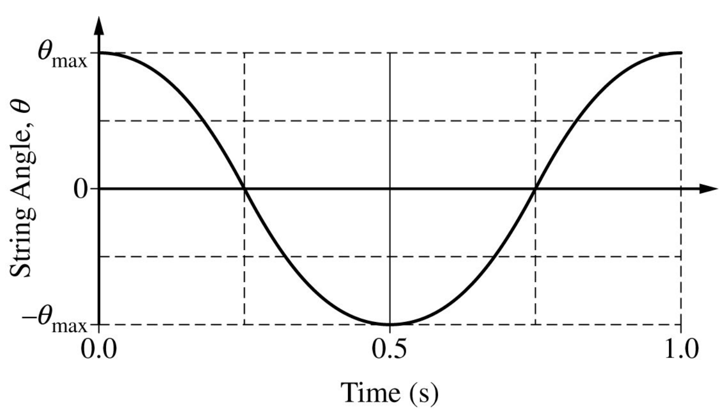
ii. Describe one aspect or step in your derivation of part (b)(i) that can be correctly linked to your answer to either part (a)(i) or part (a)(ii).



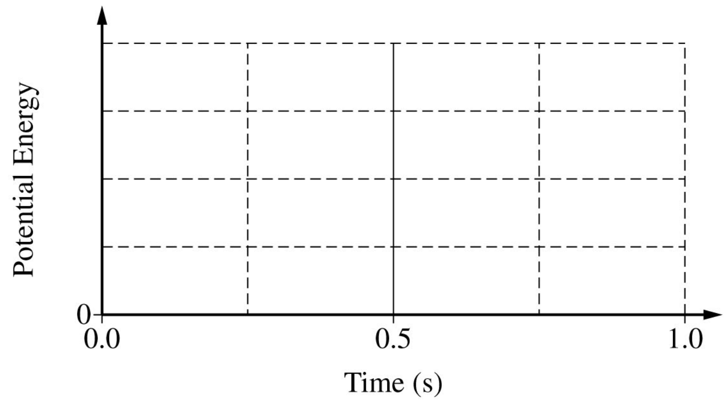
Instead of moving in a horizontal circle, the sphere now moves in a vertical plane so that it is a simple pendulum, as shown above. The maximum angle θ_{max} that the string makes from the vertical can be assumed to be small. The graph below shows data for the square of the pendulum period T as a function of string length L.



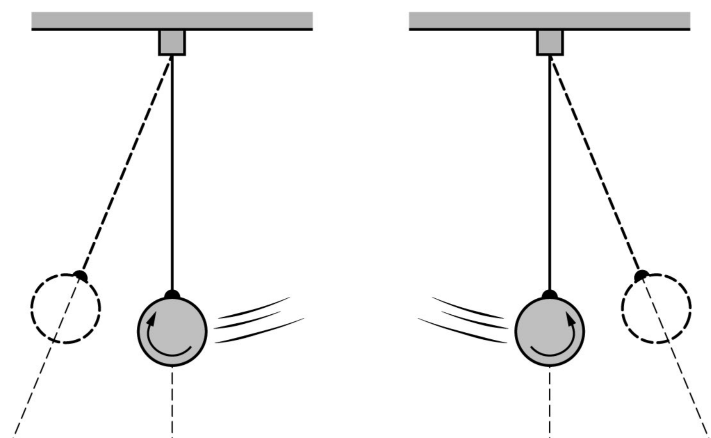
(C) On the graph above, draw a best-fit line for the data. Then use the line to calculate a numerical value for the gravitational acceleration g.



(D) The graph above shows the angle θ from the vertical as a function of time for the pendulum. On the axes below, sketch a graph of the gravitational potential energy of the sphere-Earth system for the same time interval. Take the zero of potential energy to be when the potential energy has its a minimum value.



(E) As the sphere swings back and forth, it must also rotate a small amount during each swing. The figures below indicate the direction that the sphere rotates as it is swinging in each direction.



In order for the sphere's rotation to change direction, a torque must be exerted on the sphere. When the sphere is at its maximum <u>rightward</u> displacement, what is the direction of the torque exerted on the sphere with respect to the point of attachment between the sphere and string?

____ Clockwise ____ Counterclockwise

Briefly state why the torque is in the direction you indicated.

Scoring Guidelines for Question 1: Quantitative/Qualitative Translation — 12 points

Learning Objectives: 3.A.3.1 3.B.2.1 3.B.3.3 4.D.2.1 5.B.1.2

(A) **i.** What is one aspect of Student 1's reasoning that is incorrect? — **1 point** 6.4

One point for a claim (explicit or implied) that the sphere can have a centripetal force without any individual force pointing toward the center of its circular path.

Examples of an acceptable claim:

- The centripetal force is provided by the net force on an object.
- The tension force from the string has a horizontal component, which provides the centripetal force.

---

ii. What is one aspect of Student 2's reasoning that is incorrect? — **1 point** 6.4

One point for a claim (explicit or implied) that the tension force is or can be larger than Mg.

Examples of an acceptable claim:

- The tension force is larger than Mg.
- The tension force is larger than Mg, allowing the vertical component to be equal to Mg and the net force to be zero as it must be.

Total for part (A) — **2 points**

(B) **i.** Derive an equation for the magnitude of the net force exerted on the sphere, utilizing the terms appropriate terms. — **1 point** 1.4

One point for using Newton's second law for vertical force components.

$$\sum F_y = 0$$

$$F_T \cos\theta - Mg = 0 \text{ or } F_T \cos\theta = Mg$$

One point for writing the horizontal component of string tension in terms of angle. — **1 point** 1.4

$$F_{net} = F_x = F_T \sin\theta$$

One point for substituting a correct tension force and writing an answer in terms of the stated quantities. — **1 point** 2.2

$$F_T \cos\theta = Mg, \text{ so } F_T = Mg/\cos\theta$$

$$F_{net} = F_T \sin\theta = \left(\frac{Mg}{\cos\theta}\right)\sin\theta \text{ or } Mg\tan\theta$$

---

ii. Describe one aspect or step in your derivation of part (b)(i) that can be correctly linked to your answer to either part (a)(i) or part (a)(ii). — **1 point** 6.4

One point for a correct statement linking the derivation to the answer in either (A)(i) or (A)(ii).

Examples of an acceptable description:

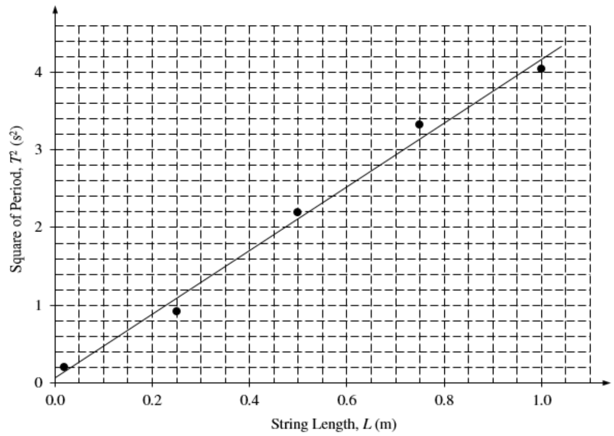
- The net force F_{net} is in the horizontal direction and equals the horizontal component $F_T \sin\theta$, as indicated by the statement $F_{net} = F_T \sin\theta$ in the derivation.
- The tension force was shown to be $F_T = Mg/\cos\theta$, which is greater than Mg as stated in the answer to (B)(ii).

Total for part (B) — **4 points**

(C) Draw a best-fit line for the data. **1 point** 5.1

One point for drawing a reasonable line of best fit. That is, the straight line drawn should have roughly the same amount of points above and below.

Example best fit line:



Then use the line to calculate a numerical value for the gravitational acceleration g. **1 point** 2.2

One point for correctly calculating the slope or its inverse, using points on the line drawn.

$$\text{Slope} = \frac{\Delta(T^2)}{\Delta L} = \frac{4.15 - 1.3}{1.0 - 0.3} = 4.07 \text{ s}^2/\text{m}$$

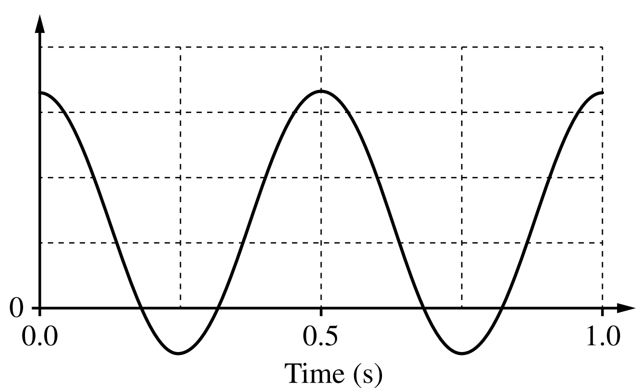
One point for a calculation of g consistent with the calculated slope or slope inverse. **1 point** 2.2

$$T = 2\pi\sqrt{L/g} \quad \text{so} \quad T^2 = 4\pi^2 L/g$$
$$\text{Slope} = 4\pi^2/g$$
$$g = 4\pi^2/\text{Slope} = 4\pi^2/\left(4.07 \text{ s}^2/\text{m}\right) = 9.7 \text{ m/s}^2$$

Total for part (C) **3 points**

(D) Sketch a graph of the gravitational potential energy of the sphere-Earth system for the same time interval. **1 point** 1.5

One point for a graph with equal maxima at 0, 0.5 s, and 1 s, and minima of zero at 0.25 s and 0.75 s.



One point for a graph that has even symmetry (mirror symmetry) about time. $t = 0.5$ s **1 point** 1.5

Notes:

- The maxima should be equal in energy, but may have any energy value.
- A graph with maxima at 0 and 1 s, and a minimum at 0.5 s, can earn the second point only.

Total for part (D) **2 points**

(E) Briefly state why the torque is in the direction you indicated. **1 point**

1.4

One point for indicating that the torque is clockwise (claim) with acceptable reasoning that connects the claim with evidence. (Note: If the incorrect selection is made, the response is not graded.)

Examples of acceptable reasoning:

1. At the sphere's maximum rightward displacement, the sphere's rotation is changing from counterclockwise (swinging to the right) to clockwise (swinging to the left). So the torque must be clockwise.
2. At the sphere's maximum rightward displacement, the gravitational force (taken to act at the center of the sphere) exerts a clockwise torque about the point of attachment to the string.

Examples of acceptable evidence:

- The sphere is rotating counterclockwise when moving to the right, toward its maximum rightward displacement.
- The sphere is rotating clockwise when moving to the left, away from its maximum rightward displacement.
- The gravitational force is in the downward direction. Treated as acting at the center of the sphere, this force is exerted at a location (the sphere's center) that is to the right of the point of attachment.

Total for part (E) **1 point**

Total for question 1 **12 points**

Question 2: Paragraph Argument Short Answer

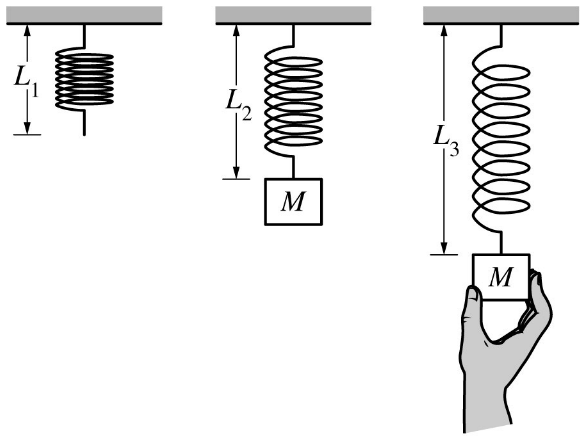
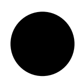


Figure 1 Figure 2 Figure 3

2. A spring with unstretched length L_1 is hung vertically, with the top end fixed in place, as shown in Figure 1 above. A block of mass M is attached to the bottom of the spring, as shown in Figure 2, and the spring has length $L_2 > L_1$ when the block hangs at rest. The block is then pulled downward and held in place so that the spring is stretched to a length $L_3 > L_2$, as shown in Figure 3.

(A) On the dot below, which represents the block in Figure 3, draw and label the forces (not components) exerted on the block. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



(B) The student releases the block. Consider the time during which the block is moving upward toward its equilibrium position and the spring length is still longer than L_2.

In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, indicate why the total mechanical energy is increasing, decreasing, or constant for each of the systems listed below.

- System 1: The block
- System 2: The block and the spring
- System 3: The block, the spring, and Earth

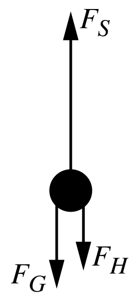
Use E_1, E_2, and E_3 to denote the total mechanical energy of systems 1, 2, and 3, respectively.

Scoring Guidelines for Question 2: Paragraph Argument Short Answer — 7 points

Learning Objectives: 3.B.2.1 3.E.1.2 4.C.1.1 5.A.2.1 5.B.4.1 5.B.4.2

(A) Draw and label the forces (not components) exerted on the block. **1 point** 1.1

Accept the following:



One point for including all three labelled forces exerted on the block:

- the upward spring force,
- the downward gravitational force,
- and the downward force of the hand holding the block.

One point for including at least one of the three forces exerted on the block, with no extraneous forces. **1 point** 1.1

Total for part (A) 2 points

(B) In a clear, coherent paragraph-length response that may also contain diagrams and/or equations, indicate why the total mechanical energy is increasing, decreasing, or constant for each of the systems listed below. **1 point** 6.4

- System 1: The block
- System 2: The block and the spring
- System 3: The block, the spring, and Earth

One point for a response with no incorrect claims about which forms of energy are present in each system.

- Note: Responses that do not explicitly refer to the forms of energy in one or more of the systems can still earn this point.

The correct forms of energy in each system are the following:

- System 1: Kinetic energy K_{block} of the block (There is no potential energy for system 1.)
- System 2: K_{block} and the potential energy U_{spring} of the spring
- System 3: K_{block}, U_{spring}, and the gravitational potential energy U_{grav} of the block-Earth system

One point for correctly providing an indication that total mechanical energy is increasing for the block. **1 point** 1.4

Examples of acceptable statements:

- The block is accelerating upward with increasing speed.
- The net force on the block is upward, in the direction of the block's velocity, so the block's kinetic energy is increasing.

One point for correct statement of why the total mechanical energy is decreasing for the block-spring system. Examples of acceptable reasoning statements: • The only external forces exerted on the block-spring system (system 2) are the gravitational force on the block and the force holding the top end of the spring in place. The gravitational force is in the opposite direction of the block's motion and so does negative work on system 2. The point of application of the force on the top end of the spring does not move, so this force does zero work on the system. Overall, negative work is being done on system 2, so E_2 must be decreasing. • System 2 has total mechanical energy: $E_2 = K_{block} + U_{spring}$, which equals $E_3 - U_{grav}$. E_3 is the total mechanical energy of System 3. E_3 is constant, while U_{grav} is increasing because the block is moving upward. So $E_2 = E_3 - U_{grav}$ must be decreasing.	**1 point** 2.1
One point for correct statement that the total mechanical energy is constant for a closed system such as the block-spring-Earth system. Examples of acceptable claim statements: • System 3 is closed, so its total mechanical energy remains constant. • No external forces act on system 3, so its total mechanical energy remains constant. Note: It is not necessary to state that energy is neither dissipated or added by converting other forms of energy into mechanical energy, since there is no mention of potential causes for these processes (e.g., friction to dissipate mechanical energy, or an explosion to add mechanical energy).	**1 point** 6.4
One point for a logical, relevant, and internally consistent argument that addresses the required argument, explanation or question asked. Example of an acceptable response: • For system 1 of just the block: When the force holding the block is removed, the block's acceleration and the net force on the block are upward since the spring force is greater than the gravitational force. The net force is in the direction of the block's motion, so its speed and kinetic energy are both increasing. The total mechanical energy is the kinetic energy for a single-object system, so E_1 is increasing. System 3 can be considered a closed system with no external forces exerted on it, so E_3 is constant. Note that: $E_3 = K_{block} + U_{spring} + U_{grav}$, where K_{block} is the block's kinetic energy, U_{spring} is the spring's potential energy, and U_{grav} is the gravitational potential energy of the block-Earth system. System 2 has total mechanical energy: $E_2 = K_{block} + U_{spring}$, which equals $E_3 - U_{grav}$. E_3 is constant, while U_{grav} is increasing because the block is moving upward. So $E_2 = E_3 - U_{grav}$ must be decreasing.	**1 point** 1.4
Total for part (B)	**5 points**
Total for question 2	**7 points**

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AP PHYSICS 1

Appendix

AP PHYSICS 1

Table of Information: Equations

AP® PHYSICS 1 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS			
Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	Coulomb's law constant,	$k = 1/4\pi\varepsilon_0 = 9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$
Speed of light,	$c = 3.00 \times 10^8$ m/s	Acceleration due to gravity at Earth's surface,	$g = 9.8\ \text{m/s}^2$

UNIT SYMBOLS									
	meter,	m	kelvin,	K	watt,	W	degree Celsius,	°C
	kilogram,	kg	hertz,	Hz	coulomb,	C		
	second,	s	newton,	N	volt,	V		
	ampere,	A	joule,	J	ohm,	Ω		

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.
II. Assume air resistance is negligible unless otherwise stated.
III. In all situations, positive work is defined as work done on a system.
IV. The direction of current is conventional current: the direction in which positive charge would drift.
V. Assume all batteries and meters are ideal unless otherwise stated.

AP® PHYSICS 1 EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

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

$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

$\left|\vec{F}_f\right| \le \mu \left|\vec{F}_n\right|$

$a_c = \frac{v^2}{r}$

$\vec{p} = m\vec{v}$

$\Delta \vec{p} = \vec{F} \Delta t$

$K = \frac{1}{2} m v^2$

$\Delta E = W = F_{\parallel} d = F d \cos\theta$

$P = \frac{\Delta E}{\Delta t}$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$

$\omega = \omega_0 + \alpha t$

$x = A\cos(2\pi f t)$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

$\tau = r_{\perp} F = r F \sin\theta$

$L = I\omega$

$\Delta L = \tau \Delta t$

$K = \frac{1}{2} I \omega^2$

$\left|\vec{F}_s\right| = k\left|\vec{x}\right|$

$U_s = \frac{1}{2} k x^2$

$\rho = \frac{m}{V}$

a = acceleration
A = amplitude
d = distance
E = energy
f = frequency
F = force
I = rotational inertia
K = kinetic energy
k = spring constant
L = angular momentum
ℓ = length
m = mass
P = power
p = momentum
r = radius or separation
T = period
t = time
U = potential energy
V = volume
v = speed
W = work done on a system
x = position
y = height
α = angular acceleration
μ = coefficient of friction
θ = angle
ρ = density
τ = torque
ω = angular speed

$\Delta U_g = m g \Delta y$

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

$T_s = 2\pi \sqrt{\frac{m}{k}}$

$T_p = 2\pi \sqrt{\frac{\ell}{g}}$

$\left|\vec{F}_g\right| = G \frac{m_1 m_2}{r^2}$

$\vec{g} = \frac{\vec{F}_g}{m}$

$U_G = -\frac{G m_1 m_2}{r}$

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2} bh$

Circle
$A = \pi r^2$
$C = 2\pi r$

Rectangular solid
$V = \ell w h$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r \ell + 2\pi r^2$

Sphere
$V = \frac{4}{3} \pi r^3$
$S = 4\pi r^2$

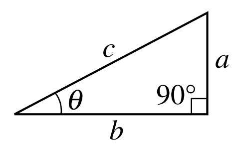
A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

Right triangle
$c^2 = a^2 + b^2$

$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$



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