Unit 5 Progress Check: FRQ

1. This question is a long free-response question. Show your work for each part of the question.

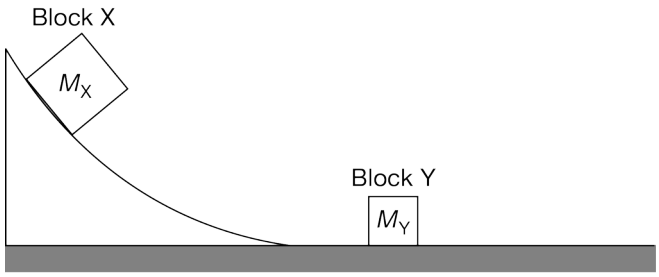

Figure 1. Initial Locations of the Blocks

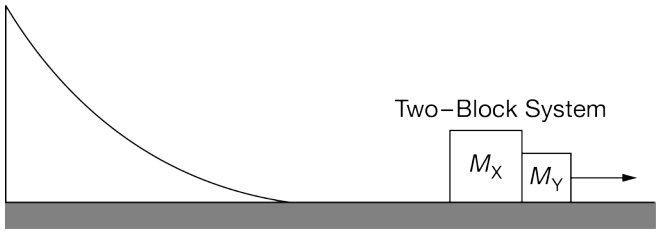

Figure 2. After the Collision

A solid block X of mass M_{X} may be placed at different locations along a curved ramp. At the bottom of the ramp is a solid block Y of mass M_{Y} that is at rest on a horizontal surface. Figure 1 shows both blocks before block X is released. A group of students must graphically determine the relationship between the release height of block X and the speed at which the two-block system travels after the blocks collide and stick together. Figure 2 shows both blocks after the collision. Frictional forces between block X and the ramp and between both blocks and the horizontal surface are considered to be negligible.

(a)

i. State the basic physics principles, laws, or equations that students could use to graphically determine the relationship between the release height of block X and the speed at which the two-block system travels after the blocks collide and stick together.

ii. Derive an equation that relates the initial release height H_{X} of block X and the speed v_s of the two-block system after the collision in terms of M_{X}, M_{Y}, and fundamental constants, as appropriate.

(b) Design an experimental procedure the students could use to graphically determine the relationship between the release height of block X and the speed at which the two-block system travels after the blocks collide and stick together.

In the table below, list the quantities and associated symbols that would be measured in your experiment and the equipment used to measure them. Also 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.

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Quantity to be Measured	Symbol for Quantity	Equipment for Measurement

Describe the overall procedure to be used, referring to the table. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty.

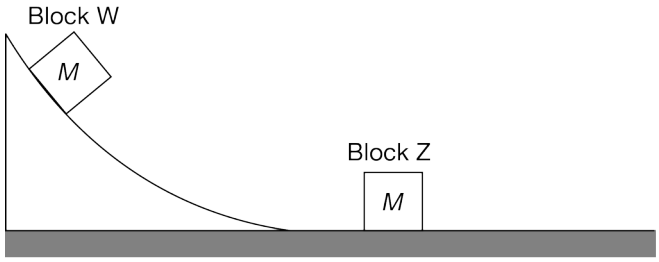

Figure 3. Initial Locations of the Blocks

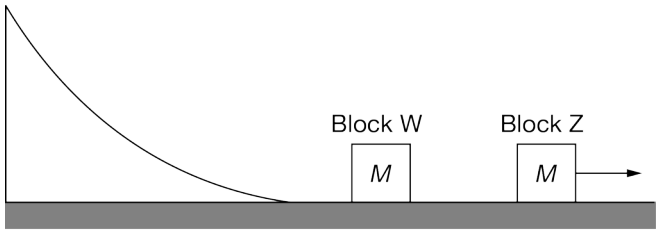

Figure 4. After the Collision

Actual Speed of Block W After Collision $(\mathrm{m/s})$	Actual Speed of Block Z After Collision $(\mathrm{m/s})$	Predicted Speed of Block Z After Collision $(\mathrm{m/s})$
0.1	1.32	1.57
0.1	1.63	1.98
-0.2	2.11	2.43
0.0	2.53	2.71

Students repeat the experiment but replace block X and block Y with block W and block Z, as shown in Figure 3.

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Block W and block Z have identical mass M. When the experiment is conducted, the students observe that the blocks do not stick together, as shown in Figure 4. The students predict the speed of block Z after the collision by assuming that the collision is perfectly elastic. They then collect data about the actual speeds of both blocks immediately after the collision, as shown in the table.

(c) Why does the predicted speed of block Z after the collision not agree with the actual speed of block Z after the collision?

Part (a)i

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

Student response accurately includes both of the following criteria.

- ☐ 1 point is earned for stating that the conservation of energy should be applied to this situation.
- ☐ 1 point is earned for stating that the conservation of momentum should be applied to this situation.

Example Response:

Students will need to use both conservation of momentum (for the collision) and conservation of energy (for the slide down the ramp) to be able to determine the relationship between the release height of block X and the speed at which the two-block system travels after they collide and stick together.

Part (a)ii

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3 ✓

Student response accurately includes all of the following criteria.

- ☐ 1 point is earned for a correct application of the conservation of momentum for an inelastic collision.
- ☐ 1 point is earned for explicitly or implicitly stating that the change in the gravitational potential energy of the block X-Earth system at the release height is converted into the kinetic energy of block Xat the bottom of the ramp.
- ☐ 1 point is earned for recognizing that the initial velocity of M_X immediately before the collision is $\sqrt{2gH_X}$.

Example Response:

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$\Sigma \overrightarrow{p}_0 = \Sigma \overrightarrow{p}_f$
$p_{X0} + p_{Y0} = p_{X0} + p_{Y0}$
$M_X v_{X0} + M_Y v_{Y0} = M_X v_{Xf} + M_Y v_{Yf}$
$M_X v_{X0} = (M_X + M_Y) v_f$

$E_0 = E_f$
$U_{g0} + U_{s0} + K_0 + W_{\text{External}} = U_{gf} + U_{sf} + K_f$
$U_{g0} = K_f$
$mgy_0 = \frac{1}{2} m v_f^2$
$v_f = \sqrt{2gy_0}$
$v_{fX} = \sqrt{2gH_X}$

$M_X v_{X0} = (M_X + M_Y) v_f$
$v_f = \frac{M_X v_{X0}}{M_X + M_Y}$
$v_f = \frac{M_X \sqrt{2gH_X}}{M_X + M_Y}$

Part (b)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5 ✓

Student response accurately includes all of the following criteria.

- ☐ 1 point is earned for listing relevant/appropriate equipment that matches the measured quantities.
- ☐ 1 point is earned for measuring the mass of both block X and block Y with an appropriate measuring device.
- ☐ 1 point is earned for measuring the vertical release height of block X with an appropriate measuring device.
- ☐ 1 point is earned for measuring the speed of the two block system immediately after the collision with an appropriate measuring device or an appropriate procedure that includes measurements of distance and time for the system.
- ☐ 1 point is earned for attempting to reduce uncertainty (e.g., multiple trials, with some parameter either fixed or varied -- e.g. “releasing block X from different vertical heights” -- as appropriate).

Example Response:

1. Use an electronic balance to measure the mass of block X and block Y.

2. Place block Yon the horizontal surface a small distance in front of the bottom of the ramp so that block X horizontally collides with block Y.

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3. Place a motion detector in front of block Y so that the two block system will travel toward the motion detector immediately after the collision.

4. Use a meterstick to measure the vertical release height of the center of mass of block X when placed on the ramp.

5. Activate the motion detector and release block X from rest.

6. Stop collecting data with the motion detector of the two block system travels to the motion detector.

8. Repeat the experiment for several trials for the release height.

9. Repeat steps 1-8 for different release heights.

Part (c)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

Student response accurately includes both of the following criteria.

- ☐ 1 point is earned for indicating that the collision is not perfectly elastic.
- ☐ 1 point is earned for indicating a conceptually appropriate reason for why the collision is not perfectly elastic.

Example Response:

The collision between block Wand block Z is not perfectly elastic even though the two blocks do not remain stuck together. During the collision, the two blocks may have momentarily stuck together or one block may have slightly caused a temporary deformation to occur with the surface of the other block.

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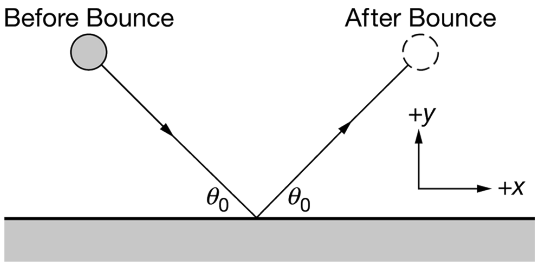
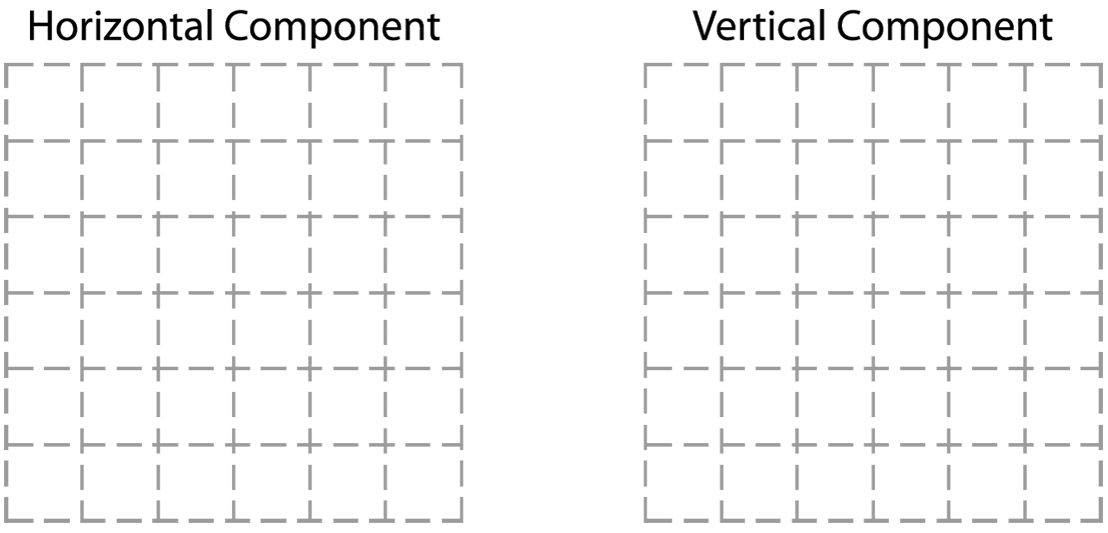
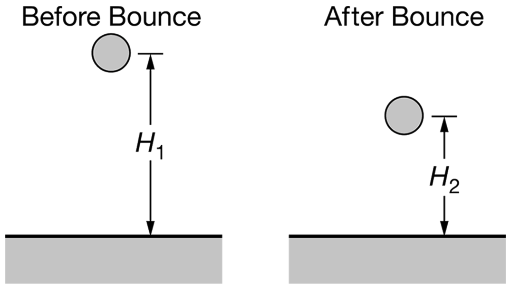
2. This question is a short free-response question. Show your work for each part of the question.



A ball is thrown toward the ground. The figure shows the direction of the ball before it reaches the ground and the direction of the ball after it bounces off the ground. After the bounce, the ball leaves the ground with the same speed that it had before the bounce. The angle between the ground and the ball's direction of travel is θ_0 before and after the ball bounces off the ground. The positive directions are indicated in the figure.

(a) Each grid below represents a component of the change in momentum of the ball as a result of the bounce. On each grid, draw a vector arrow to indicate the direction and relative magnitude of the change in momentum of the ball as a result of the bounce. If there is no change in momentum for a given component, write "NO CHANGE" under the corresponding grid.





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(b) A ball of mass M is released from rest at height H_1 above the ground. After the ball reaches the ground, it bounces and travels to height H_2 above the ground, as shown in the figure. In a clear, coherent paragraph-length response that may also contain equations and drawings, explain, using the conservation of momentum and the conservation of energy, why $H_2 < H_1$.

Part (a)

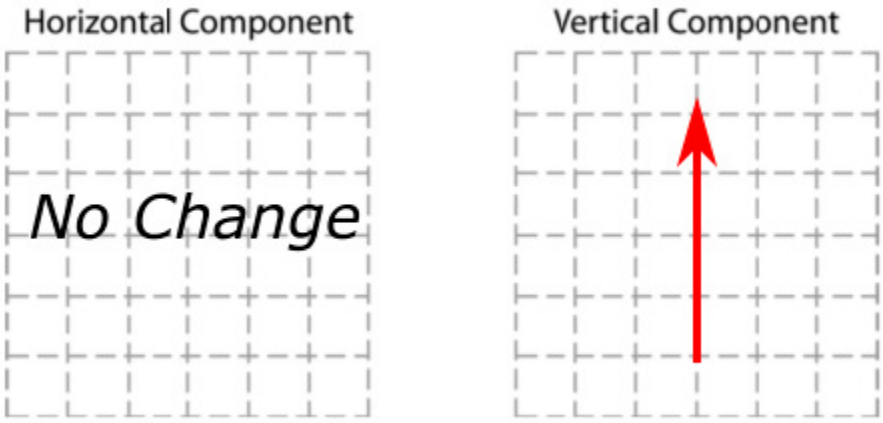
Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2 ✓

Student response accurately includes both of the following criteria.

- ☐ 1 point is earned for writing "NO CHANGE" for the horizontal component of the change in momentum for the ball.
- ☐ 1 point is earned for drawing an upward arrow for the vertical component of the change in momentum for the ball.

Example Response:



Part (b)

Select a point value to view scoring criteria, solutions, and/or examples and to score the response.

0	1	2	3	4	5 ✓

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Student response accurately includes all of the following criteria.

- 1 point is earned for indicating that the collision of the ball with the ground is an inelastic collision.
- 1 point is earned for indicating that the momentum of the ball immediately before the bounce is not the same as the momentum of the ball immediately after the collision.
- 1 point is earned for stating that the kinetic energy of the ball immediately before the bounce is not the same as the kinetic energy of the ball immediately after the collision.
- 1 point is earned for stating that some of the mechanical energy of the ball or the ball-Earth system is converted into nonmechanical energy, which is why the ball has less mechanical energy to reach height H_1
- 1 point is earned for a logical, relevant, and internally consistent argument that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response.

Example Response:

The gravitational potential energy of the ball-Earth system is converted into kinetic energy immediately before the ball reaches the ground. During the bounce, mechanical energy of the ball is converted into nonmechanical forms of energy, which decreases the kinetic energy of the ball after the bounce occurs. This means that the collision is inelastic, and the total momentum of the ball decreases since some of its momentum was transferred to the ground. With less kinetic energy, there is not enough mechanical energy to convert into gravitational potential energy of the ball-Earth system to reach H_1

Claims, Evidence, and Reasoning Statements:

Claim: Height $H_2 < H_1$

Evidence: After the ball reaches the ground, it bounces and travels to height H_2 above the ground, as shown in the figure, which is not as high off of the ground as height H_1

Reasoning Statement(s): The gravitational potential energy of the ball-Earth system is converted into kinetic energy immediately before the ball reaches the ground. During the bounce, mechanical energy of the ball is converted into nonmechanical forms of energy, which decreases the kinetic energy of the ball after the bounce occurs. This means that the collision is inelastic, and the total momentum of the ball decreases since some of its momentum was transferred to the ground. With less kinetic energy, there is not enough mechanical energy to convert into gravitational potential energy of the ball-Earth system to reach H_1