Chief Reader Report on Student Responses:

2017 AP® Physics 1 Free-Response Questions

• Number of Students Scored	170,447		
• Number of Readers	364		
• Score Distribution	Exam Score	N	%At
	5	9,243	5.4
	4	27,572	16.2
	3	34,612	20.3
	2	49,614	29.1
	1	49,406	29.0
• Global Mean	2.40		

The following comments on the 2017 free-response questions for AP® Physics 1 were written by the Chief Reader, Peter Sheldon, Professor of Physics, Randolph College. They give an overview of each free-response question and of how students performed on the question, including typical student errors. General comments regarding the skills and content that students frequently have the most problems with are included. Some suggestions for improving student preparation in these areas are also provided. Teachers are encouraged to attend a College Board workshop to learn strategies for improving student performance in specific areas.

Question #1

Topic: DC Circuits

Max. Points: 7 **Mean Score:** 2.38

What were responses expected to demonstrate in their response to this question?

This question assessed learning objectives 5.B.3.1, 5.B.9.3, and 5.C.3.1.
The responses to this question were expected to demonstrate the following:

- The ability to analyze series and parallel circuits and to compare potential difference, energy, and power.
- The ability to apply Kirchhoff's loop rule to rank the potential differences across lightbulbs.
- Recognition that each circuit draws a different amount of power and the ability to correlate circuit power (or energy or current) to battery life.
- The ability to give a coherent and correct argument to support their reasoning.

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- Responses that correctly identified the series and parallel circuits from the images provided, and then ranked the potential difference across the lightbulbs in the context of the diagrams showed an understanding of the underlying concepts. The explanations went beyond identifying the circuit configurations as series or parallel.
- Responses that correctly linked potential difference, current, or resistance to the power output of the different circuits, and then implicitly or explicitly showed that power output was dependent upon the configuration of the lightbulbs or the equivalent resistance of the entire circuit revealed understanding of how these concepts are linked. The responses expressed clear thoughts for a cohesive explanation. Completely qualitative arguments were presented by some responses, while others used rationales that included quantitative reasoning, and both were acceptable.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Increased resistance results in increased power when the battery potential and lightbulb resistance are fixed quantities.	• Circuits with higher equivalent resistance draw lower current, resulting in lower power consumption.
• The power consumed by the circuit is proportional to the energy the battery could provide; hence, high power would result in long battery life.	• A circuit with a higher power will run out of energy faster than a circuit with lower power.
• Linking the power consumption to the number of lightbulbs rather than the wiring configuration.	• The total power consumed depends on the configuration of the lightbulbs, equivalent resistance, and battery voltage.

• Students believing that irrelevant things were relevant, such as the number of wires, the lengths of the wires, the proximity of the lightbulb to the battery, and the connection to positive or negative terminals.	• The wires are to be considered ideal, with zero resistance, and have no effect on the power consumption of the circuits.
• Students wrote in non-scientific terms using analogies or conceptual examples they had learned in class, rather than using the physics terminology. Students use voltage, current, energy incorrectly (e.g., "the voltage moves through the circuit").	• Correct terminology includes "voltage across," "current through" or "current in," "energy dissipated."

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Students need to be explicitly told that work done in spaces outside the response area will not be graded. Many students performed calculations next to the images of the three circuits but did not reference the work in the answer space.
- Since no points are awarded simply for checking the correct selection, students should at least make an attempt to explain some physics after they have made a selection.
- The most basic things need to be practiced: correct terminology (e.g., "voltage across"), and that proximity to the power course does not have any effect on the properties of circuit.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

Teachers of AP Physics 1 can find useful resources in the Course Audit webpage and AP Central Home Page for AP Physics 1. The following curriculum modules will provide additional information on these concepts: 1. Multiple Representations of Knowledge: Mechanics and Energy. The downloadable AP 1 and AP 2 lab manual may provide practical application of these concepts.

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Question #2

Topic: Lab question, friction

Max. Points: 12 **Mean Score:** 5.47

What were responses expected to demonstrate in their response to this question?

This question assessed learning objectives 2.B.1.1, 3.A.1.2, 3.B.1.1, 3.B.1.2, 3.B.1.3, 3.B.2.1, and 3.C.4.1. The responses to this question were expected to demonstrate the following:

- The ability to design an experiment, indicate measurements and equipment required, and describe a valid procedure.
- The ability to identify the forces acting on an object in contact with a surface and resolve all forces into components parallel and perpendicular to the surface.
- Understanding how to apply Newton's second law to an object in order to arrive at a coefficient of friction between two surfaces.
- Understanding how to differentiate between static friction and kinetic friction.
- Recognizing that the coefficient of friction describes only the properties of two surfaces in contact resulting from interatomic forces.

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- Students who were able to design an experiment to measure the coefficient of static friction understood that they needed the block to interact with the board in such a way that it went from a state of rest to a state of motion.
- Students were generally able to draw appropriate diagrams and describe the experimental procedure.
- Students understood how to apply Newton's laws in two dimensions in order to derive an expression for a coefficient of friction.
- Students were able to analyze data, and identify and eliminate outliers.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Not realizing the difference between static and kinetic friction.	• Students stated correctly that the maximum force just before the block starts to move identifies static friction. Many students used experiments with constant motion or even constant acceleration showing that they were trying to solve for the coefficient of kinetic friction.
• Lack of understanding that coefficient of friction describes two specific surfaces in contact, and proposed experiments in which data was taken for the block on two different surfaces.	• Most students properly described an experiment in which the block and the board were sliding or attempted to slide against each other.

• Thinking that $F_N = mg$ on an incline, and showing a poor understanding of vector components.	• Students properly wrote that the normal force on an incline is $mg\cos\theta$.
• Poor ability to analyze data. Some students were only able to recognize differences in individual numbers, and not look for a trend. Other students did not even address the data given and spoke to the theoretical relationship only.	• Many students properly identified trends in the data and recognized outliers.
• Poor association of the use of the word static, associating it with static electricity.	• Students properly related static friction to the interaction between two surfaces at rest relative to each other.

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Fully read the question before attempting to answer it.
- When answering the question, write in the appropriate space. If the student has written in any other space, they must draw an arrow or write text to draw attention to those parts of their answer. They should not cross out answers unless they have something else to write. We often see correct answers crossed out. Students should write legibly.
- Remind students about the published meanings for words like calculate, determine, sketch, or derive. Students need to understand that derive means that they should start with a fundamental relationship and then substitute and solve to get an answer.
- Students should practice reading their written answers to others to see if they a) answer the question and b) are understandable.
- Practice analyzing data and using specific data to support a conclusion.
- Have students write lab experiment procedures. Many students wrote measurements without an action. Include measurements to be taken and describe HOW that measurement is to be taken. Avoid stating the use of "known" force when it has to be measured. Nothing is implied—be clear and specific. ALL students should participate in lab—not just watch—so that they understand how to take measurements. Don't include calculations or analysis in the lab procedure.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

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Question #3 **Topic:** Conservation of Angular Momentum
Max. Points: 12 **Mean Score:** 3.48

What were responses expected to demonstrate in their response to this question?

This question assessed learning objectives 3.F.1.2, 3.F.2.1, 3.F.3.1, 4.D.2.1, 4.D.3.1, 5.E.1.1, and 5.E.1.2.
The responses to this question were expected to demonstrate the following:

- Understanding how to connect principles of physics (torque, angular momentum, and impulse) to observed behavior of a physical system.
- The ability to derive a relationship using conservation of angular momentum.
- Understanding how functional relationships in an unfamiliar equation connect to physical reasoning.

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- Many responses clearly discussed and internalized the meaning of torque and rotational inertia, and their relationship to a change in angular speed.
- Many responses showed work at some level with angular momentum conservation.
- The biggest content issue was a misunderstanding of the vector nature of momentum, in particular why a bouncing object delivers more impulse than a sticking object.
- A reasonable number of students earned a point for addressing functional dependence of an unfamiliar equation.
- Many responses didn't distinguish between deriving a relationship from first principles vs. plugging a bunch of variables into an equation and solving for one of those variables. For derivations, the responses we've seen show students focused on getting an answer by any means necessary, without thinking about the starting point for the chain of reasoning that could lead to a correct conclusion.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Students do not show an understanding that the analysis of collisions requires starting with conservation of momentum, not conservation of energy	• The rebounding disk changes its momentum more than does the sticking disk.
• Students do not start derivations from first principles	• Angular momentum is conserved: $L = L'$
• Students do not show an understanding that analyzing an equation for physical plausibility begins with addressing functional dependence—direct or inverse relationships—not with which variables "should" or "should not" be associated with other variables	• In this equation, the angular speed varies inversely with the mass of the disk. This doesn't make physical sense because…

• Students often use imprecise language, analogies, or descriptions that are not physics principles to justify responses	• The disk applies greater torque the farther from the pivot it strikes. (Not "leverage" or "like when you open a door.")

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Teachers seem to be addressing the content issues appropriately. It's the skills in this question that need focus from teachers.
- Work with students on *briefly*—in one sentence—addressing functional dependence in equations. A major issue in this question was responses containing multiple sentences or overabundant explanations without focus. Throughout the school year, teachers can discourage students from such broad, unsuccessful responses. Concise, to-the-point science writing is a skill that is required for the AP Physics 1 exam. If teachers consistently award credit in class *only* for concise, to-the-point answers, students will be better prepared for the demands of the AP exam.
- And in class all year, teachers can work on logical mathematical communication in derivations. Require students to show their starting principle and to annotate their steps. Most importantly, don't focus on answers and algebraic manipulation to the detriment of clear and correct physics steps. Award more credit to the student who starts in the right place but makes an algebra error than to the student with the correct answer amongst a jumble of equations.
- Have students practice their justifications in terms of fundamental physics principles and using the correct terminology. Teachers need to be precise in their language and have students be similarly precise in their language.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

Teachers of AP Physics 1 can find useful resources in the Course Audit webpage and AP Central Home Page for AP Physics 1. The following curriculum modules will provide additional information on these concepts: 1. Rotational Motion, 2. Multiple Representations of Knowledge: Mechanics and Energy. The downloadable AP 1 and AP 2 lab manual may provide practical application of these concepts.

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Question #4

Topic: Conservation of Energy

Max. Points: 7 **Mean Score:** 2.01

What were responses expected to demonstrate in their response to this question?

This question assessed learning objectives 3.A.1.1, 4.C.1.1, 4.C.1.2, 5.B.3.3, 5.B.4.1, 5.B.4.2, and 5.B.5.4. The responses to this question were expected to demonstrate the following:

- Understanding conservation of energy for an object moving through a height change.
- Recognizing when to treat a problem from an energy point of view.
- Recognizing that the time of flight for a horizontal projectile depends only on the height at launch.
- Understanding that the change in gravitational potential energy is path independent, dependent only on net height change.
- The ability to select an appropriate reference point for potential energy.

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- Most recognized that this could be solved with an energy approach.
- Most recognized that the energy changes from potential to kinetic, but that the total amount remains constant.
- Most showed an understanding that potential energy was related to the height and that kinetic energy was related to the velocity.
- Many did not address that the time of flight for the projectile is the same if launched from the same height, with the same vertical velocity.
- Most recognize that if the height change is the same then the blocks have the same velocity, but don't explicitly connect it to potential energy.
- The responses showed a struggle with reasoning in terms of fundamental physics principles. Many responses did not focus on the big ideas and how they were applied to the problem.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Many students don't distinguish between the potential energy and the change in potential energy	• Ignoring friction, the kinetic energy, and therefore the speed, at the bottom of the ramp depends only on the change in potential energy between the top and the bottom of the ramp, which depends on the height change between the top and bottom of the ramp.
• Many don't recognize path independence for conservative systems	• Since the change in the potential energy between the top and bottom of the ramp is the same for both ramps, the kinetic energy and therefore the speed at the end of the ramp will be the same for both blocks.

• Many do not recognize that although the blocks get to the end of the ramp with the same speed, it doesn't mean that they get there at the same time	• Because the slope of ramp 1 is steeper at the beginning, block 1 reaches its maximum speed first so it reaches the end of the ramp first and hits the ground first.
• Many do not recognize that time of flight for a projectile is not dependent on the horizontal speed	• Since the blocks leave the ramps at the same height and no vertical velocity, they have the same time of flight regardless of the horizontal velocity.

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Students need to be able to write legibly and clearly.
- Students would benefit from practicing written justifications that address the big ideas in physics and first principles.
- Students should practice using the correct physics terminology.
- Teachers need to be precise in their language and model that for students, encouraging the students to be precise in their language.

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

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Question #5 **Topic:** Waves

Max. Points: 7 **Mean Score:** 2.63

What were responses expected to demonstrate in their response to this question?

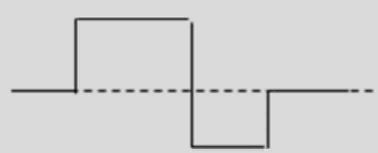
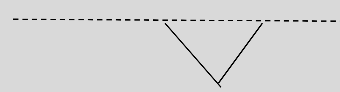
This question assessed learning objectives 3.A.1.1, 6.A.1.2, 6.D.1.1, and 6.D.2.1.
The responses to this question were expected to demonstrate the following:

- The ability to translate a position versus time graph to a velocity versus time graph.
- Understanding the difference between the speed of a pulse versus the speed of a point in the medium (string).
- The ability to apply the principle of superposition.
- Understanding the difference between constructive and destructive interference when two wave pulses overlap.

How well did the responses address the course content related to this question? How well did the responses integrate the skills required on this question?

- The responses address the basic concepts of wave motion and can connect position correctly to velocity.
- The responses nicely integrated the skill of graphing to demonstrate understanding of wave motion.
- The responses were very clear on part b where students needed to demonstrate the principle of superposition.
- Overall the responses address the content appropriately and integrate the skills required to answer the question.

What common student misconceptions or gaps in knowledge were seen in the responses to this question?

Common Misconceptions/Knowledge Gaps	*Responses that Demonstrate Understanding*
• Velocity of wave versus velocity of a point on the string. • Translating from a position versus time graph to a velocity versus time graph.	• A graph of velocity as a function of time, which is the slope of the pulse identified 
• Drawing two distinct, overlapping pulses.	• A single pulse that shows the superposition of the two given pulses at the time given 

Based on your experience at the AP® Reading with student responses, what advice would you offer to teachers to help them improve the student performance on the exam?

- Students should practice with physical, visual representations of waves (e.g., tuning forks, Slinkies, and video simulations)
- Students should practice graphically adding and subtracting two overlapping pulses
- Students need to be able to translate between a graph of position as a function of time to a graph of velocity as a function of time, and to understand the significance of slope
- Students should use a ruler when graphing so that the answer is clear as to whether or not the line is supposed to be straight or curved

What resources would you recommend to teachers to better prepare their students for the content and skill(s) required on this question?

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