# Chief Reader Report on Student Responses:

## 2022 AP® Physics C: Mechanics Set 2 Free-Response Questions

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| • Number of Students Scored | 46,301 | | |
| • Number of Readers | 471 (for all Physics exams) | | |
| • Score Distribution | Exam Score | N | %At |
| | 5 | 12,222 | 26.4 |
| | 4 | 11,893 | 25.7 |
| | 3 | 9,867 | 21.3 |
| | 2 | 7,212 | 15.6 |
| | 1 | 5,107 | 11.0 |
| • Global Mean | 3.41 | | |

The following comments on the 2022 free-response questions for AP® Physics C: Mechanics were written by the Chief Reader, Brian Utter, Teaching Professor, University of California, Merced. 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

**Task:** Short Answer
**Topic:** Newton's Laws of Motion
**Max Score:** 15
**Mean Score:** 6.75

### *What were the responses to this question expected to demonstrate?*

The responses were expected to demonstrate the ability to:

- Draw free body diagrams indicating forces exerted on a system and their directions with appropriate labels.
- Determine an expression for an angle in terms of position. This requires application of the geometric definition of a trigonometric function and representing the angle in terms of the position for a moving object.
- Apply Newton's second law.
- Identify different types of forces, such as the normal force, tension, gravitational force, and friction.
- Derive expressions for the normal force and the net horizontal force. This requires correct identification of the vector force components and representing those components in terms of the position of the object rather than the angle.
- Derive an expression for the work done by a varying force. This requires application of the integral definition of work and substituting/using the correct vector component.
- Compare the energy dissipated in two intervals of motion and justify the comparison. This requires relating the friction force to the changing normal force and a justification for why the normal force changes with position.

### *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 responses demonstrated correct drawing and labeling of the force diagram. Some responses included a force diagram that was not consistent with the picture in the question prompt, improper labeling (e.g., indicating the friction force as simply "$\mu$" or the gravitational force as "$g$," writing an incorrect expression like "$\mu mg$" for friction), or included extraneous forces, such as "$F_{\text{applied}}$" or "$F_{\text{velocity}}$." For many responses, the force diagram was the only part that earned points.
- In many responses, students were unable to represent the angle in terms of $x$ and $y$. This application of geometry is not an explicit learning objective in the course, but it is essential knowledge that is a necessary basis for using vectors.
- Most responses showed an understanding of vector components, but some defaulted to standard assumptions that horizontal components contain cosine and vertical components contain sine.
- Many responses did not correctly *derive* expressions starting from fundamental equations with appropriate substitutions, even if the response was able to correctly represent the expression.
- Some responses correctly represented the work done with an integral expression containing the correct vector component.
- Some responses were able to select the correct comparison of two energies but few were able to adequately justify the comparison.

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

| *Common Misconceptions/Knowledge Gaps* | *Responses that Demonstrate Understanding* |
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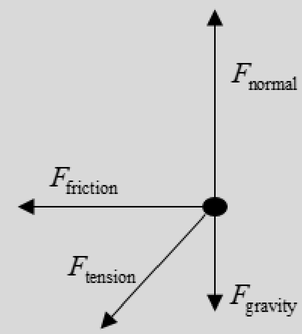
| • Incorrect force diagrams showing incorrect direction for the forces.<br>• Force labels that were incorrect or incomplete, such as using $\mu$ by itself to represent a friction force or "$G$" to represent the gravitational force.<br>• Force labels that were incorrect mathematical expressions, such as "$mg$" for the normal force or "$\mu_k mg$" for friction.<br>• Adding extraneous forces, such as "$F_{applied}$" or "$F_{velocity}$" pointing in the direction of motion. | <br><br>• Correct responses used clear, simple, and logical labels indicating forces. |
| • Attempts to represent the angle in terms of quantities other than $x$, such as forces.<br>• Attempts to represent the angle in terms of constant-acceleration kinematics.<br>• Incorrect representation of a trigonometric function. | • $\tan\theta = \frac{x}{y}$<br>• $\arctan\left(\frac{x}{y}\right) = \theta$ |
| • Stating a final answer without showing any steps for the derivation.<br>• Applying the wrong trigonometric function to represent the vertical component of the tension force.<br>• Not substituting the expression for $\theta$ from part (b) into the vector component. | • Beginning with an appropriate force summation, such as $\Sigma F_y = 0$ or $F_n - F_g - F_{Ty} = 0$ in part (c)(i) or $F_{net} = -F_{Tx} - F_f$ in part (c)(ii).<br>• Representing $F_{Ty}$ as $F_T\cos\theta$, and $F_{Tx}$ as $F_T\sin\theta$, because the angle was defined between the string and vertical, not horizontal.<br>• Replacing $\theta$ with an expression from part (b), such as $\arctan\left(\frac{x}{y}\right)$ or replacing the trig function with an appropriate ratio, such as:<br>$\cos\theta = \frac{y}{\sqrt{y^2 + x^2}}$ or $\sin\theta = \frac{y}{\sqrt{y^2 + x^2}}$ |

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| • Stating a final answer for work without showing any steps for the derivation.<br>• Assuming that the horizontal component of tension was constant and, therefore, not integrating force with respect to distance.<br>• Using the entire net force expression from part (c)(ii) when the prompt specified the horizontal component of the tension force.<br>• Applying the standard definition of dot product, using $\cos\theta$. Because the angle was defined from vertical instead of horizontal the dot product required $\sin\theta$ to multiply parallel components of the force and displacement. | • Correct response to a *derive* requires steps and substitutions.<br>$W = \int_a^b F \cdot dr$<br>$W = \int_0^L -F_{\text{Tx}} \cdot dx$<br>$W = \int_0^L -F_{\text{T}} \sin\theta \, dx$<br>$W = \int_0^L -F_{\text{T}} \frac{x}{\sqrt{x^2 + y^2}} dx$ |
| • Checking more than one option, or no options, or incompletely erasing a choice.<br>• Justifying the energy comparison with information that was not known or defined in the prompt.<br>• Attempting to justify using only equations, with no words (or symbols) to show the understanding of the relationship. | • Correct responses marked "$E_1 > E_2$."<br>• Correct justification connects the changing normal force to the change in position or angle and the friction force to the normal force.<br>*"As the sled moves, the angle increases, which decreases the normal force. The friction force is proportional to the normal force, so the friction force decreases, which decreases the work done."*<br>• Responses could also earn the justification point by connecting the friction force to the angle or position, with reference to the normal force equation derived in part (c)(i).<br>$F_{\text{f}} = \mu_{\text{k}} F_{\text{N}} = \mu_{\text{k}}\left(mg + F_{\text{T}}\left(\frac{y}{\sqrt{x^2 + y^2}}\right)\right)$<br>*The equation shows that an increase in position x causes a decrease in friction force.* |

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

- Free body diagrams are a fundamental part of introductory physics but are likely a topic covered early in the year. Teachers should emphasize clear, simple labels for the force arrows, consistent with standard examples in exam rubrics. Students should continue to see free body diagrams as part of their work throughout the school year so that they remain prepared to draw good free body diagrams on the exam.
- Responses frequently failed to recognize that the prompt asked for a representation of the angle in terms of $x$ and $y$, and instead attempted to derive an expression in terms of forces. Some responses incorrectly represented the trig function ratios, and some did not recognize that a trig function was needed. Teachers should take a little time to review the geometric definitions of the trigonometric functions and give students practice in representing trig functions as ratios of the sides of a triangle, rather than only in terms of an angle. This skill becomes very important in electricity and magnetism; students that are moving on to Physics C: E&M or will be taking further physics in college will benefit from the practice in Physics C: Mechanics.
- The most common error in (c)(i), (c)(ii), and (d) was failing to *derive* an expression. Many responses correctly stated the result, but a "derive" prompt requires a general starting point and steps or substitutions to reach the result. A single equation cannot earn full points for a derivation.
    - Teachers should model the process of derivation to show students the thinking process and the expectations of the exam.
    - Small-group activities in which students collectively discuss and complete a derivation can be helpful in building student confidence and understanding of the process of derivation.
- The second most common error in part (c)(i) to part (d) was not substituting the angle expression from part (b). Even responses that had the correct angle expression in part (b) did not always carry out the substitution in part (c)(i) to earn the second point. Some, however, correctly substituted the expression from part (b), even if the expression was not correct, which shows a good understanding of the expectations of the exam.
    - Teachers should coach students to recognize that if they can't determine a correct answer to one part of the question, they can still earn credit by showing good physics in the later parts and correctly substituting an incorrect expression.

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

- Teachers can use AP Classroom to direct students to the AP Daily videos in the Forces and Energy units.
- Teachers can use AP Classroom to direct students to the Faculty Lectures on Forces and Energy.
- Teachers can assign topic questions and/or personal progress checks in AP Classroom to monitor student progress and identify areas for additional instruction or content and skill development.

## Question 2

**Task:** Experimental Design
**Topic:** Impulse and Momentum
**Max Score:** 15
**Mean Score:** 6.50

***What were the responses to this question expected to demonstrate?***

The responses were expected to demonstrate the ability to:

- Indicate that impulse changes momentum.
- Graph the individual momenta of two objects of different masses before and after an inelastic collision.
- Use the conservation of energy for objects on springs.
- Use momentum conservation to derive the speed of two objects after a collision.
- Draw a best-fit line when given a set of plotted data points.
- Calculate the slope of the best-fit line drawn and relate the slope of the best-fit line to a given equation.
- Analyze the functional dependence between two variables to determine how a change in one variable will affect the other variable.

***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 often recognized that the impulse from the spring was larger than the impulse of Block 1 on Block 2.
- Most students recognized that the momentum of Block 1 is increasing prior to the collision with Block 2 and will be smaller in magnitude and constant after the collision.
- Most students also recognized that the changes in momenta for both blocks are equal and opposite (Block 1 loses while Block 2 gains the same amount).
- Many students in part (c) correctly began the derivation with a statement of conservation of energy of the block on the spring (elastic potential energy converted to kinetic energy) in order to solve for the velocity of Block 1 once it left the spring and then correctly used a statement of conservation of momentum to solve for the velocity of the two block system after the collision. Students who did not earn full points typically attempted to use energy conservation, not realizing that energy was not conserved because the collision is inelastic.
- Most responses clearly showed students know not to simply connect data points when drawing a line of best fit. However, there was a significant number of responses where students did connect the first and last data point or even began at the origin and drew a line to the last data point.
- Students clearly demonstrated their ability to calculate the slope of a line, but a large fraction of responses did not clearly or correctly relate the slope to the mass of Block 2 using the equation given in part (c).
- Students who were confident in analyzing functional dependence between two variables provided very clear and correct justifications in part (e).

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

| *Common Misconceptions/Knowledge Gaps* | *Responses that Demonstrate Understanding* |
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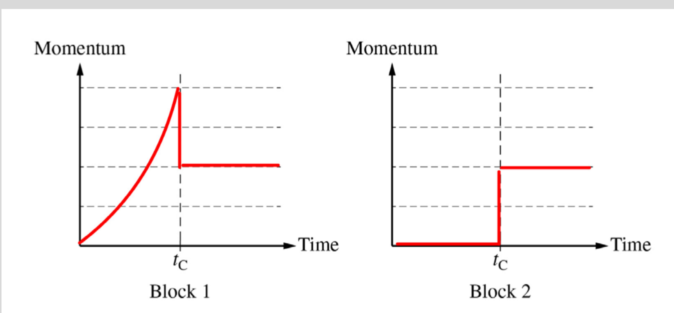
| • Students sometimes assumed that impulses from different systems must be equal and opposite because the change in momentum is always zero. | • Students should say that the change in momentum on Block 1 from the spring has to be greater than the change in momentum from the collision because the momentum Block 1 gained by the spring ( $J_S$ ) was not fully dissipated or transferred in the collision ( $J_2$ ) because Block 1 continued to move right after the collision. |
| • Students often drew final momentums of the system as equal because the objects moved together after a perfectly inelastic collision. The objects do not have the same mass or momentum, only the same velocity.<br><br>• Students attempted to draw momentum increasing during the block's motion on the spring but oftentimes mistakenly drew a linear relationship or parabola rather than an increasing concave down curve.<br><br><br> | • Block 1: Students should draw an increasing concave down curve to a maximum at the indicated collision time, $t_c$. (This is part of a cosine curve because the restoring force is proportional to the position.) The line then needed to drop to show that the momentum of Block 1 decreases due to the collision.<br><br>• Block 2: Students need to show a zero line up until the indicated collision time, $t_c$. The line then rises to a value that is lower than the line drawn for Block 1. At the collision time, the graph should demonstrate an understanding of conservation of momentum by reflecting equal and opposite changes in the momentum of the blocks. |
| • Students incorrectly combined spring force or energy into a momentum expression or tried to use Newton's second law and kinematics. | • Students should have shown a clear expression for conservation of energy.<br><br>$\frac{1}{2}k\Delta x^2 = \frac{1}{2}m_1 v_1^2$<br><br>• Students also needed an expression using conservation of momentum.<br><br>$m_1 v_1 = (m_1 + m_2)v$<br><br>• Students then need to be able to use substitution to obtain the final equation given. |

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| • Students incorrectly drew lines of best fit having significantly more data above or below the line. Some responses connected the origin to an arbitrary point. Others connected the first and last data point. | • Students should use a straightedge to draw a line of best fit. The best-fit line should have approximately the same number of points above and below the line, follow the trend of the data, and not assume that the line must go through the origin. |
| • Students used data that was not on their line of best fit to calculate a slope or did not clearly show what data was used to do the calculation.<br><br>• Students plugged in a single data point to the equation for the line, which is inaccurate if the line did not pass through the origin. | • Calculate the slope of the line using two points on the line. The clearest responses indicate two points on the line that are used to calculate the slope.<br><br>• Clearly identify the slope and its relationship to $m_2$ .<br><br>$\text{Slope} = \frac{v}{\Delta x} = \frac{\sqrt{km_1}}{m_1 + m_2}$ |
| • Students who did not use the equation from part (d) had a hard time adequately connecting the energy from the spring to the collision in order to support their claim.<br><br>• Students who used the equation in part (d) needed to say more than “directly related” to earn credit. Often, the justifications were too vague and simply restated the check box they chose. | • Students should have identified that the slope of the data, $\frac{v}{\Delta x}$ , remains constant, then referenced the equation given, $\frac{v}{\Delta x} = \frac{\sqrt{km_1}}{m_1 + m_2}$ , saying that as $m_2$ increases $\sqrt{k}$ must increase. |

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

- Remind students that they are permitted to bring a straightedge or ruler to the exam.
- Have students practice questions that incorporate the use of conservation of energy and conservation of momentum in the same question. This will allow students to develop their skills and recognize scenarios where the use of conservation of energy and conservation of momentum are appropriate. There are online simulations for collisions where great inquiry-based questions can be explored.
- Students should graph data by hand, draw best-fit lines, and calculate slopes for experiments done in class. Students need to practice drawing lines of best fit based on scattered data. Remind students that not all lines go through the origin.
    - Use similar graph styles and scales to those found on AP Exams to increase familiarity with the style.
- Practice justification and reasoning skills with students. What makes a response a valid and adequate justification is hard to explain but easier to model and practice.
    - Using ranking tasks in the classroom can inspire students to convince other classmates of their choices using solid reasoning to support their claims.
- Provide opportunities for students to use Claim-Evidence-Reasoning in the classroom to practice clearly justifying their answers to questions.
- Students need to clearly show their steps in a derivation, i.e., no skipping of steps. This is also true for prompts that ask students to calculate values. Students must show where the values are coming from and how they are being used in their work in order to earn full credit.

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

- Teachers can use AP Classroom to direct students to the AP Daily videos in the Energy and Momentum units.
- Teachers can use AP Classroom to direct students to the Faculty Lectures on Energy and Momentum.
- Teachers can assign topic questions and/or personal progress checks in AP Classroom to monitor student progress and identify areas for additional instruction or content and skill development.

## Question 3

**Task:** Short Answer
**Topic:** Rotation
**Max Score:** 15
**Mean Score:** 5.60

### *What were the responses to this question expected to demonstrate?*

The responses were expected to demonstrate the ability to:

- Draw a force diagram to represent forces exerted on a lever in equilibrium.
- Identify that for a system in rotational equilibrium, the net sum of torques is zero and that the torque exerted by a force applied at the pivot point is zero.
- Substitute appropriate expressions to represent gravitational and spring forces.
- Use multiple steps that follow a logical algebraic pathway to derive a symbolic expression for the displacement from equilibrium of a spring that applies a torque to a lever to balance the torques due to other forces.
- Identify that the angular acceleration of a rotating system is directly proportional to the sum of torques acting on it and inversely proportional to the rotational inertia of the system.
- Apply correct trigonometric substitutions and lever arms into torque expressions.
- Use multiple steps that follow a logical algebraic pathway to derive a symbolic expression for the angular acceleration of a lever oscillating due to opposing torques applied by the lever's weight and a spring force.
- Sketch a graph that shows a functional relationship between angular acceleration and time.
- Identify that the acceleration due to effects of a spring force is maximum at maximum spring displacement, minimum at spring equilibrium, and changes at a non-linear rate.
- Predict how angular acceleration changes when equal masses are added onto an accelerating lever at points equidistant but on opposite sides of the pivot point. Then, justify this prediction using rotational dynamics concepts of torque and rotational inertia.

### *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?*

- Several responses showed difficulty with drawing diagrams with the correct placement of gravitational and pivot force vectors or with the correct direction for the spring force. Some also mislabeled forces.
- Several responses included unclear distinctions between force and torque or focused solely on forces when using torque is necessary to examine rotational dynamics.
- When deriving the expression for displacement of the spring in part (b), responses often did not establish equality between the gravitational and spring forces exerted on the bar.
- Several responses incorrectly attempted conservation of energy solutions or used expressions for spring energy when substituting for spring force. A few applied incorrect rotational kinematics.
- Many responses used incorrect substitution or neglected to substitute trigonometric functions or lever arms into torque expressions. Some substituted expressions associated with only one force.
- A few responses included extraneous forces in the diagram or derivations. Most commonly, this was the "force applied by the hand that appears in the prompt" prior to the moment they are to focus on.
- Many responses had errors in graphing the change in angular acceleration over time.
- Many responses did not account for an increase in rotational inertia or that there was no change in net torque after equal masses are added equidistant to the pivot point of an accelerating lever. Many responses addressed only one of the two factors.

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

| *Common Misconceptions/Knowledge Gaps* | *Responses that Demonstrate Understanding* |
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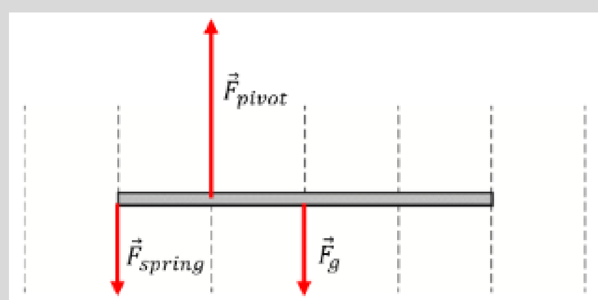
| Mislabeling forces in part (a), most commonly including:<br>• Labeling the force due to the spring as simply "*K*."<br>• Force of gravity simply as "gravity" or "*G*." | • Appropriate labels directly state or abbreviate the names of the force involved. In most cases using $F_x$, where *x* is the first letter of the name of the force, is appropriate. It is also appropriate to use expressions that are equivalent to forces.<br>• $F_G$, $F_g$, $F_{grav}$, $mg$, "gravitational force," "$F$ on board by Earth," "$F_{\text{Earth on Board}}$," and "$F_{\text{E, Board}}$" could be used for the force due to gravity. The labels *G* and *g* are not appropriate labels for the force due to gravity. $F_{spring}$, $F_s$, $F_k$, $kx$, "*spring force*," or similar labels may be used for the force exerted by the spring. |
| Incorrect placement of force vectors in part (a):<br>• Vectors that do not touch the bar in the diagram.<br>• Placing the vector for the force due to gravity at the far end of the bar (point furthest from the pivot point).<br>• Placing the force due to gravity so that it lines up with the "normal force" at the pivot point.<br>• While it is appropriate to label the force due to the pivot as a "normal force," it should be at the location of the pivot. Responses often misplaced this force at the center of the bar to line it up with the force of gravity.<br>• Drawing the spring force vector pointing upwards. It is possible that some respondents interpreted the pictures in the prompt as showing that the hand pushed the bar so that it compressed the spring. This would mean that the spring would apply a force in the upward direction after the hand is no longer touching it. However, in that case, the bar would not be in rotational and linear equilibrium, as it is intended to be in the prompt. Nevertheless, several responses show this mistake, especially when also omitting the force due to the pivot. | • Force vectors should be placed at appropriate application locations in the diagram, should touch the bar, and should point in the correct direction. This includes recognizing that the gravitational force is exerted on the center of mass and points downwards, that the force due to the pivot points upward, and that the spring force is restorative and thus opposes the direction of the spring displacement, pointing downward at the left edge of the bar. Linear equilibrium is established by the pivot force opposing the weight and spring forces. Rotational equilibrium is established around the pivot because the torques associated with spring and gravitational forces cancel each other out.<br> |

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| Force vs. torque:<br><br>• Unclear distinctions between force and torque, or focusing solely on forces, when using torque is necessary to examine rotational dynamics in parts (b) and (c).<br><br>• In part (b) attempts at dynamics solutions in terms of forces, without appropriate justification to state that the effects due to the force of gravity are equivalent to those due to the spring force. | • Derivations in parts (b) and (c) must account for torque or effects of forces exerted a distance from the pivot.<br><br>• In part (b) responses must demonstrate that the torques associated with spring and gravitational forces are equivalent because the board is in rotational equilibrium and that because these forces are exerted at the same distance from the pivot point, they must be equal. |
| • Neglecting to use appropriate signs to account for opposing directions of torques applied in the rotational form of a Newton's second law statement. | • Responses must use signs to indicate that torques associated with effects of spring and gravitational forces are exerted in different directions. |
| • Substituting for force of a spring with expressions of energy of a spring. | • Responses must use spring force ( $kx$ ) instead of spring energy ( $\frac{1}{2}kx^2$ ) to represent the force due to the spring. |
| • Incorrectly attempting conservation of energy or rotational kinematics solutions. | • Successful responses used rotational dynamics, specifically net torque equations for equilibrium from part (b) and Newton's second law from part (c) conditions. |
| • Incorrectly substituting or neglecting to substitute trigonometric functions into torque expressions. | • In part (c) responses must use $\cos\theta$, $\sin(90-\theta)$, or $\sin(90+\theta)$ substitutions into the torque expressions associated with both spring and gravitational forces. |
| • Incorrectly substituting lever arms in torque expressions. | • In parts (b) and (c) responses must use correct lever arm substitutions (most often $\frac{L}{4}$) into the torque expressions associated with both spring and gravitational forces.<br><br>• Some responses appropriately split the part of the weight exerted to the left of the pivot ( $\frac{1}{4}mg$ at $\frac{L}{8}$ ) from the part exerted the right of the pivot ( $\frac{3}{4}mg$ at $\frac{5L}{8}$ ), which leads to the same final solution. |
| Extraneous forces:<br><br>• Adding multiple vectors to represent force of gravity at different points of the bar without properly splitting weight or placing effects in the correct locations. | • It is acceptable to split the part of the weight exerted to the left of the pivot ( $\frac{1}{4}mg$ at $\frac{L}{8}$ ) from the part exerted the right of the pivot ( $\frac{3}{4}mg$ at $\frac{5L}{8}$ ). |

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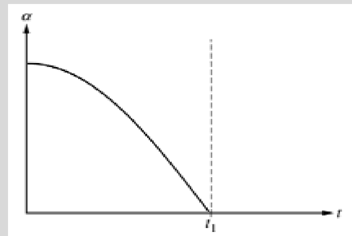
| • Incorrectly including additional force vectors or terms representing extraneous forces in derivations, often the force applied by hand shown in the prompt. | • Responses should not include force applied by hand because it is no longer present at the times they were asked to focus on. |
| Errors in sketching angular acceleration over time:<br>• Starting sketch at zero during maximum spring displacement and then increasing over time.<br>• Graphs that are concave up or have no concavity. | • Responses must include a sketch that starts at a maximum as the spring is fully stretched, continuously decreases to a minimum of zero at the time the spring reaches equilibrium, and changes at a non-linear rate (concave down).<br> |
| • No mention of the change in rotational inertia or that there is no change in net torque after equal masses are added equidistant to the pivot of an accelerating lever.<br>• Referring to rotational inertia as a "cause" for rotational acceleration rather than a factor that moderates the effect of torque on a rotating mass. | • Responses should note an increase in rotational inertia and that torque changes equally in either direction (or that no net change occurs), leading to a decrease in angular acceleration. It is important that both factors are addressed in the response.<br>• It is preferable that students use rotational dynamics terms, such as rotational inertia, instead of mass and torque instead of forces. Without mention of distance from pivot, linear terms are insufficient. |

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

- Give students ample opportunity to practice drawing force diagrams in the context of rotational dynamics. Encourage students to use force labels that directly abbreviate the name of the force. Make sure students place vectors at application points and point away from them in the correct direction.
- Experimental, conceptual, and computational practice focusing on:
    - Starting derivations from equations representing fundamental physics statements, making appropriate substitutions for expressions symbolizing physical quantities, and showing all logical algebraic steps, and isolation of desired variable.
    - Distinguishing spring force and energy applications and their appropriateness for different conditions.
    - Applying trigonometric and lever arm substitutions necessary in torque equations.
    - Distinguishing between $\sin\theta$ and $\cos\theta$ applications.
    - Examining how the acceleration, because of the spring force, relates to spring displacement and/or change over time.
    - Predicting effects of adding or removing masses to an accelerating lever.
    - Examining torque as the cause for acceleration moderated by rotational inertia.
- Encourage students to practice organizing their work neatly. If they do work that ends up not being relevant to their final solution, students should use a method to bring attention to the section that is relevant (such as a box surrounding the section that readers should attend to).
- General practice carefully reading free response instructions and choosing what responses to prioritize in an exam. Many responses drew extraneous forces or forces in the incorrect direction, directly contradicting explicit language from the prompt. Given the time constraint for the exam, it is helpful for the student to start with questions they are likely to do well on, even if that means going out of order.

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

- Teachers can use AP Classroom to direct students to the AP Daily videos in the Rotation unit.
- Teachers can use AP Classroom to direct students to the Faculty Lectures on Rotation.
- Teachers can assign topic questions and/or personal progress checks in AP Classroom to monitor student progress and identify areas for additional instruction or content and skill development.