Helping students learn Newton's laws using the ISLE approach

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All materials are at
https://drive.google.com/drive/folders/1vEotuSjQ4N28FDoIZTCAa3gWeFyfH0rh

Chapter 3: Dynamics in on dimension or Newton’s laws

I estimated the time needed for everything that I planned, it is about 130 min, so we will not be able to do everything, whatever is left - please do on your own and post questions on the Facebook group, ok? Thank you.

Need to know

Newtonian Mechanics

Seat belts and air bags save about 250,000 lives worldwide every year because they significantly reduce the risk of injury (belts alone by about 40% and belts with air bags by about 54%). How do seat belts and air bags provide this protection?

- How do seat belts and air bags save lives?
- If you stand on a bathroom scale in a moving elevator, does its reading change?
- Can a parachutist survive a fall if the parachute does not open?

IN THE LAST CHAPTER, we learned to *describe* motion—for example, to determine a car's acceleration when it stops abruptly during a collision. However, we did not discuss the causes of the acceleration. In this chapter, we will learn *why* an object has a particular acceleration. This knowledge will help us *explain* the motion of many objects: cars, car passengers, elevators, skydivers, and even rockets.

BE SURE YOU KNOW HOW TO:

- Draw a motion diagram for a moving object (Section 2.2).
- Determine the direction of acceleration using a motion diagram (Section 2.7).
- Add vectors graphically and determine their components (Sections 2.3, 2.4, and 2.6).

Possible “the need to know”

https://www.youtube.com/watch?v=Bw0Ps8-KDlQ watch first 20 seconds or even less

What are the questions that the students can pose here?

1. Why did the dummy fall forward?
2. Why was the airbag needed?

Do not ask for answers at this point. Say: “By the end of the unit you will be able to answer both questions with confidence!”

2:13

Students should be able to:

1. Identify a system for analysis and objects interacting with the system.
2. "Read and write" with force diagrams, labeling forces with two subscripts.
3. Find force components along chosen axes (in one dimension).
4. Find consistency between a motion diagram and a force diagram for a system (recognize the relationship between $\Sigma\vec{F}$ and $\Delta\vec{v}$). Explain how we know that objects do not move in the direction of the sum of the forces exerted on them (by referring to the experiments).
5. Explain the role of inertial reference frames for using Newton's laws to analyze motion and thus the role of Newton's first law in the set of laws.
6. Describe the experiments from which they developed Newton's laws and use the laws to predict the outcomes of simple one –dimensional processes.
7. Write Newton's second law in component form for a system using a force diagram.
8. Compare and contrast Newton's second and third laws.
9. Explain the difference between an operational definition of acceleration $\left(\vec{a} = \frac{\Delta\vec{v}}{\Delta t}\right)$ and a cause-effect relationship $\left(\vec{a} = \frac{\Sigma\vec{F}}{m}\right)$
10. Apply Newton's laws to solve problems.
11. Explain why objects have the same free-fall acceleration on Earth.

Brief summary of student difficulties with one-dimensional dynamics

The most difficult is the meaning of the word “force” as a quantity that characterizes an interaction between two objects as opposed to the motion of an object.

The reason for this difficulty is the language we use in everyday life. The difficulty that stems from our teaching is thinking that *ma* is a force and using *ma* to calculate any force. Other common difficulties include thinking that objects move in the direction of forces, and that any two forces that are the same in magnitude and opposite in direction are Newton’s third law forces. When drawing force diagrams for an object of interest, students mistakenly put forces exerted by the object of interest on some other object.

The next set of activities is from ALG Chapter 3 and OALG Chapter 3

ALG Chapter 3.docx

https://docs.google.com/document/d/1ViQg9K_8FhP-qsN1X_Lf4QXJ4V8cq5P9/edit?usp=sharing&ouid=116596599972817327593&rtpof=true&sd=true

All together ALG 3.1.1 ALG Chapter 3.docx 10 min

3.1.1 Observe and represent

PIVOTAL Lab or class: Equipment per group: whiteboard and markers, 1 medicine ball (alternative: bowling ball), 1 basketball (alternative: volleyball, or a kid's inflatable rubber ball with similar size to a bowling/medicine ball).

Each member of the group while standing: hold a medicine ball in one hand and a basketball ball in the other hand (make sure you hold the medicine ball first and then follow up with the basketball). Focus on what you need to do to hold each ball still. The goal of this activity is to learn to draw a new representation called a "force diagram." Do this on a piece of paper or on a small whiteboard with your group. Share your ideas with each other.

a. Centered at the top of your page/whiteboard, draw a sketch of a person standing on the ground, holding the balls, one in each hand. To draw a force diagram, you first need to identify systems/objects of interest. In this case, each ball is a system or an object of interest. Draw a circle around each ball to signify this. Divide the rest of your page/whiteboard into a left column for one ball and a right column for the other.

b. The next question you need to ask yourselves is what other objects are interacting with each system/object of interest? So in this case, what other objects are interacting with each ball? If you are stuck, discuss the following: What do you think would happen to the ball if your hand were the only object interacting with it? List the objects interacting with each ball at the top of that ball's column.

c. Drawing the force diagram: Below your lists of interacting objects, leaving enough space, draw a dot that represents each ball as a point-like object. On each dot draw an arrow to show how your hand pushes on the ball. Let the tail of the arrow start at the dot. This arrow represents the force that your hand exerts on the ball. How could you label this force arrow to show that it is the force your hand exerts on the ball? Add this label to your representation for each ball.

d. Repeat this for the other interactions you identified. Represent these interactions on the force diagrams. Try to make the lengths of the force arrows in the two diagrams representative of the relative magnitudes of the forces. The arrows on the force diagram represent force vectors, physical quantities that have both magnitude and direction.

e. Discuss with your group: The word "force" is used in physics for a physical quantity that characterizes the interaction between two objects. A single object does not have a force because a force is defined as the interaction of two objects. Using the definition of a force in physics, give three examples from everyday life when the use of the term force does not match the meaning of this word in physics.

All together 1 OALG 3.1.2 10 min

OALG 3.1.2 Test your idea

[https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-3-1-2]

a. In the previous activity, did you think that air interacted with the ball?

b. If yes, do you think that the total force that the air exerts on the ball points up or down?

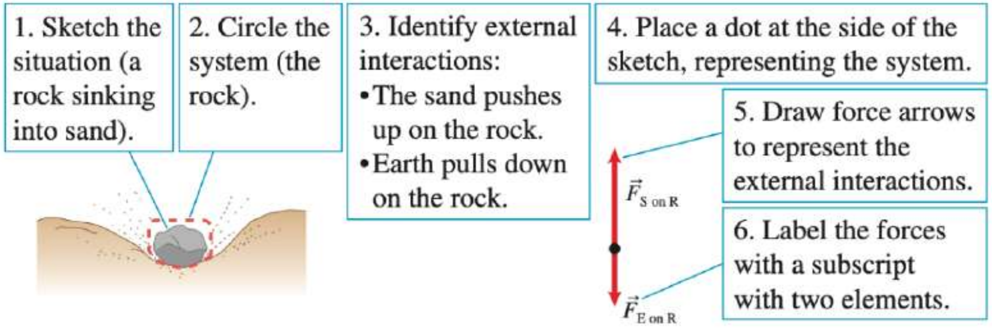
c. What experiment(s) can you perform to test your idea about whether the air pushes up or down on the ball? Describe the experiment(s) and state the predictions of what should happen based on each hypothesis – (1) the air pushes up on the ball and (2) the air pushes down on the ball.

d. Watch the video of the experiment using the link above. Which hypothesis about the air pushing on the ball does the experiment reject? If you are having trouble answering this question, read and interrogate subsection “Testing a hypothesis” on page 53 of the textbook.

Reflect on the HD reasoning process that we engaged

1. Accepted the hypothesis as true even if we did not like it.
2. Designed (or provided the design of) an experiment for which the hypothesis could predict the outcome.
3. Made a clear prediction of the outcome of the experiment before doing it using the hypothesis and explained HOW we did it.
4. Conducted (observed the experiment) and compared the outcome to the prediction.
5. REJECTED the hypothesis!

PHYSICS TOOL BOX 3.1 Constructing a force diagram



TIP Remember that on the force diagram, you only draw forces exerted *on* the system. Do not draw forces that the system exerts on other objects! For example, the rock exerts a force on the sand, but we do not include this force in the force diagram since the sand is not part of the system.

Notice that the upward-pointing arrow representing the force exerted by the sand on the rock is longer than the downward-pointing arrow representing the force exerted by Earth on the rock. The difference in lengths reflects the difference in magnitudes of the forces.

Team 1 OALG 3.2.1

OALG 3.2.1 Observe and find a pattern

The experiment in the video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-3-2-1 helps you investigate the relationship between the forces that the platform scale and the spring scale exert on the object when they are both supporting the object and the object is at rest. Watch the video and describe the pattern in words and mathematically using your knowledge of vectors. Use the table on the next slide.

Experiment	List the objects interacting with the cylinder of interest.	Draw a force diagram for the cylinder.	Discuss the relationship between the direction(s) and magnitudes(s) of the vectors on your force diagram.
(a) You hang a cylinder from a string attached to a spring scale; the scale reads 5 N.			
(b) You lower the cylinder onto a platform scale. The spring scale reads 3 N, the platform scale reads 2 N.			
(c) You remove the spring scale and leave the cylinder on the platform scale; it reads 5 N.			

Team 2 OALG 3.2.1

OALG 3.2.1 Observe and find a pattern

The experiment in the video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-3-2-1 helps you investigate the relationship between the forces that the platform scale and the spring scale exert on the object when they are both supporting the object and the object is at rest. Watch the video and describe the pattern in words and mathematically using your knowledge of vectors. Use the table on the next slide.

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(a) You hang a cylinder from a string attached to a spring scale; the scale reads 5 N.			
(b) You lower the cylinder onto a platform scale. The spring scale reads 3 N, the platform scale reads 2 N.			
(c) You remove the spring scale and leave the cylinder on the platform scale; it reads 5 N.			

Team 3 OALG 3.2.1

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Team 4 OALG 3.2.1

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(c) You remove the spring scale and leave the cylinder on the platform scale; it reads 5 N.			

What was the goal of the activity that we just did? Attention to?

- A scale doesn't read the same as Earth's downward pull–other forces must be taken into account.
- Two forces up can cancel (balance) one force down.

Team 1 OALG 3.3.1

Watch the video [Spring scale up and down: Qualitative Testing Experiment] and use it to fill in the table on the next 2 slides.

The system is the bob.

Observational experiment	Analysis	
	Motion diagram for the bob	**Force diagram for the bob**
Experiment 1. A bob is supported by a spring scale. The bob is at rest.		
Experiment 2. The bob accelerates up (being pulled by the scale).		
Experiment 3. The bob is moving up at constant speed.		

Observational experiment	Analysis	
	Motion diagram for the bob	**Force diagram for the bob**
Experiment 4. The bob moves up slowing down to a stop.		
Experiment 5. The bob accelerates down.		
Experiment 6. The bob slows to a stop when moving down.		

Team 2 OALG 3.3.1

Watch the video [Spring scale up and down: Qualitative Testing Experiment] and use it to fill in the table on the next 2 slides.

The system is the bob.

$\Delta \vec{v}$

Observational experiment	Analysis	
	Motion diagram for the bob	**Force diagram for the bob**
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Team 3 OALG 3.3.1

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Team 4 OALG 3.3.1

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	Motion diagram for the bob	Force diagram for the bob
Experiment 4. The bob moves up slowing down to a stop.		
Experiment 5. The bob accelerates down.		
Experiment 6. The bob slows to a stop when moving down.		

What patterns did you see in the motion and force diagrams?

All together

OALG 3.3.2 Observe and find a pattern

Find a heavy object that you can hold in one hand. Safely throw it up vertically using one hand, and catch using the same hand (it can be a medicine ball if you have one, a 1-L bottle of water or something of that kind). Read the descriptions of the experiments below and perform them, paying attention to how your hands feel holding, throwing, or catching the ball. Then construct a motion diagram and a force diagram for the ball's motion during each experiment. Based on our investigation in Activity 3.1.2, you can ignore any force or forces that the air might exert on the ball. Alternative - use your phone and PhyPhox app

a. Hold the object at rest in your hand. Focus on how heavy it feels.

b. Throw the object upward. Focus on the time interval when it is still in your hand going up.

c. Observe its motion *after* it leaves your hand until it reaches the top of its flight.

d. Observe its motion *after* it reaches the top of its flight.

e. Catch the object. Focus on how heavy it feels while you are stopping it with your hand.

f. Examine the results of all 5 experiments. Is there the same pattern in the directions of the sum of the forces that other objects exert on the ball and in the directions of the velocity change arrows on the motion diagram as in the previous activity? If so, describe the pattern.

g. Use the pattern that you found in Activity 3.3.1 and in this activity to formulate a statement relating the direction of the sum of the forces exerted on an object by other objects and on one or more of the kinematics quantities that describe its motion

Team 1 OALG 3.3.4

OALG 3.3.4 Test an idea

a. Watch the video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-3-3-4a

to note the reading of the scale when the person puts a bean bag on it.

b. Use the pattern formulated in activity 3.3.1 to make a prediction about the reading of the scale when you drop the bean bag on it. Will it be more, less or the same compared to the reading you recorded? Use motion and force diagrams to make the prediction.

c. Watch the video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-3-3-4b

and compare your prediction to the outcome of the experiment. What can you say about the pattern formulated in Activity 3.3.1? Does it hold for this experiment too?

Team 2 OALG 3.3.4

OALG 3.3.4 Test an idea

a. Watch the video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-3-3-4a

to note the reading of the scale when the person puts a bean bag on it.

b. Use the pattern formulated in activity 3.3.1 to make a prediction about the reading of the scale when you drop the bean bag on it. Will it be more, less or the same compared to the reading you recorded? Use motion and force diagrams to make the prediction.

c. Watch the video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-3-3-4b

and compare your prediction to the outcome of the experiment. What can you say about the pattern formulated in Activity 3.3.1? Does it hold for this experiment too?

Team 3 OALG 3.3.4

OALG 3.3.4 Test an idea

a. Watch the video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-3-3-4a

to note the reading of the scale when the person puts a bean bag on it.

b. Use the pattern formulated in activity 3.3.1 to make a prediction about the reading of the scale when you drop the bean bag on it. Will it be more, less or the same compared to the reading you recorded? Use motion and force diagrams to make the prediction.

c. Watch the video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-3-3-4b

and compare your prediction to the outcome of the experiment. What can you say about the pattern formulated in Activity 3.3.1? Does it hold for this experiment too?

Team 4 OALG 3.3.4

OALG 3.3.4 Test an idea

a. Watch the video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-3-3-4a

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b. Use the pattern formulated in activity 3.3.1 to make a prediction about the reading of the scale when you drop the bean bag on it. Will it be more, less or the same compared to the reading you recorded? Use motion and force diagrams to make the prediction.

c. Watch the video https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-3-3-4b

and compare your prediction to the outcome of the experiment. What can you say about the pattern formulated in Activity 3.3.1? Does it hold for this experiment too?

Time for telling

What should you have learned from the last two activities?

Where was the observer who drew all those diagrams?

All together, this activity needs to be always done with the teacher

	Motion diagram	**Force diagram**
a. For the ball, as observed by you on the train, i.e., draw the diagrams as seen in your reference frame.		
b. For the ball, as observed by your friend on the platform. i.e., draw the diagrams as seen in your friend's reference frame.		

3.4.1 Represent and reason

Imagine you're sitting on a stationary train and your friend is standing on the platform looking through the window. On the table in front of you is a tennis ball. The train starts to pull away from the station, speeding up as it does so. Draw motion and force diagrams for the ball as observed **a.** by you and **b.** by your friend as the train starts to accelerate. Remember the rule for force diagrams: A force describes an interaction between two objects. If you can't identify the object that is exerting a force on the object of interest, you can't put it in the force diagram!

Discuss with your group: Is there a reference frame in which the force and motion diagrams are inconsistent with the rule you've just developed relating force and motion diagrams? What do you think is the characteristic of this reference frame that makes the force and motion diagrams inconsistent with each other? Think of other examples of reference frames in everyday life where the motion and force diagrams for an object in that reference frame are inconsistent with the rule you've developed. Should you discard the rule you've developed? Or (more preferably) come up with a statement (called an "assumption") about when the rule will and won't work.

https://mediaplayer.pearsoncmg.com/assets/_frames.true/secs-egv2e-strange-forces

Watch the following videos and describe what you saw

Watch (video experiment 1, [ALG 3.5.1a]) and (video experiment 2, [ALG 3.5.1b])

Describe in simple words what you observed. What is the difference between cart 1 and cart 2?

What forces are making cart 1 accelerate? What forces are making cart 2 accelerate? Draw force diagrams for both carts.

This step is needed before the student go on to analyze data.

Analysis of video experiment 1	
Acceleration (m/s^2)	Sum of the forces (N)
0	0
0.38	0.2
0.74	0.3
1.67	0.5
2.8	0.75
4.3	1.2
Analysis of video experiment 2	
Acceleration (m/s^2)	Mass (kg)
0.27	0.56
0.20	0.76
0.15	0.96
0.13	1.16
0.10	1.36

Team 1 ALG 3.5.1 Use the next slide for answers

Watch (video experiment 1, [ALG 3.5.1a]) and (video experiment 2, [ALG 3.5.1b])

Use the data in the table on SLIDE 41 to devise a relationship that shows how each cart's acceleration depends on the cart's mass and on the sum of the forces exerted on the cart by the string or fan, Earth, and the track. Note: When doing such an analysis, devise a relationship for each independent variable one at a time and for the dependent variable (for example, use some of the data to see how the acceleration depends on the net force exerted and then use other parts of the data to see how the acceleration depends on the mass of the cart). Then combine these relationships to get a final relationship.

Team 2 ALG 3.5.1 Use the next slide for answers

Watch (video experiment 1, [ALG 3.5.1a]) and (video experiment 2, [ALG 3.5.1b])

Use the data in the table on SLIDE 41 to devise a relationship that shows how each cart's acceleration depends on the cart's mass and on the sum of the forces exerted on the cart by the string or fan, Earth, and the track. Note: When doing such an analysis, devise a relationship for each independent variable one at a time and for the dependent variable (for example, use some of the data to see how the acceleration depends on the net force exerted and then use other parts of the data to see how the acceleration depends on the mass of the cart). Then combine these relationships to get a final relationship.

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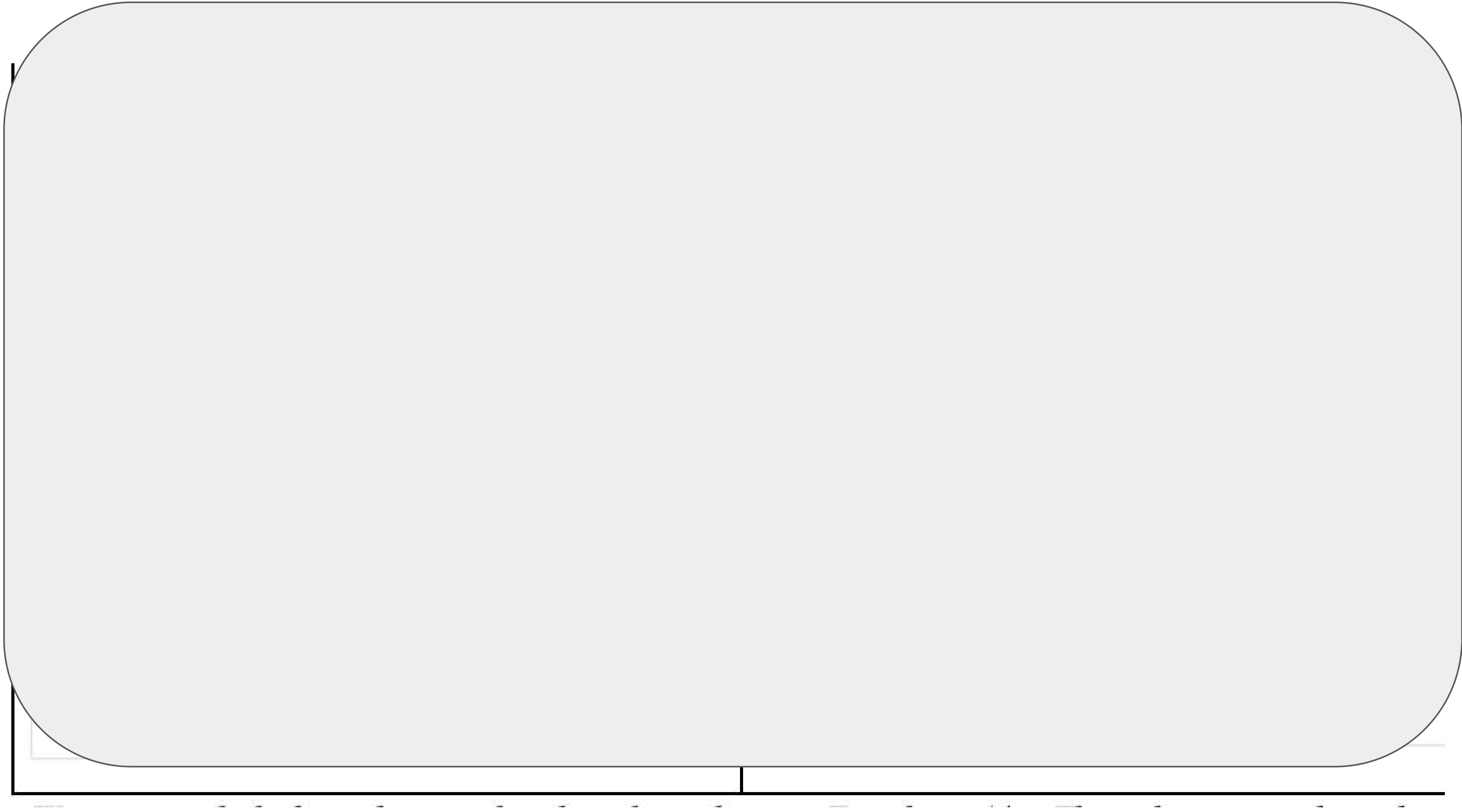
Team 4 ALG 3.5.1 Use the next slide for answers

Watch (video experiment 1, [ALG 3.5.1a]) and (video experiment 2, [ALG 3.5.1b])

Use the data in the table on SLIDE 41 to devise a relationship that shows how each cart's acceleration depends on the cart's mass and on the sum of the forces exerted on the cart by the string or fan, Earth, and the track. Note: When doing such an analysis, devise a relationship for each independent variable one at a time and for the dependent variable (for example, use some of the data to see how the acceleration depends on the net force exerted and then use other parts of the data to see how the acceleration depends on the mass of the cart). Then combine these relationships to get a final relationship.



All together ALG Chapter 3.docx

OALG 3.6.1 Reason

You learned in Chapter 2 that in the absence of air, all objects on Earth fall with the same acceleration of 9.8 m/s^2 independently of their mass. How is this possible if the acceleration of an object is inversely proportional to its mass? Construct a mathematical relationship for the magnitude of the force that Earth exerts on an object of mass m. Think of different possibilities.

OALG 3.6.2 Test your idea

You have a spring scale calibrated in newtons and a set of objects of known masses. Imagine that you hang objects of different masses on the spring scale and record its reading. Then you plot the graph of the data. The mass of the objects in kilograms is on the horizontal axis and the reading of the scale in newtons is on the vertical axis.

a. Draw a force diagram for each of the hanging objects when each is at rest. What can you say about the magnitude of the force that the scale exerts on the object and the magnitude of the force that Earth exerts on the object?

b. Use the mathematical relationship that you constructed in Activity 3.6.1 to predict the slope of the graph. Explain how you made your prediction.

c. Observe the video of the experiment https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-3-6-2 , collect the data, and plot the data using the same axes as in your prediction. Did your prediction match the outcome of the experiment? What does the match/mismatch tell you about the relation you devised in Activity 3.6.1?

All together

OALG 3.81 Observe and explain

Hold your forearm horizontally and your hand perpendicular to the arm

so that your palm faces away from you.

Try to bend your wrist so that your hand bends closer to your forearm.

Notice how far you can bend it.

Then, holding your forearm the same way, push a vertical wall with your hand (see the photo below) and observe how far it bends. Explain why you can bend your hand much more when it pushes against the wall.

OALG 3.8.2 Observe and find a pattern

Watch this video of several experiments of two people pulling on scales https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-3-8-2.

a. Stop the video at any moment and record the readings of the scales. Make a data table for the readings.

b. Describe the pattern you find in words and mathematically.

c. Devise and state a general hypothesis about the relationship between the force that object A exerts on object B to the force that object B exerts on object A.

Should be in teams but only if time permits :)

OALG 3.8.3 Test your idea

The videos show collisions of carts of different masses and speeds (do not watch them yet). The carts have force probes attached to them. Each probe records the force that the other car exerts on the force probe.

a. Use the hypothesis that you devised in part **c** of Activity 3.8.2 (not your intuition) to predict which force probe (if any) will have a higher reading during the collision in the following experiments:

1. A moving cart hits a stationary cart. Both cars have the same masses.
2. A moving heavy cart hits a light stationary cart. The heavy cart is twice as heavy as the light one.
3. Two carts move toward each other with about the same speeds. One cart is twice as heavy as the other.

b. Watch the videos https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-3-8-3
and explain the meaning of the graphs shown after each experiment. What does the blue curve mean? What does the yellow curve mean? How do the graphs allow you to compare the outcomes of the experiments to your predictions?

c. What is your judgment of the hypothesis being tested?

d. Formulate a rule relating the forces that two interacting objects exert on each other. If you are having trouble, read and interrogate Section 3.8 in the textbook up to Conceptual Exercise 3.6.

Back to the need to know

1. Why did the dummy fall forward?
2. Why was the airbag needed?

What did you learn today?