2022

AP® | CollegeBoard

AP® Physics 1: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 3

☑ Scoring Guidelines

☑ Student Samples

☑ Scoring Commentary

Question 3: Experimental Design — 12 points

(a) For listing relevant equipment that matches the measured quantities — **1 point**

For listing measurements of quantities sufficient to determine the kinetic energy of the block — **1 point**

For listing measurements of quantities sufficient to determine the gravitational potential energy of the block-Earth system — **1 point**

For a plausible procedure (i.e., can be done in a typical school physics lab) — **1 point**

For attempting to reduce uncertainty — **1 point**

Example Response

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement
Mass of block	m_B	Mass balance
Distance that block falls (initial height above floor)	d	Meterstick
Time for block to fall	t_B	Stopwatch

1. *Measure the mass of the block with the mass balance.*
2. *Hold the block in place with the string taut and measure the distance d with the meterstick.*
3. *Release the block and start the stopwatch.*
4. *Stop the stopwatch when the block hits the floor.*
5. *Record* d *and* t_B.
6. *Repeat steps* 3-5 *to get three separate trials at the same starting distance* d.
7. *Repeat steps* 2-6 *for several different starting distances* d.

Total for part (a) — 5 points

(b) For indicating that mass and velocity are needed — **1 point**

Scoring Note: This need not be the final velocity.

For a valid explanation of how the final kinetic energy could be determined — **1 point**

Scoring Note: This needs to be the FINAL kinetic energy.

Example Response

You can calculate the block's average speed by dividing $\frac{d}{t_B}$. *The block's final speed* v_F *is twice the average,* $\frac{2d}{t_B}$. *The kinetic energy* K *can then be calculated from*

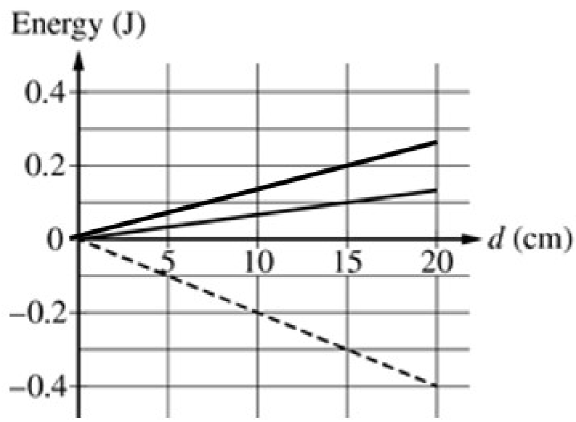
$$K = \frac{1}{2} m_B (v_F)^2 .$$

Total for part (b) — 2 points

(c)	For drawing a straight line that passes through the origin and has a positive slope	**1 point**
	For drawing a line that yields a total energy sum of zero at all values of d	**1 point**

Scoring Note: The correct line passes through the origin and (15 cm, 0.2 J).

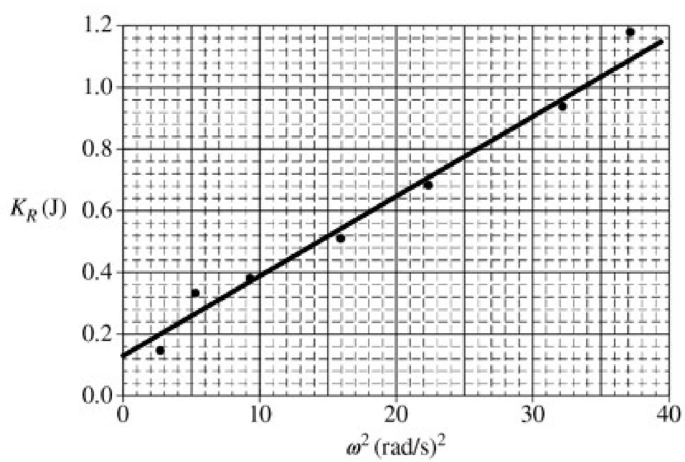
Example Response



Total for part (c) **2 points**

(d)(i)	For drawing a reasonable best-fit line	**1 point**

Example Response



(d)(ii) For correctly calculating a value for the slope using points on the line drawn, or a statement that a calculator was used to do a linear regression **1 point**

For **both** of the following: **1 point**

- correctly relating the slope of the graph to the rotational inertia
- a value of the rotational inertia I consistent with the calculated slope with correct units

Example Response

$$\text{slope} = \frac{1.04 - 0.20}{35 - 2.5} = 0.0258 \text{ kg} \cdot \text{m}^2$$

From $K = \frac{1}{2}I\omega^2$*, we have* $\text{slope} = \frac{1}{2}I$

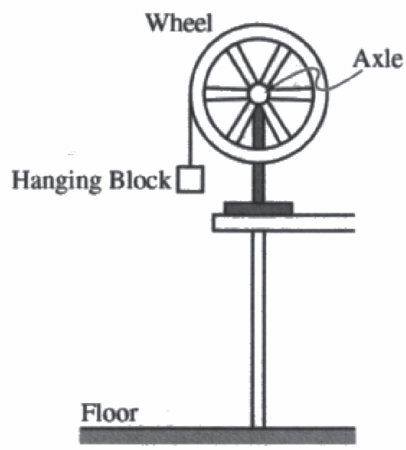
The rotational inertia is $I = 2 \times \text{slope} = 0.0517 \text{ kg} \cdot \text{m}^2$

Total for part (d) 3 points

Total for question 3 12 points

Question 3

Begin your response to **QUESTION 3** on this page.



3. (12 points, suggested time 25 minutes)

A wheel is mounted on a horizontal axle. A light string is attached to the wheel's rim and wrapped around it several times, and a small block is attached to the free end of the string, as shown in the figure. When the block is released from rest and begins to fall, the wheel begins to rotate with negligible friction.

Two students are discussing how different forms of energy change as the block falls. One student says that the kinetic energy of the block increases as it falls. The second student says that this is because gravitational potential energy is converted to kinetic energy. The students decide to test whether the decrease in gravitational potential energy is equal to the increase in the block's kinetic energy from when the block starts moving to immediately before it reaches the floor.

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

Question 3

Continue your response to **QUESTION 3** on this page.

(a) Design an experimental procedure that the students could use to compare the increase in the block's translational kinetic energy with the decrease in the gravitational potential energy of the block-Earth system as the block falls.

In the table, list the quantities that would be measured in your experiment. Define a symbol to represent each quantity and list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

In the space to the right of the table, describe the overall procedure. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table.

If needed, you may include a simple diagram of the setup with your procedure.

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement
Distance block falls	y	meterstick
Mass of block	m	mass balance
velocity of block	v	motion sensor

Procedure (and diagram, if needed)

1. Measure the mass of the block using the balance
2. Measure height of the block from the floor to its initial position using a meterstick
3. Place a motion sensor on the floor to measure the final velocity of the block
4. Repeat procedure ten times to reduce experimental uncertainty

(b) Explain how the students could determine the kinetic energy of the block immediately before it reaches the floor using the quantities you indicated in the table in part (a).

Use the measured mass of the block and the velocity captured by the motion sensor before it hits the floor to calculate

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

Question 3

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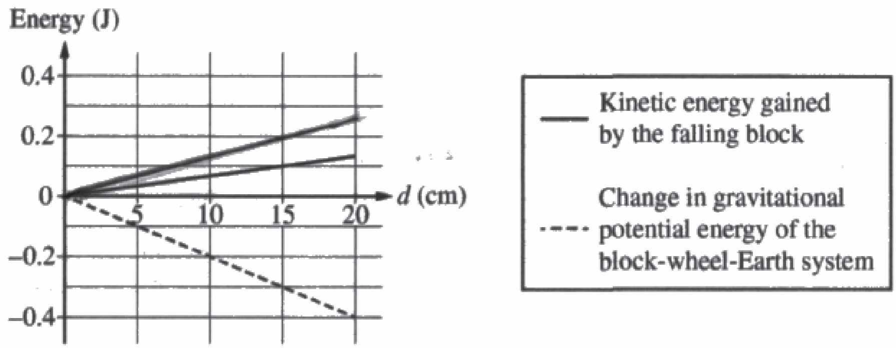
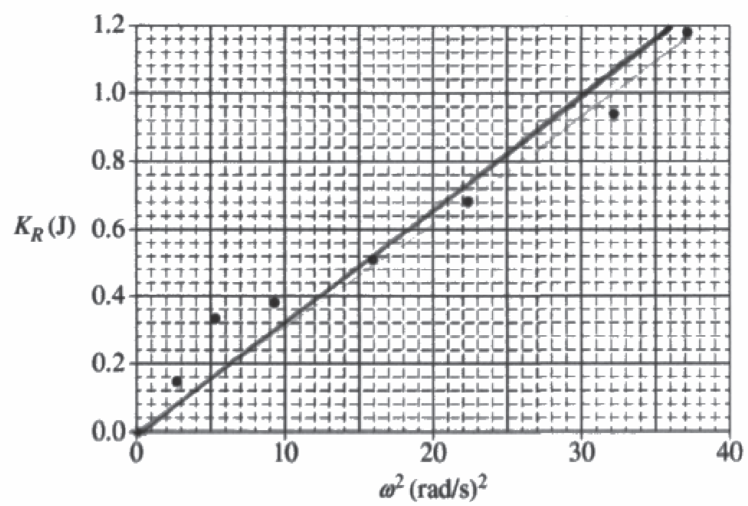


(c) The graph above represents both the change in the gravitational potential energy of the block-wheel-Earth system and the translational kinetic energy gained by the block as functions of the block's falling distance d. On the graph, draw a line or curve to represent the rotational kinetic energy of the wheel as a function of the block's falling distance d.

(d) The students also measure the angular velocity ω of the wheel as the block falls and determine the rotational kinetic energy K_R of the wheel. The students then make a graph of K_R as a function of ω^2, as shown.



i. On the above graph, draw a straight line that best represents the data.

ii. Using the line you drew for part (d)(i), calculate an experimental value for the rotational inertia of the wheel.

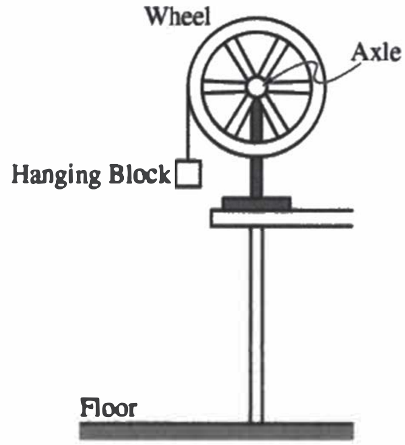
$K_R = \frac{1}{2} I \omega^2$

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

$\left(\frac{1}{30}\right) 2 = 0.0667 \frac{J}{(rad/s)^2}$

Question 3

Begin your response to **QUESTION 3** on this page.



3. (12 points, suggested time 25 minutes)

A wheel is mounted on a horizontal axle. A light string is attached to the wheel's rim and wrapped around it several times, and a small block is attached to the free end of the string, as shown in the figure. When the block is released from rest and begins to fall, the wheel begins to rotate with negligible friction.

Two students are discussing how different forms of energy change as the block falls. One student says that the kinetic energy of the block increases as it falls. The second student says that this is because gravitational potential energy is converted to kinetic energy. The students decide to test whether the decrease in gravitational potential energy is equal to the increase in the block's kinetic energy from when the block starts moving to immediately before it reaches the floor.

Question 3

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In the table, list the quantities that would be measured in your experiment. Define a symbol to represent each quantity and list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

In the space to the right of the table, describe the overall procedure. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table.

If needed, you may include a simple diagram of the setup with your procedure.

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement
height	Δy	meterstick
velocity	v	motion sensor
mass	m	scale

Procedure (and diagram, if needed)

1. Position the meterstick so that it can measure Δy as the block falls and the motion sensor to measure v.
2. Find m of the block.
3. Drop the block, using the motion sensor to find its v at various increments of Δy, such as every 0.1 m.
4. Calculate K using $\frac{1}{2}mv^2$ and U using mgh.
5. Repeat in two more trials.

(b) Explain how the students could determine the kinetic energy of the block immediately before it reaches the floor using the quantities you indicated in the table in part (a).

Use the motion sensor to determine its velocity before it reaches the ground, and find m to use in the equation $K = \frac{1}{2}mv^2$.

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Question 3

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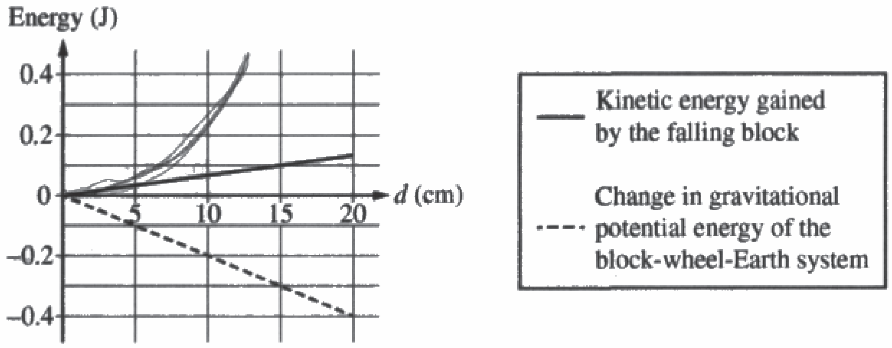

(c) The graph above represents both the change in the gravitational potential energy of the block-wheel-Earth system and the translational kinetic energy gained by the block as functions of the block's falling distance d. On the graph, draw a line or curve to represent the rotational kinetic energy of the wheel as a function of the block's falling distance d.

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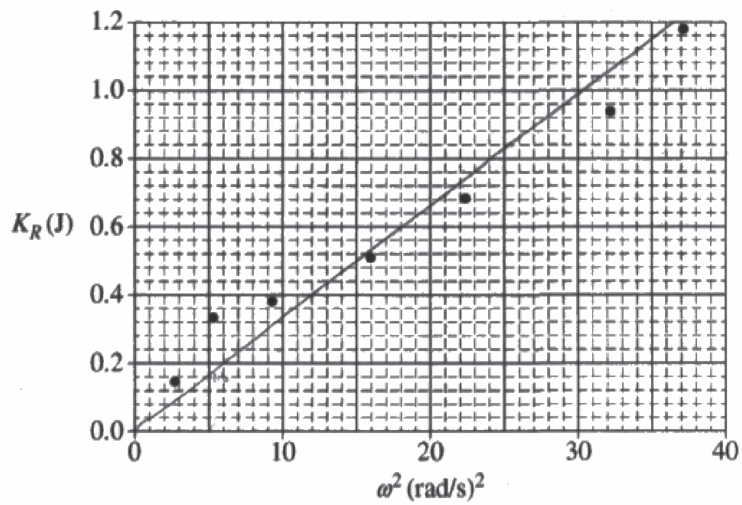

i. On the above graph, draw a straight line that best represents the data.

ii. Using the line you drew for part (d)(i), calculate an experimental value for the rotational inertia of the wheel.

slope $(K_r/\omega^2) = \frac{1.6\ J}{5\ rad/s^2} = $ 0.32 J/rad/s²

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Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

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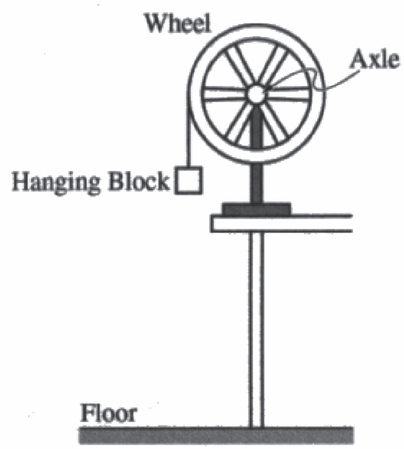
Q5330/12

Question 3

Begin your response to **QUESTION 3** on this page.



3. (12 points, suggested time 25 minutes)

A wheel is mounted on a horizontal axle. A light string is attached to the wheel's rim and wrapped around it several times, and a small block is attached to the free end of the string, as shown in the figure. When the block is released from rest and begins to fall, the wheel begins to rotate with negligible friction.

Two students are discussing how different forms of energy change as the block falls. One student says that the kinetic energy of the block increases as it falls. The second student says that this is because gravitational potential energy is converted to kinetic energy. The students decide to test whether the decrease in gravitational potential energy is equal to the increase in the block's kinetic energy from when the block starts moving to immediately before it reaches the floor.

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In the table, list the quantities that would be measured in your experiment. Define a symbol to represent each quantity and list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

In the space to the right of the table, describe the overall procedure. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table.

If needed, you may include a simple diagram of the setup with your procedure.

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement
mass	m	Scale
Time	t	Stopwatch
Distance	x	measuring tape

Procedure (and diagram, if needed)

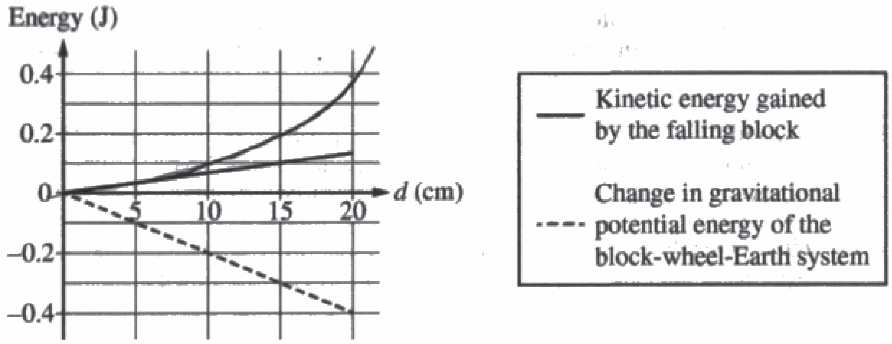
Begin with calculating the start gravitational potential energy of the block Earth system. Drop the block and begin timing calculate the kinetic energy with $K = \frac{1}{2}mv^2$ by using the measuring tape to find distance combined with the time to find velocity. Calculate gravitational potential energy when block is dropped and compare to kinetic

(b) Explain how the students could determine the kinetic energy of the block immediately before it reaches the floor using the quantities you indicated in the table in part (a).

By using the m of the block and using $K = \frac{1}{2}mv^2$

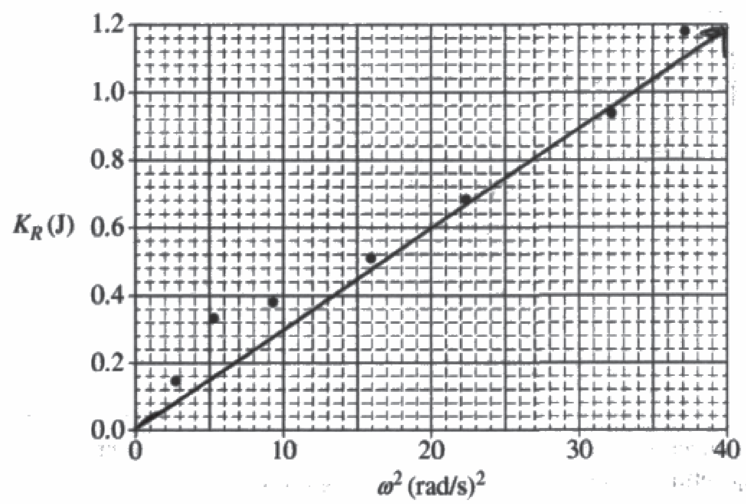
Question 3

Continue your response to **QUESTION 3** on this page.



(c) The graph above represents both the change in the gravitational potential energy of the block-wheel-Earth system and the translational kinetic energy gained by the block as functions of the block's falling distance d. On the graph, draw a line or curve to represent the rotational kinetic energy of the wheel as a function of the block's falling distance d.

(d) The students also measure the angular velocity ω of the wheel as the block falls and determine the rotational kinetic energy K_R of the wheel. The students then make a graph of K_R as a function of ω^2, as shown.



i. On the above graph, draw a straight line that best represents the data.

ii. Using the line you drew for part (d)(i), calculate an experimental value for the rotational inertia of the wheel.

rotational inertia = I

Question 3

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

The responses were expected to demonstrate the ability to:

- Design a procedure for an experiment to measure changes in kinetic energy and gravitational potential energy, including a method to reduce experimental uncertainty.
- Identify the quantities needed to calculate changes in kinetic and potential energies, including the kinetic energy of the block immediately before it hits the floor.
- Analyze data gathered by an experimental procedure.
- Apply conservation of energy to account for the rotational kinetic energy of the wheel. Specifically, responses should indicate that because the total mechanical energy of the block-wheel-Earth system remains zero throughout the block's motion, the total energy should be zero over the full range of the graph.
- Draw a reasonable best-fit line that follows the trend suggested by the data points in the graph, includes approximately the same number of data points above and below the line, and is not forced to go through data points or the origin.
- Use the slope of the best-fit line to calculate rotational inertia.

Sample: 3A
Score: 12

Part (a) earned 5 points. The first point was earned for equipment listed in the response that matches the relevant measured quantities. The second point was earned for a procedure described in the response that could be used to measure quantities sufficient to find the kinetic energy of the block. The third point was earned for a procedure described in the response that could be used to measure quantities sufficient to find the change in the gravitational potential energy in the block-Earth system. The fourth point was earned for a procedure that is a plausible way to compare changes in K and U_g, because the procedure describes finding the displacement and velocity of the block at the same location. The procedure described in the response can be performed in a physics laboratory. The fifth point was earned for a procedure that includes a way to reduce experimental uncertainty. Part (b) earned 2 points. The first point was earned for a response that indicates that mass and velocity are needed. The second point was earned for a response that indicates that the velocity used to calculate the final kinetic energy is "the velocity captured by the motion sensor before it hits the floor." Part (c) earned 2 points. The first point was earned for a response that shows a straight line that passes through the origin and has a positive slope. The second point was earned for a line drawn in the response that yields a total energy of zero over the whole range of the graph. Part (d) earned 3 points. The first point was earned for a best-fit line in the response that is reasonable. The second point was earned for a correct calculation of the slope of a line that passes through the origin. The third point was earned for a response that correctly relates the slope of the line to the rotational inertia and calculates a value of the rotational inertia with correct units.

Question 3 (continued)

Sample: 3B
Score: 8

Part (a) earned 5 points. The first point was earned for equipment listed in the response that matches the relevant measured quantities. The second point was earned for a procedure described in the response that could be used to measure quantities sufficient to find the kinetic energy of the block. The third point was earned for a procedure described in the response that could be used to measure quantities sufficient to find the change in the gravitational potential energy in the block-Earth system. The fourth point was earned for a procedure that is a plausible way to compare changes in K and U_g, because the procedure describes finding the displacement and velocity of the block at the same location: "find its v at various increments of Δy." The procedure described in the response can be performed in a physics laboratory. The fifth point was earned for a procedure that includes a way to reduce experimental uncertainty. Part (b) earned 2 points. The first point was earned for a response that indicates that mass and velocity are needed. The second point was earned for a response that indicates that the velocity is used to calculate the final kinetic energy. Part (c) earned 0 points. The first point was not earned because the response does not show a straight line. The second point was not earned because the curve drawn in the response does not yield a total energy of zero over the whole range of the graph. Part (d) earned 1 point. The first point was earned for a best-fit line in the response that is reasonable. The second point was not earned because the response uses a point that is not on this graph to calculate the slope. The third point was not earned because the response does not correctly relate the slope of the line to the rotational inertia or include correct units.

Sample: 3C
Score: 4

Part (a) earned 3 points. The first point was earned for equipment listed in the response that matches the relevant measured quantities. The second point was earned for a procedure described in the response that could be used to measure quantities sufficient to find the kinetic energy of the block. The third point was earned for a procedure described in the response that could be used to measure quantities sufficient to find the change in the gravitational potential energy in the block-Earth system. The fourth point was not earned because the response includes a procedure that is not a plausible way to compare changes in K and U_g; the response does not indicate that the displacement and velocity of the block are measured at the same location. The fifth point was not earned because the procedure does not include a way to reduce experimental uncertainty. Part (b) earned 1 point. The first point was earned for indicating that mass and velocity are needed. The second point was not earned because the response does not indicate that the final velocity is used. Part (c) earned 0 points. The first point was not earned because the response does not show a straight line. The second point was not earned because the curve drawn in the response does not yield a total energy of zero over the whole range of the graph. Part (d) earned 0 points. The first point was not earned because the best-fit line in the response is not reasonable; five data points are above the line while only one data point is below the best-fit line. The second point was not earned because the response does not include a calculation of slope. The third point was not earned because the response does not include a calculation of the rotational inertia of the wheel.