SECTION 9

Force and Energy: Different Insights

Section Overview

Students view the roller coasters in terms of both a force and energy. They draw concept maps to see how energy, forces, and accelerations are connected then investigate the concept that forms a bridge between energy and forces. Energy as a scalar quantity cannot adequately describe the thrills produced so students are introduced to vector addition to better appreciate how forces contribute to roller-coaster fun.

Students learn why changes in accelerations of the roller coaster come from a changing path. They determine whether the speed of a roller coaster at different points would vary and how changing the slope of an incline affects speed and acceleration when the distance from a reference point is the same. This section also explains the difference between scalar and vector quantities and shows students how vectors are added. Students reflect on the conservation of energy principle to see how energy at one point is the same as energy at another point of the ride if no significant energy is lost due to friction.

Background Information

Roller coasters can be analyzed using forces or energy considerations. As a scalar quantity, energy is a simpler way to calculate the speeds at all points on the roller coaster. To do this, you use the concept of conservation of mechanical energy and recognize that the sum of gravitational potential energy and kinetic energy will be identical for all points on the roller coaster (neglecting any losses). On straight-line slopes of the roller coaster, forces and accelerations can be used to calculate speeds. On curved parts of the track, however, this kind of calculation is quite difficult because the vector sum of the gravitational force and the normal force is constantly changing. Energy considerations do not tell us about how quickly the speeds change. To do this, the forces and accelerations approach is required. The accelerations are what provide the thrills of a roller coaster. In this case, you need to look at the forces at each point on the roller coaster. The concept map brings together all of the enduring understandings illustrated in this chapter concerning energy and forces. The creation of the concept map is a valuable way in which to review the concepts within the chapter. After each team creates its own concept map, it would be interesting to have the teams share their concept maps. There is no one “correct” concept map. The different links that students create will reveal different ways of connecting the concepts. The concept map may also uncover some misconceptions or confusions and can serve as a formative assessment to guide review before students begin their roller-coaster design projects. Research on the differences between novices and experts point out that experts rely on general principles and patterns to analyze new situations while novices look for superficial similarities.

This section attempts to guide students in recognizing that roller coasters can be analyzed by both energy and force considerations. However, when the roller-coaster ride has lots of turns and irregularities, an analysis of forces will be quite difficult. On the other hand, energy considerations cannot give any insights into how much time it takes for the roller coaster to get from one location to another. It would be worthwhile to have one set of students invent questions that are easier to answer with force considerations and another set of students invent questions that are easier to answer with energy considerations. They can then switch questions and try to answer with the two concepts (e.g., try answering the force questions using energy and then force concepts). The two maps are connected through the concept of work ($W = F_{\parallel}d$). Creating a roller coaster requires calculations of both speeds and accelerations.

Crucial Physics

- Vectors have magnitude (how much) and direction (which way). Scalars only have magnitude.
- Scientists may use a force or an energy approach to gaining insights into physical phenomena. Forces are vector quantities, hence the force approach requires and provides information about the magnitude and directions involved in interactions between objects. Energy is a scalar, hence the energy approach does not give or need detailed information about directions involved.

Learning Outcomes	Location in the Section	Evidence of Understanding
Describe instances in which two cars will attain the same speed but require different times to reach those speeds.	***Investigate*** Step 9	Students use energy principles to predict what happens when two carts are released from the same point but have slopes at different angles.
Recognize that force is described by vectors and energy is described by scalars.	***Investigate*** Steps 6 and 7 ***Physics Talk***	Students determine roller coasters at the same height have the same energy, regardless of the path, thus making energy a scalar quantity. Students analyze the forces at different point of a roller-coaster ride and recognize that the normal force depends on the path of a roller coaster.
Explain how force and energy considerations provide different insights into roller-coaster rides.	***Physics Talk***	Students explain how forces determine the acceleration of a roller coaster and energy determines the speed of a roller coaster at different points.
Discover whether energy or force considerations are more appropriate for analyzing aspects of roller-coaster rides.	***Investigate*** Steps 5 – 7 ***Physics Talk***	Students apply energy concepts to investigate the roller-coaster speed at various points, and force concepts to determine accelerations at those points.

Section 9 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Notes, sticky, pad, 3 in. x 3 in.		5 per class
Candy, piece (in wrapper paper)*	2 per group	
Pennies*		100 per class

*Additional items needed not supplied

Time Requirements

- Allow one class period or 45 minutes for this section's *Investigate*.

Teacher Preparation

- No special planning is required.

Safety

- Caution the students to hide the penny or candy in *Part B* in an area that is safely accessible, and that their directions to locate the hidden object should be to direct the other groups by a safe path.

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Notes, sticky, pad, 3 in. x 3 in.		5 per class
Candy, piece (in wrapper paper)*		2 per class
Pennies*		100 per class

*Additional items needed not supplied

Time Requirements

- Allow one class period or 45 minutes for the *Investigate* (all parts), the *Physics Talk,* as well as other parts of the section from the *Pacing Guide*.

Teacher Preparation

- Make one copy of the concept map in this *Teacher's Edition* for each group, as well as a transparency for an overhead projector or similar device.
- Make Blackline Masters and/or transparencies of the diagrams for *Investigate Steps 6*, *7* and *9* in the *Student Edition*.
- Pre-hide the pennies or candy with locations marked on index cards. Give one card to each group and have them write directions for finding the penny or candy. Upon completion, have the groups swap the cards, and try to locate the objects using the directions from the other groups.

Safety

- Hide the penny or candy in *Part B* in an area that is safely accessible, and where student directions to locate the hidden object can be directed by a safe path.

NOTES

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Organizing ideas in a concept map	***Investigate*** Steps 1-4	**Augmentation** • Students with memory recall and reading difficulties may have a difficult time writing down four concepts because they cannot remember or locate the concepts in their reading. Students are also nervous to write down ideas that are incorrect for fear of being embarrassed. Refer these students to specific pages in their text to scan for concepts or check for accuracy. • Decrease the requirement to two or three concepts per student. **Accommodation** • Provide energy, force, and acceleration concepts on small pieces of paper and ask students to sort the ideas in a way that makes sense to them. Instruct the students that, as long as they can explain the connection between two words, there is no incorrect way to sort them.
Reading comprehension	***Physics Talk***	**Augmentation** • Use a drawing or refer back to *Step 6* and *Step 7* in the *Investigate*. Ask students to explain the transfer of *GPE* and *KE* in the roller-coaster system using their text or their own understanding of the concepts. **Accommodation** • Provide a drawing/graphic organizer that shows the transfer of *GPE* and *KE* on the roller coaster. Model a think-aloud to explain the transfer of energy using the drawing as a reference. Then ask students to re-explain the energy transfer in their own words.
Adding vectors	***Active Physics Plus*** ***Physics to Go*** Question 1	**Augmentation** • Provide direct instruction and many opportunities to practice adding vectors before students are required to add vectors for the *Chapter Challenge*. • Model how to measure and draw angles using a protractor. • Many students have used the Pythagorean theorem to solve problems in math class, but they have a difficult time generalizing and applying this skill to a new situation. Model how to draw the vector diagram described in *Active Physics Plus, Question 1*. Then ask students to describe how to find the magnitude of the change in velocity using the Pythagorean theorem. **Accommodation** • Some students may need assistance drawing vector diagrams until they become more independent and proficient. Students with fine motor difficulties or students who struggle to notice details may struggle to draw vector diagrams.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Organization	***Investigate*** Step 1	Make sure students are familiar with how to organize information with a concept map.
Vocabulary comprehension	***Investigate*** Step 5	Check to make sure students understand the meaning of "redundant." Explain that in the context of solving a problem, you may be able to find an answer without thinking about forces, or without thinking about energy, in which case there is redundant information—more information than you need.
Vocabulary comprehension Understanding concepts	***Physics Talk*** Adding Scalars and Adding Vectors	Review the definitions of "vector," "scalar," and "displacement." Collaborate with the students' math teachers to determine what level of comprehension students have obtained for the Pythagorean theorem. To give students practice adding vectors, draw some orthogonal vectors on the board and ask volunteers to add them. Choose one volunteer to calculate the magnitude using the Pythagorean theorem and another to find the magnitude with a ruler. For an extra challenge, include a set of three vectors to add for which the vector sum is zero.
Understanding concepts	***Physics Talk*** Energy—A Scalar Quantity	Review the three bullet points. Choose a different ELL volunteer to explain each one. If students have difficulty understanding the third bullet point, review the equations for gravitational potential energy ($GPE = mgh$) and kinetic energy $\left(KE = \frac{1}{2}mv^2\right)$. The variables in these equations are m, v, and h, but the mass of the roller-coaster car does not change, so at any point h determines v.
Understanding concepts	***Physics Talk*** Force—A Vector Quantity	Review the term "resultant" with students. It may help students to think of the resultant as the result of adding two vectors.
Understanding concepts	***Physics Essential Questions*** Why should you care?	Ask students to explain why a pound and a ton are units of force.

Consider finishing this section with a cloze activity. Cloze activities are useful tools for summarizing material and for giving English-language learners an opportunity to practice using their science vocabulary words in context. Write the following paragraph on the board, or type and photocopy it, replacing the underlined words with a write-on line. Encourage volunteers to fill in the blanks, or have all students do the activity on paper.

4-9a Blackline Master

Force is a <u>vector</u> quantity, which describes both <u>magnitude</u> and <u>direction</u>. Energy is a <u>scalar</u> quantity. To add vectors, use <u>vector addition</u>.

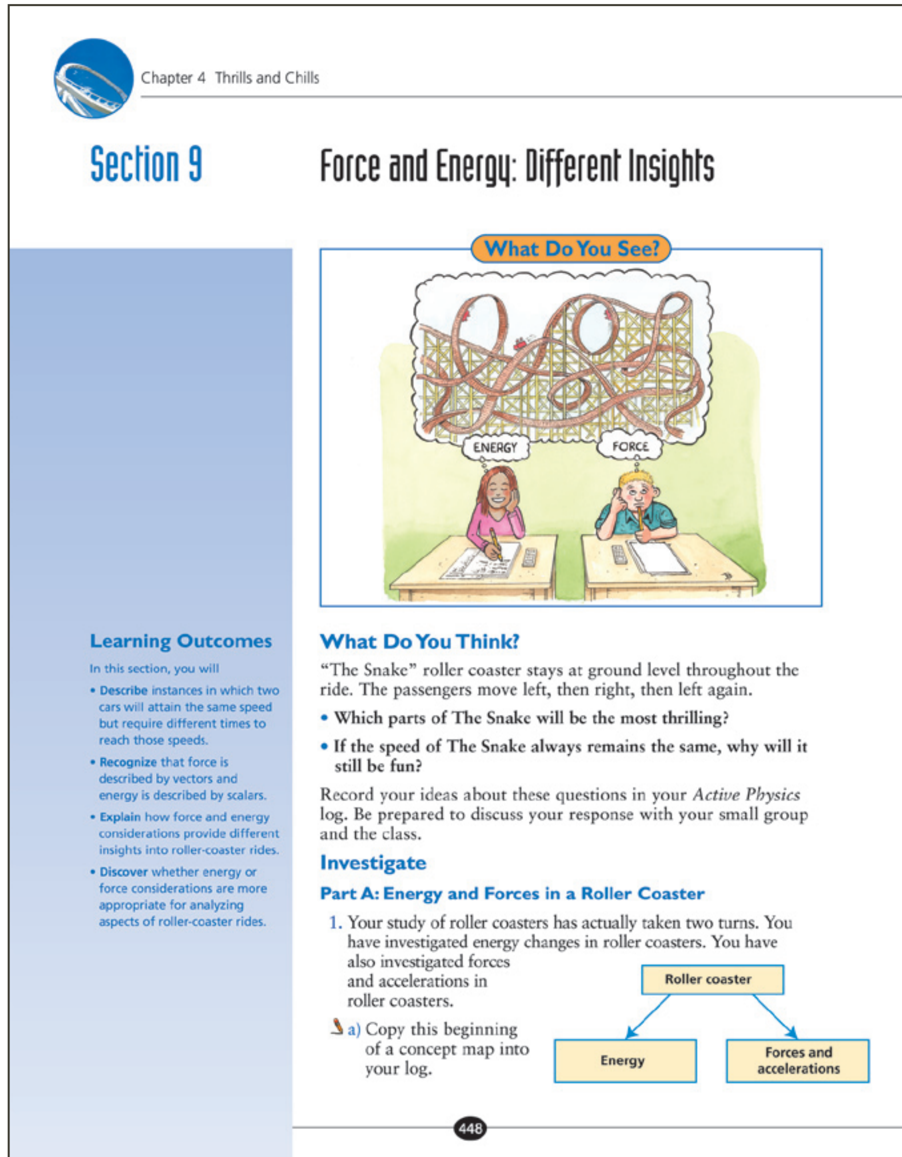
The <u>total mechanical energy</u> (gravitational potential energy + kinetic energy) of a roller-coaster car at any two points on a track is <u>constant</u>. If the kinetic energies of a roller-coaster car at two points on a track are equal, the <u>speed</u> of the car at those two points is also <u>equal</u>. Newton's second law, <u>$F = ma$</u>, is important when thinking of forces acting to accelerate passengers.

SECTION 9

Teaching Suggestions and Sample Answers

What Do You See?

This illustration immediately makes a connection with the title of this section. Students will most likely respond to this connection. Project the illustration on an overhead and ask students why the boy and the girl are thinking about different quantities—how do these affect a roller-coaster ride. Emphasize that the purpose of a *What Do You See?* section is to stimulate interest and draw an initial response that provides an impetus for scientific inquiry. Ask students to focus on different aspects of the illustration and how the images contribute to the artist's intent. Discuss the various possibilities that the students present and note a few responses on the board for future reference, so that students are able to see later how their knowledge of physics concepts has progressed.



Chapter 4 Thrills and Chills

Section 9 Force and Energy: Different Insights

What Do You See?

Learning Outcomes

In this section, you will

- **Describe** instances in which two cars will attain the same speed but require different times to reach those speeds.
- **Recognize** that force is described by vectors and energy is described by scalars.
- **Explain** how force and energy considerations provide different insights into roller-coaster rides.
- **Discover** whether energy or force considerations are more appropriate for analyzing aspects of roller-coaster rides.

What Do You Think?

"The Snake" roller coaster stays at ground level throughout the ride. The passengers move left, then right, then left again.

- **Which parts of The Snake will be the most thrilling?**
- **If the speed of The Snake always remains the same, why will it still be fun?**

Record your ideas about these questions in your *Active Physics* log. Be prepared to discuss your response with your small group and the class.

Investigate

Part A: Energy and Forces in a Roller Coaster

1. Your study of roller coasters has actually taken two turns. You have investigated energy changes in roller coasters. You have also investigated forces and accelerations in roller coasters.

a) Copy this beginning of a concept map into your log.

448

The investigation of roller coasters with two procedures, one that depends upon the analysis of forces and accelerations and the other which relies upon the determination of energies and their transformations, empowers students to develop competence in specific areas of inquiry. Students organize the factual knowledge learned through the investigations presented in this chapter in the design process and retrieve them for application in the *Chapter Challenge.* The expressions of this broad foundation among students encourages them to find coherence between force and energy models. Different insights into the same challenge scaffolds student learning; perceptive, reasonable explanations emerge for how to design a coaster to deliver thrills while being safe when students employ either analytical model. No specific student prior conceptions appear in this section because it encompasses all of the content learned throughout the chapter. Teachers may wish to refer to misconceptions highlighted on forces and motion in previous chapters.

What Do You Think?

These questions lead students to think about the nuances of physics concepts they will be covering in this section. Students might suggest that the loops and angular turns will be the most thrilling. If they do, you could ask them to give reasons for their answer. The second question will most likely reveal students' prior misconceptions, since they tend to equate higher speeds with greater thrills for the ride. At this stage, assure them that their answers are valuable and they should not be concerned with the accuracy of those answers. To draw students closer to the concepts they will be investigating, prompt them to recall those physics terms that they think could be related to the answers. Encourage them to record these terms in their *Active Physics* logs, along with their responses to the questions. Remind students that they will get a chance to update their answers once have carried out their experiments in the *Investigate* and understood the *Physics Talk*.

Investigate

Part A: Energy and Forces in a Roller Coaster

1.a)–4.

Concept lists and concept maps will differ among the students. Two concept maps are shown on the following pages with the connection.

4-9b **Blackline Master**

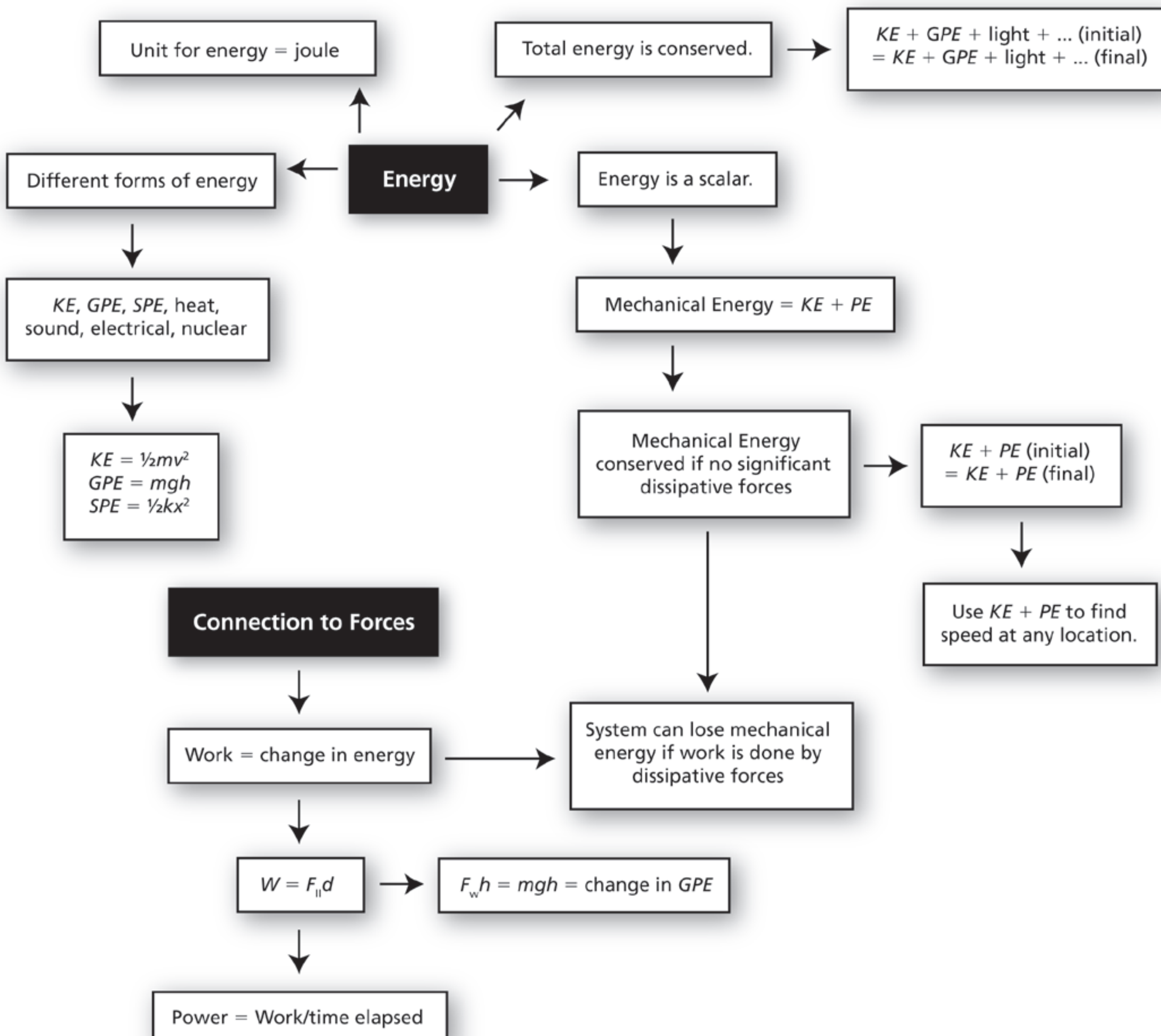
What Do You Think?

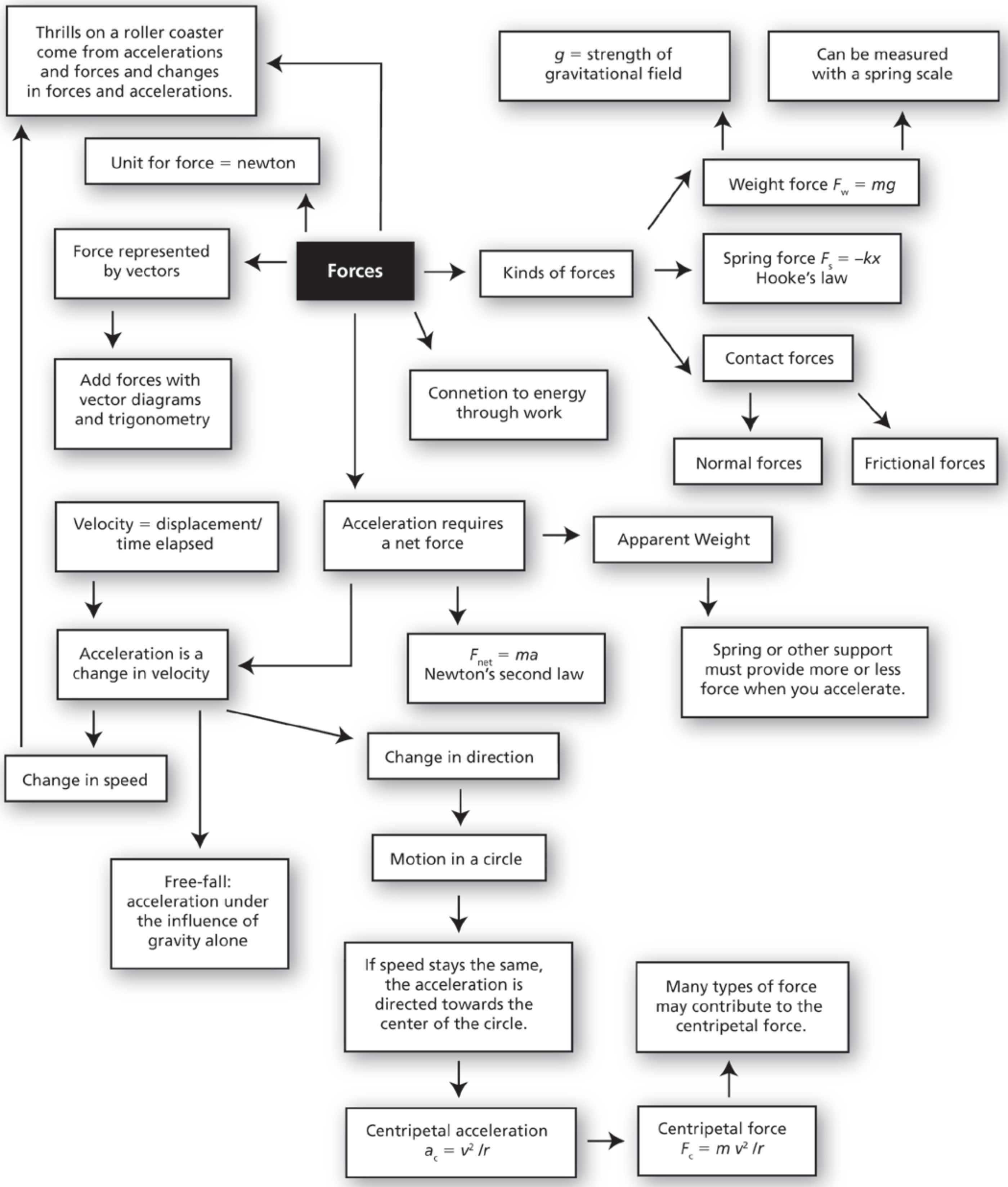
A Physicist's Response

The parts that will be the most thrilling will be where the accelerations are the greatest. This will be around the tight turns or the quick left-right-left turns. Speed does not provide the thrills of the roller coaster—it is the rapid changes in speed or large accelerations that provide the thrills. Even if the speed remains the same throughout the ride, the rapid changes in direction of the snake will still require large accelerations as the direction component of the velocity is changing. It is the accelerations and associated required forces that supply the thrills.

CHAPTER 4

NOTES


Unit for energy = joule
Total energy is conserved.
KE + GPE + light + ... (initial) = KE + GPE + light + ... (final)
Different forms of energy
Energy
Energy is a scalar.
KE, GPE, SPE, heat, sound, electrical, nuclear
Mechanical Energy = KE + PE
KE = ½mv²
GPE = mgh
SPE = ½kx²
Mechanical Energy conserved if no significant dissipative forces
KE + PE (initial) = KE + PE (final)
Use KE + PE to find speed at any location.
Connection to Forces
Work = change in energy
System can lose mechanical energy if work is done by dissipative forces
W = F∥d
Fwh = mgh = change in GPE
Power = Work/time elapsed



Thrills on a roller coaster come from accelerations and forces and changes in forces and accelerations.
g = strength of gravitational field
Can be measured with a spring scale
Unit for force = newton
Weight force $F_w = mg$
Force represented by vectors
Forces
Kinds of forces
Spring force $F_s = -kx$ Hooke's law
Add forces with vector diagrams and trigonometry
Connetion to energy through work
Contact forces
Normal forces
Frictional forces
Velocity = displacement/ time elapsed
Acceleration requires a net force
Apparent Weight
Acceleration is a change in velocity
$F_{net} = ma$ Newton's second law
Spring or other support must provide more or less force when you accelerate.
Change in direction
Change in speed
Motion in a circle
Free-fall: acceleration under the influence of gravity alone
If speed stays the same, the acceleration is directed towards the center of the circle.
Many types of force may contribute to the centripetal force.
Centripetal acceleration $a_c = v^2/r$
Centripetal force $F_c = m v^2/r$

NOTES

A concept map is a way to organize your thoughts. It serves as a good review of what you have learned. Creating a concept map often helps you increase your understanding. On a set of note-sized pieces of paper (or sticky-note paper), write down at least four things you know about energy and how it relates to roller coasters. Each note should have one concept only. (Review *Sections* 2 and 3 for assistance.)

2. Sort the concepts into a map that connects the concepts in a logical fashion. Add these concepts to your log.

3. On a new set of note-sized pieces of paper (or sticky-note paper), write down at least four things you know about forces and accelerations and how they relate to roller coasters. Each note should have one concept only. (Review *Sections 1, 4, 5* and *6* for assistance.)

4. Sort the concepts into a map. Add these concepts to your log.

5. The left half of your map reminds you of the relationships between energy concepts. The right half of your map reminds you of the relationships among force and acceleration concepts.

a) Is there a bridge between these two sides of the map? Describe how energy is related to forces and accelerations. (Review *Section 7* for assistance.)

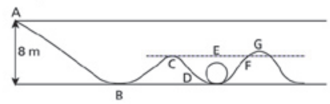
You use both energy and force approaches to understand roller coasters because they both provide you with valuable information. Sometimes it is easier to look at a roller coaster as an energy ride, while other times it is best to look at a roller coaster as a force ride. As you become more comfortable with physics, you will become better at matching what you want to know with the energy or the force approach. Sometimes you need both and sometimes they are redundant.

6. In the roller coaster below, the initial height of the roller coaster is given.

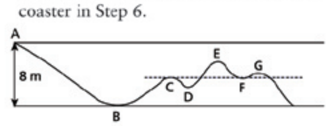
a) At which two points does the roller coaster have the same speed if friction is negligible?

b) How did you determine your answer? Write down your approach in your log.

c) At which point would the roller-coaster car experience the largest contact (normal) force from the track? Write down in your log how you arrived at an answer.



7. Describe how the new roller coaster shown below is different from the roller coaster in Step 6.



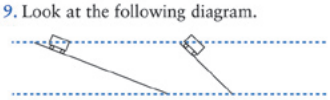
a) In this roller coaster, at which two points does the roller coaster have the same speed if friction is insignificant?

b) How did you determine your answer? Write down your approach in your log.

8. In either roller coaster, part of the track could have been replaced with horizontal track indicated by the dotted line.

a) Why would the flat track be less fun than the roller-coaster track?

9. Look at the following diagram.



a) Using energy principles, predict which cart would have the greater speed when it reaches the bottom.

4-9c Blackline Master

5.a)

The concept of work provides a link between energy concepts and force concepts.

6.a)

The roller coaster has the same speed at points that have the same height. In this diagram, the roller coaster has the same speed at points C and F.

6.b)

The roller coaster has the same speed at points C and F because the gravitational potential energy is the same at these two points due to having the same height. Because the total energy must be conserved, if the *GPE* is the same, the *KE* must also be the same at these points.

6.c)

The roller-coaster car experiences the largest contact force (normal force) from the tracks at the bottom of the circular loop where it is traveling in a circular path at high speed.

7.

The roller coaster does not have a vertical loop.

7.a)

The roller coaster has the same speed at points C and F.

7.b)

The points C and F are at the same height and therefore have the same gravitational potential energy and the same kinetic energy.

8.a)

The roller coaster would travel with a constant speed along the dotted line. Traveling at a constant speed is not nearly as much fun as traveling with changes in speed.

9.a)

Both coaster cars will have the same speed. Both carts have the same loss in gravitational potential energy and the same gain in kinetic energy. With the same kinetic energy and the same mass, they will have identical speeds $\left(KE = \frac{1}{2}mv^2\right)$.

9.b)

The cart moving along the steeper incline will get to the bottom in less time. If you take a look at the limiting case, an almost horizontal track, it will take a long time for the cart to descend.

Part B: Using Vectors to Describe a Path

1.a–b)

Students' hiding places and directions will vary. All directions should include the distances in meters or steps and the directions.

2.a–c)

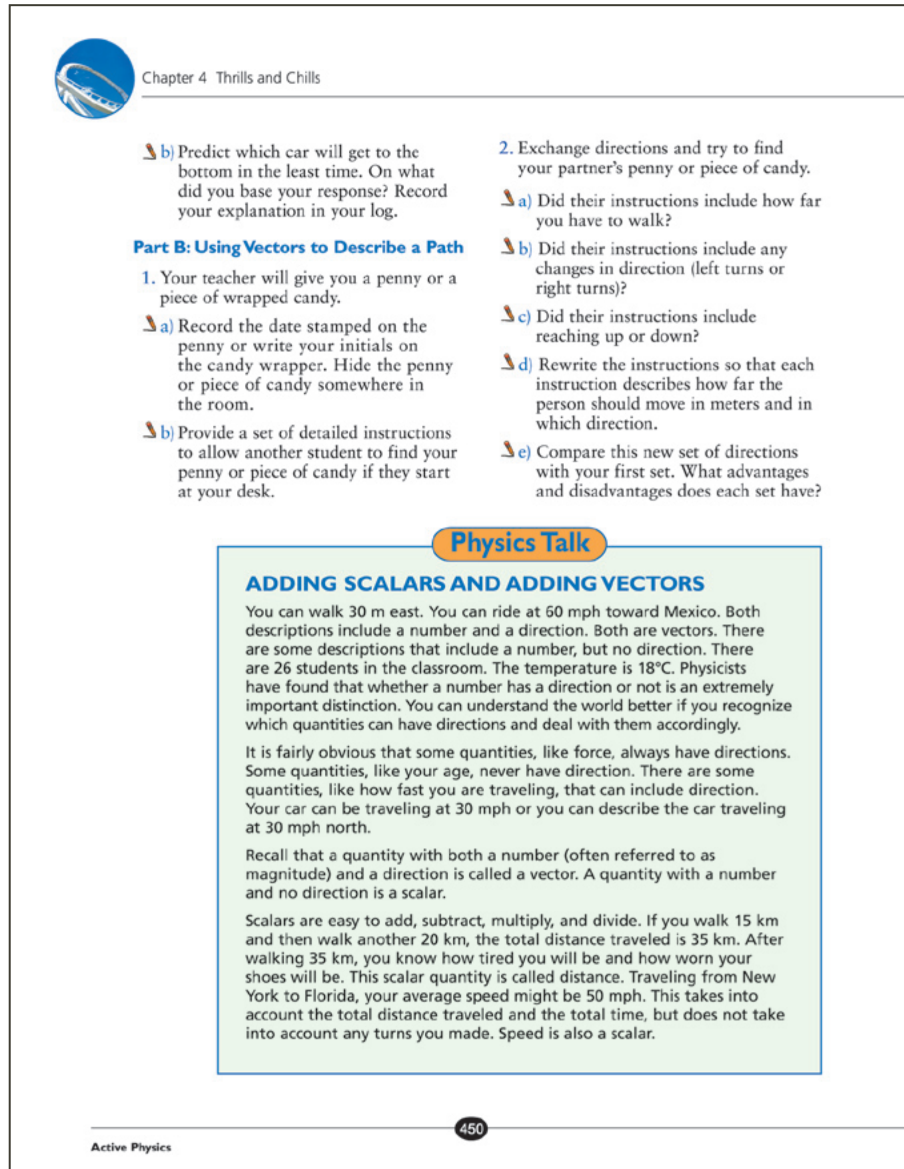
Students critique the directions provided to their group.

2.d)

Students rewrite the directions after the critique.

2.e)

The new set of instructions should be clearer than the original set.


Chapter 4 Thrills and Chills

b) Predict which car will get to the bottom in the least time. On what did you base your response? Record your explanation in your log.

Part B: Using Vectors to Describe a Path

1. Your teacher will give you a penny or a piece of wrapped candy.

a) Record the date stamped on the penny or write your initials on the candy wrapper. Hide the penny or piece of candy somewhere in the room.

b) Provide a set of detailed instructions to allow another student to find your penny or piece of candy if they start at your desk.

2. Exchange directions and try to find your partner's penny or piece of candy.

a) Did their instructions include how far you have to walk?

b) Did their instructions include any changes in direction (left turns or right turns)?

c) Did their instructions include reaching up or down?

d) Rewrite the instructions so that each instruction describes how far the person should move in meters and in which direction.

e) Compare this new set of directions with your first set. What advantages and disadvantages does each set have?

Physics Talk

ADDING SCALARS AND ADDING VECTORS

You can walk 30 m east. You can ride at 60 mph toward Mexico. Both descriptions include a number and a direction. Both are vectors. There are some descriptions that include a number, but no direction. There are 26 students in the classroom. The temperature is 18°C. Physicists have found that whether a number has a direction or not is an extremely important distinction. You can understand the world better if you recognize which quantities can have directions and deal with them accordingly.

It is fairly obvious that some quantities, like force, always have directions. Some quantities, like your age, never have direction. There are some quantities, like how fast you are traveling, that can include direction. Your car can be traveling at 30 mph or you can describe the car traveling at 30 mph north.

Recall that a quantity with both a number (often referred to as magnitude) and a direction is called a vector. A quantity with a number and no direction is a scalar.

Scalars are easy to add, subtract, multiply, and divide. If you walk 15 km and then walk another 20 km, the total distance traveled is 35 km. After walking 35 km, you know how tired you will be and how worn your shoes will be. This scalar quantity is called distance. Traveling from New York to Florida, your average speed might be 50 mph. This takes into account the total distance traveled and the total time, but does not take into account any turns you made. Speed is also a scalar.

450

Active Physics

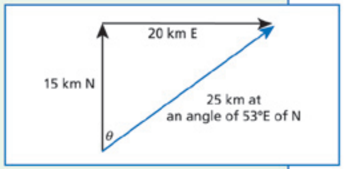
Physics Talk

Students recall and apply the concepts of scalars and vectors to different quantities that affect a roller coaster's ride. They learn why energy is a scalar quantity and force is a vector. The *Physics Talk* explains the difference between scalar and vector quantities and why it is easier to perform mathematical calculations with scalars. It is important for students to realize the distinction between scalar and vector quantities. To check whether they can distinguish between the scalar and vectors, write a few quantities like speed, temperature, distance, and displacement on the board. And ask students to determine which quantity is a scalar or a vector. Then ask students to write a brief description of scalar and vector quantities giving examples.

Because both force and energy determine important features of a roller-coaster ride, it is important for students to know why energy at different points of the ride is easier to work out before the forces and accelerations along a path are determined. Ask students to note that energy considerations are independent of path and are useful in determining the speed of the roller coaster, but force (which is a vector) will impact the thrills during the ride.

For students to design their roller coaster they must know the *GPE* of the coaster at the beginning of the ride. Knowing the *GPE* will enable them to calculate the final speed the roller coaster, CHAPTER 4

Displacement is described by a vector. You may walk 15 km north and then walk another 20 km east; both displacements have a magnitude (the distance traveled) and a direction. Your total displacement is only 25 km. To add vectors, you must draw them and use vector addition. In this case, when the two vectors are perpendicular to each other, vector addition is an application of the Pythagorean theorem. You can also draw the diagram to scale and measure the distance and the angle. The distance can be measured using a ruler and the scale of the diagram. Using a protractor, you find the angle is close to 53° east of north (east of the north direction).



Energy – A Scalar Quantity

Energy is a scalar and addition of scalars is simple. As you explored in earlier activities, the roller-coaster ride may have *GPE* (gravitational potential energy) and *KE* (kinetic energy). It may have used electrical energy to lift the roller coaster to the top of the first hill. All energies can be calculated, and they are all measured in the same units, joules. To find the total energy at any place or at any time, you just add up all the energies. This is what makes the roller-coaster analysis using energies so powerful. After the roller coaster begins moving downhill, the sum of *GPE* and *KE* remains the same. The roller coaster begins with *GPE* and as the coaster car moves, the *GPE* converts to *KE* as the roller coaster picks up speed and then converts the energy back to *GPE* as the cart goes higher and loses speed. Whatever the energy of the roller coaster is at the beginning of the ride, that is the energy at all times as long as friction is not significant. If two points on the roller-coaster ride have the same height, then they must have the same *GPE*. If they have the same *GPE*, then they also have identical *KE*. It doesn't matter what the cart did between the two points. It may have gone up, down, or in a loop-the-loop, but the *KE* will be the same at all points a specified distance above the ground.

In this *Investigate*, you looked at a roller coaster in *Step 6*. The speeds of the coaster carts are the same at points C and F. Both points C and F have the same height and therefore have the same *GPE*. Since all points on the roller coaster have the same total mechanical energy (*GPE* + *KE*) then both points must have the same *KE*. The same *KE* implies the same speed ($KE = \frac{1}{2}mv^2$).

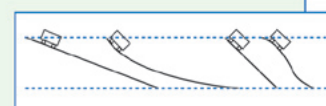
In the roller coaster in *Step 7* of this section, the speeds of the coaster cars were still the same at points C and F even though the track changed between C and F.

In roller-coaster physics, energy considerations tell you three things:

as energy is mostly conserved throughout the ride (if friction is not significant). You should emphasize to the students that it doesn't matter how many loops the roller coaster goes through, the *KE* at all points along a certain height from the ground will be the same (again, neglecting losses). Students can refer to *Steps* 6 and 7 of the *Investigate* to understand that roller coasters have the same kinetic energy at the same height, even though the tracks might have changed. Discuss the diagram at the end of the *Physics Talk* and point out why the *GPE* and *KE* are the same on two inclines at the same points but the acceleration varies due to the changing direction of the normal force.

- The total mechanical energy (*GPE* + *KE*) is the same at every point (as long as friction is not significant or motors do not add energy).
- The *GPE* depends only on the height from a reference position (*GPE* = *mgh*) since the mass and the gravitational force remain the same.
- If two points on a roller coaster have the same height, the roller coaster is moving at the same speed at those two points.

Energy considerations are path independent. You can look at the energy at one point and compare it to the energy at a later point. The energy will remain the same. It does not matter what happens between the places that are of interest.



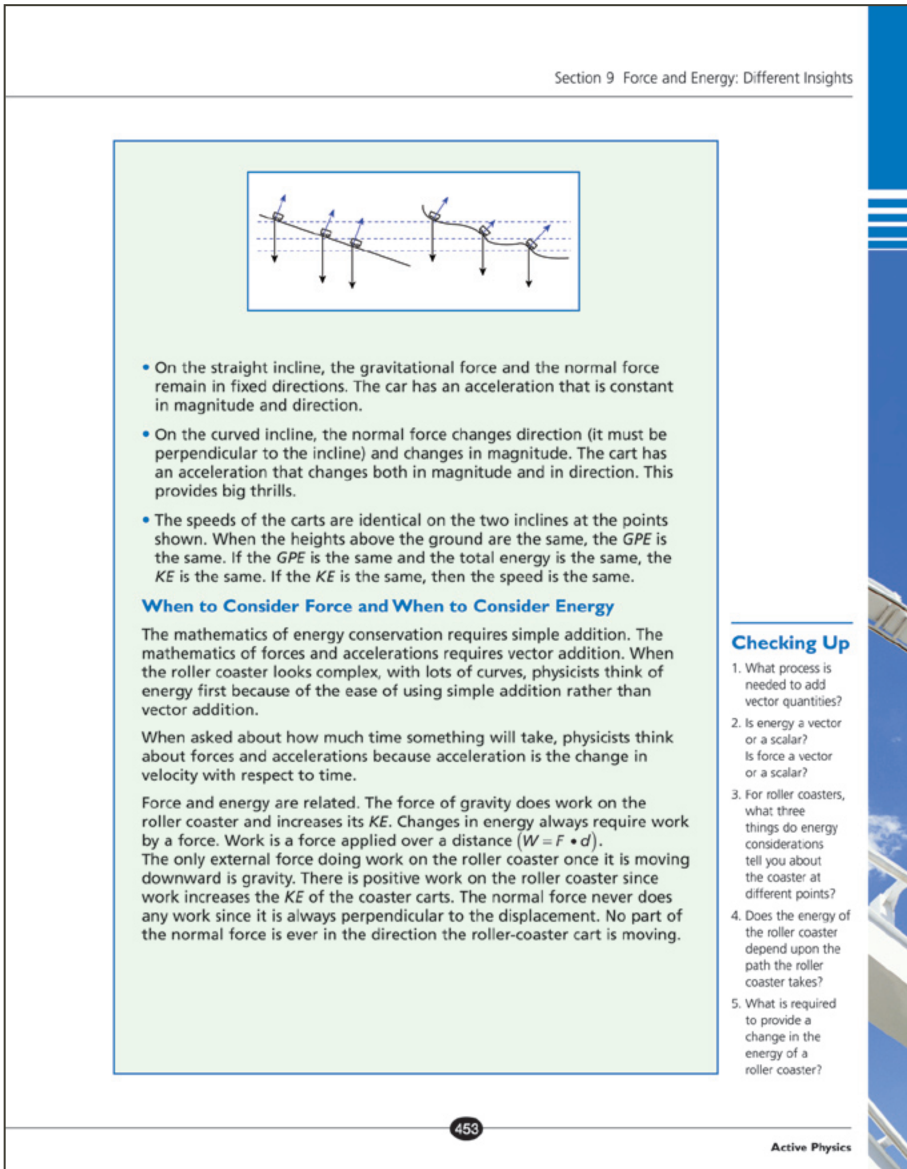
In the four roller-coaster sections shown in the diagram, the coaster cars begin at the top with zero *KE* and 20,000 J of *GPE*. When they reach the bottom, all will have the same *KE* (kinetic energy). This means that they will all have the same speed. To find this *KE* or speed, you only have to look at the beginning point and the final point. The path does not affect the final speed since you are not considering friction as a factor.

Force – A Vector Quantity

Although the roller-coaster cars all get to the bottom with the same speed, they do not get there in the same time. To find the time, you would have to look at the forces and this becomes a vector problem. In all tracks, the force of gravity is always down. The normal contact force between the track and the carts is always perpendicular to the track.

The straight tracks are the easiest to analyze. The force of gravity and the normal force remain in fixed directions. You move down the incline and go faster and faster. The steeper the slope, the larger the gravitational force down the incline and the quicker you get to the bottom. It is a big acceleration for a short time and you reach the maximum speed. On a small incline, there is a small resultant force down the incline. It is a small acceleration for a long time, but you reach the same maximum speed.

The inclines with shifting directions add to the thrill. Your speed changes as you move to different heights. As you move closer to the ground, your speed increases. The normal force (the force of the track on the carts) and the contact force of the cart on you are always changing direction. This causes you to accelerate in lots of different directions. The changes in the acceleration (both in size and in direction) give you that bouncy feeling and the thrill of the roller coaster. The diagram on the next page shows the gravitational force and normal forces at different points on a roller coaster.



- On the straight incline, the gravitational force and the normal force remain in fixed directions. The car has an acceleration that is constant in magnitude and direction.
- On the curved incline, the normal force changes direction (it must be perpendicular to the incline) and changes in magnitude. The cart has an acceleration that changes both in magnitude and in direction. This provides big thrills.
- The speeds of the carts are identical on the two inclines at the points shown. When the heights above the ground are the same, the *GPE* is the same. If the *GPE* is the same and the total energy is the same, the *KE* is the same. If the *KE* is the same, then the speed is the same.

When to Consider Force and When to Consider Energy

The mathematics of energy conservation requires simple addition. The mathematics of forces and accelerations requires vector addition. When the roller coaster looks complex, with lots of curves, physicists think of energy first because of the ease of using simple addition rather than vector addition.

When asked about how much time something will take, physicists think about forces and accelerations because acceleration is the change in velocity with respect to time.

Force and energy are related. The force of gravity does work on the roller coaster and increases its *KE*. Changes in energy always require work by a force. Work is a force applied over a distance ($W = F \bullet d$). The only external force doing work on the roller coaster once it is moving downward is gravity. There is positive work on the roller coaster since work increases the *KE* of the coaster carts. The normal force never does any work since it is always perpendicular to the displacement. No part of the normal force is ever in the direction the roller-coaster cart is moving.

Checking Up

1. What process is needed to add vector quantities?
2. Is energy a vector or a scalar? Is force a vector or a scalar?
3. For roller coasters, what three things do energy considerations tell you about the coaster at different points?
4. Does the energy of the roller coaster depend upon the path the roller coaster takes?
5. What is required to provide a change in the energy of a roller coaster?

Checking Up

1.

To add vector quantities, they must drawn first and then added using vector addition.

2.

Energy is a scalar quantity and force is a vector.

The total mechanical energy ($GPE + KE$) is the same at all points as long as friction is not significant. The *GPE* depends only on the height from a position of reference, since mass and the gravitational force remain the same. If two points on a roller coaster have the same height, the roller caster is moving at the same speed at those two points. Thus, the three things that energy considerations will tell you are the speed, height, and the energy at any point.

4.

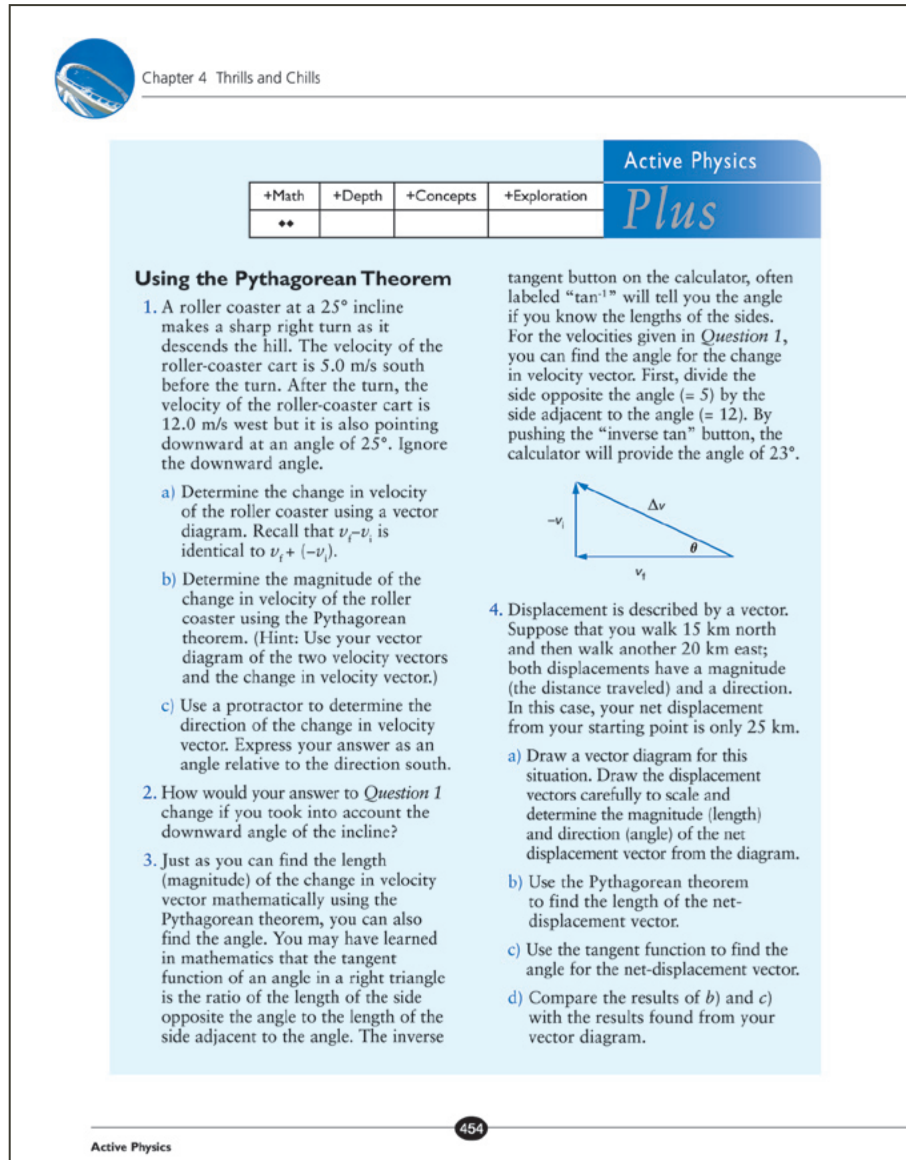
No, the energy of the roller coaster is independent of the path taken.

5.

Work is required to cause a change in the energy of the roller coaster.

Active Physics Plus

The questions that students solve in this section show how changes in direction affect the acceleration of a roller coaster. Students use both graphical and mathematical methods (the Pythagorean theorem) to solve problems of vector addition. They also use a protractor to see how the angular result of vector addition compares to that computed by the Pythagorean theorem and angular calculations using trigonometry.


Chapter 4 Thrills and Chills

Active Physics **Plus**

+Math	+Depth	+Concepts	+Exploration
◆◆			

Using the Pythagorean Theorem

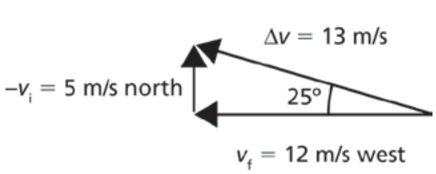
1. A roller coaster at a 25° incline makes a sharp right turn as it descends the hill. The velocity of the roller-coaster cart is 5.0 m/s south before the turn. After the turn, the velocity of the roller-coaster cart is 12.0 m/s west but it is also pointing downward at an angle of 25°. Ignore the downward angle.
   a) Determine the change in velocity of the roller coaster using a vector diagram. Recall that $v_f - v_i$ is identical to $v_f + (-v_i)$.
   b) Determine the magnitude of the change in velocity of the roller coaster using the Pythagorean theorem. (Hint: Use your vector diagram of the two velocity vectors and the change in velocity vector.)
   c) Use a protractor to determine the direction of the change in velocity vector. Express your answer as an angle relative to the direction south.
2. How would your answer to *Question 1* change if you took into account the downward angle of the incline?
3. Just as you can find the length (magnitude) of the change in velocity vector mathematically using the Pythagorean theorem, you can also find the angle. You may have learned in mathematics that the tangent function of an angle in a right triangle is the ratio of the length of the side opposite the angle to the length of the side adjacent to the angle. The inverse tangent button on the calculator, often labeled "$\tan^{-1}$" will tell you the angle if you know the lengths of the sides. For the velocities given in *Question 1*, you can find the angle for the change in velocity vector. First, divide the side opposite the angle (= 5) by the side adjacent to the angle (= 12). By pushing the "inverse tan" button, the calculator will provide the angle of 23°.

4. Displacement is described by a vector. Suppose that you walk 15 km north and then walk another 20 km east; both displacements have a magnitude (the distance traveled) and a direction. In this case, your net displacement from your starting point is only 25 km.
   a) Draw a vector diagram for this situation. Draw the displacement vectors carefully to scale and determine the magnitude (length) and direction (angle) of the net displacement vector from the diagram.
   b) Use the Pythagorean theorem to find the length of the net-displacement vector.
   c) Use the tangent function to find the angle for the net-displacement vector.
   d) Compare the results of *b)* and *c)* with the results found from your vector diagram.

Active Physics 454

1.a)

See diagram below.



1.b)

Given:

$v_i = -5$ m/s; $v_f = -12$ m/s;

$$\Delta v = \sqrt{(-v_i)^2 + (v_f)^2}$$
$$\Delta v = \sqrt{(5 \text{ m/s})^2 + (-12 \text{ m/s})^2}$$
$$\Delta v = 13 \text{ m/s}$$

1.c)

Using trigonometry or a protractor, the angle is 113° northwest of south.

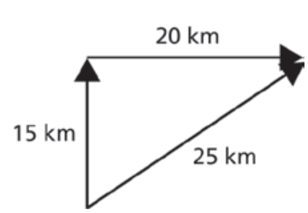
2.

Adding the downward angle of 25° would add a third vector in the third dimension to the solution, requiring a three-part Pythagorean theorem solution.

3.

Students use the calculator.

4.a)



4.b)

Given:

$d_i = 15$ km; $d_f = 20$ km

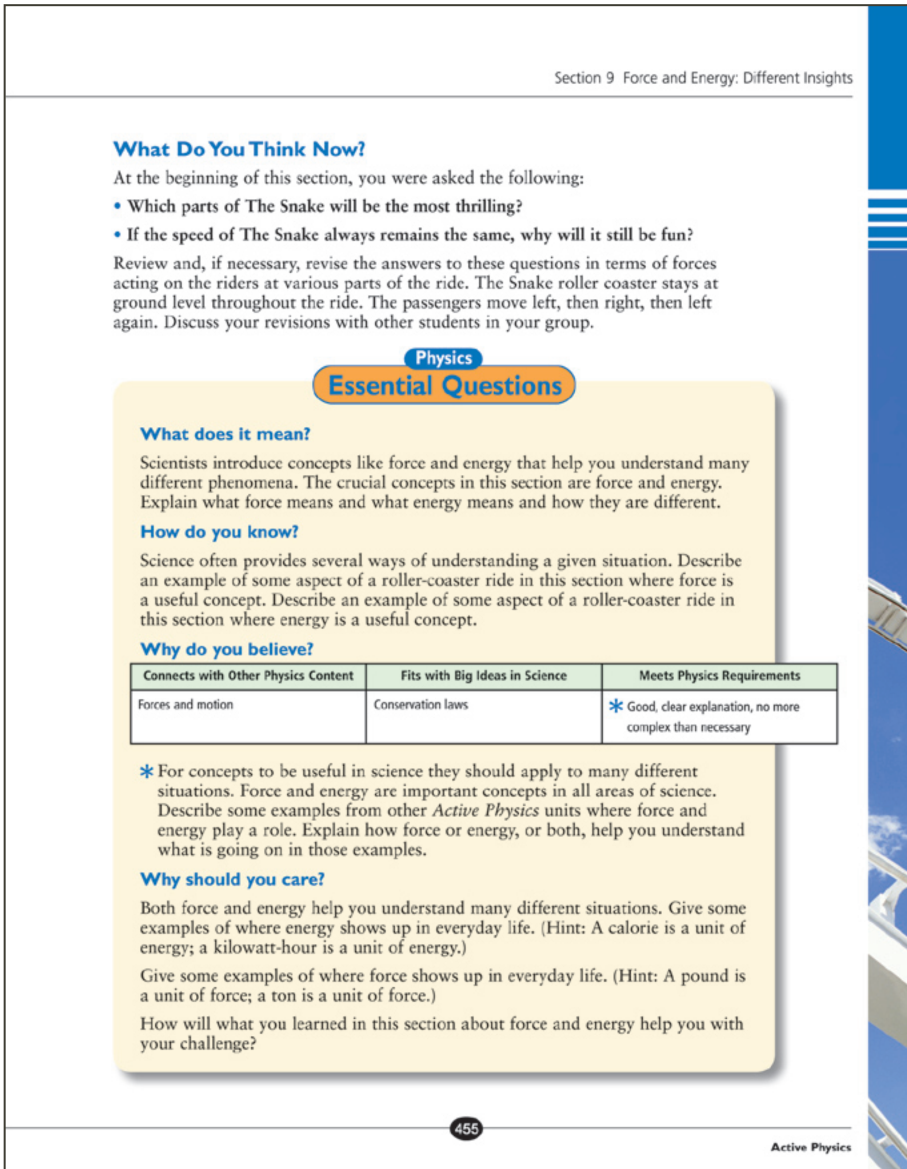
$$\Delta d = \sqrt{(15 \text{ km})^2 + (20 \text{ km})^2} = 25 \text{ km}$$

4.c)

$$\tan\theta = \frac{20 \text{ km}}{15 \text{ km}} = 1.33$$
$$\theta = 53.1^\circ$$

4.d)

The measured angle and calculated angle should be almost identical if the drawing was done carefully to scale.



What Do You Think Now?

At the beginning of this section, you were asked the following:

- **Which parts of The Snake will be the most thrilling?**
- **If the speed of The Snake always remains the same, why will it still be fun?**

Review and, if necessary, revise the answers to these questions in terms of forces acting on the riders at various parts of the ride. The Snake roller coaster stays at ground level throughout the ride. The passengers move left, then right, then left again. Discuss your revisions with other students in your group.

Physics Essential Questions

What does it mean?

Scientists introduce concepts like force and energy that help you understand many different phenomena. The crucial concepts in this section are force and energy. Explain what force means and what energy means and how they are different.

How do you know?

Science often provides several ways of understanding a given situation. Describe an example of some aspect of a roller-coaster ride in this section where force is a useful concept. Describe an example of some aspect of a roller-coaster ride in this section where energy is a useful concept.

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Forces and motion	Conservation laws	* Good, clear explanation, no more complex than necessary

* For concepts to be useful in science they should apply to many different situations. Force and energy are important concepts in all areas of science. Describe some examples from other *Active Physics* units where force and energy play a role. Explain how force or energy, or both, help you understand what is going on in those examples.

Why should you care?

Both force and energy help you understand many different situations. Give some examples of where energy shows up in everyday life. (Hint: A calorie is a unit of energy; a kilowatt-hour is a unit of energy.)

Give some examples of where force shows up in everyday life. (Hint: A pound is a unit of force; a ton is a unit of force.)

How will what you learned in this section about force and energy help you with your challenge?

What Do You Think Now?

Students should revise and update their answers to the *What Do You Think?* questions. Students can now check how the physics terms written along with their original responses to the questions may be relevant to their revised answers. Encourage students to share their *What Do You Think Now?* answers with other students in their groups. Discuss how changes in acceleration are produced and what forces act on the roller coaster while it is ascending or descending. You might want to discuss *A Physicist's Response* with your class. Point out that the thrills that riders experience are around sharp turns when there are significant changes in acceleration. Remind students that they could now revisit the *What Do You Think?* section. A progression of how their understanding developed will help them realize how their learning of physics concepts has evolved.

Physics Essential Questions

What does it mean?

Forces can produce accelerations. There are contact forces like tension and the normal force where one object touches another and action-at-a-distance forces like the electrostatic force and the force of gravity. Energy is the ability to apply a force over a given distance. Moving objects have kinetic energy; some objects have potential energy due to their position in the gravitational field (*GPE*) or the compression of a spring (*SPE*). Energy is a scalar and force is a vector.

How do you know?

Force is useful in trying to determine someone's apparent weight at the bottom of a loop. Energy is a useful concept in determining the speed at different points of the roller coaster.

Why do you believe?

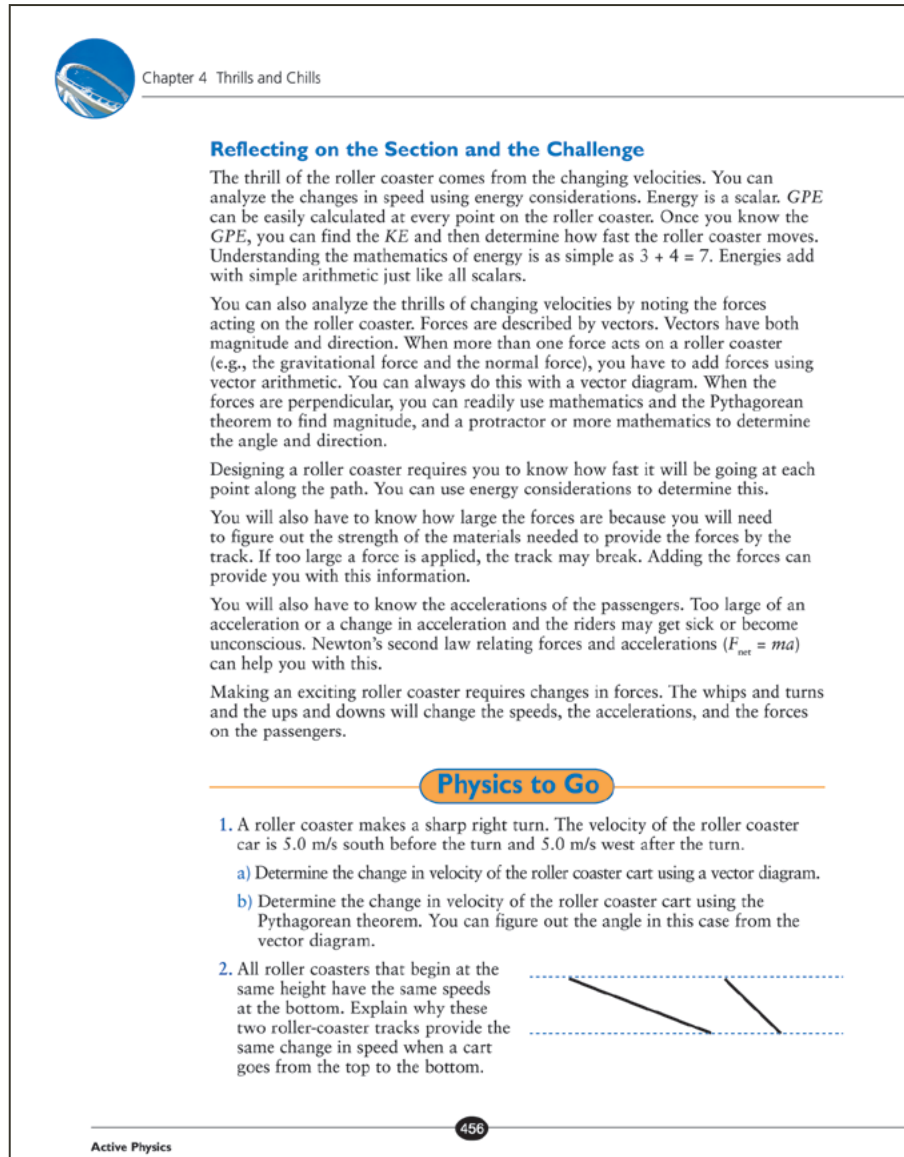
Forces are important in understanding how balls are accelerated in sporting events. Energy is important in determining how high a ball will travel in baseball.

Why should you care?

You can measure the energy used during exercise and compare that to the calories of food you eat. You weigh yourselves by measuring the force that a scale must apply to hold us up. Both energy and force are important for understanding different parts of the roller-coaster ride.

Reflecting on the Section and the Challenge

Read or have a student read this section aloud. Highlight the energy and force consideration that students should reflect on. Draw attention to the difference between scalar and vector quantities and why scalar quantities are easier to compute mathematically. Ask students to apply their understanding of energy conservation and conversions to a roller-coaster ride. Review how to calculate the kinetic energy at a point on the ride, and how this determines the speed of a roller coaster. Because accelerations and rapid changes in acceleration produce the thrills, show students how the forces acting on the roller coasters can be analyzed by drawing a vector diagram on the board. Students should also reflect on how the magnitude of forces and acceleration during a roller-coaster ride determine the safety of passengers.


Chapter 4 Thrills and Chills

Reflecting on the Section and the Challenge

The thrill of the roller coaster comes from the changing velocities. You can analyze the changes in speed using energy considerations. Energy is a scalar. *GPE* can be easily calculated at every point on the roller coaster. Once you know the *GPE*, you can find the *KE* and then determine how fast the roller coaster moves. Understanding the mathematics of energy is as simple as 3 + 4 = 7. Energies add with simple arithmetic just like all scalars.

You can also analyze the thrills of changing velocities by noting the forces acting on the roller coaster. Forces are described by vectors. Vectors have both magnitude and direction. When more than one force acts on a roller coaster (e.g., the gravitational force and the normal force), you have to add forces using vector arithmetic. You can always do this with a vector diagram. When the forces are perpendicular, you can readily use mathematics and the Pythagorean theorem to find magnitude, and a protractor or more mathematics to determine the angle and direction.

Designing a roller coaster requires you to know how fast it will be going at each point along the path. You can use energy considerations to determine this.

You will also have to know how large the forces are because you will need to figure out the strength of the materials needed to provide the forces by the track. If too large a force is applied, the track may break. Adding the forces can provide you with this information.

You will also have to know the accelerations of the passengers. Too large of an acceleration or a change in acceleration and the riders may get sick or become unconscious. Newton's second law relating forces and accelerations ($F_{net} = ma$) can help you with this.

Making an exciting roller coaster requires changes in forces. The whips and turns and the ups and downs will change the speeds, the accelerations, and the forces on the passengers.

Physics to Go

1. A roller coaster makes a sharp right turn. The velocity of the roller coaster car is 5.0 m/s south before the turn and 5.0 m/s west after the turn.
   a) Determine the change in velocity of the roller coaster cart using a vector diagram.
   b) Determine the change in velocity of the roller coaster cart using the Pythagorean theorem. You can figure out the angle in this case from the vector diagram.
2. All roller coasters that begin at the same height have the same speeds at the bottom. Explain why these two roller-coaster tracks provide the same change in speed when a cart goes from the top to the bottom.

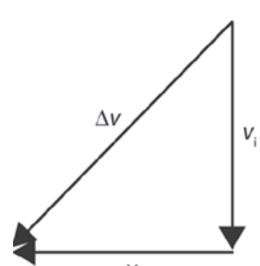
456

Active Physics

Physics to Go

1.a)

Because the first direction is going south and the other is going west, the change in direction is 90°. Students draw two vectors, 5 m/s south and then 5 m/s west, joining the ends of the vectors as done at right. The length of this new vector is the resultant velocity.



1.b)

Using the Pythagorean theorem, the resultant velocity is 7.1 m/s at an angle of 45° west of south.

2.

Both roller coasters begin with identical gravitational potential energies and zero kinetic energies. Their total energies will be identical at the bottom. Since their gravitational potential energies at the bottom are both zero, their kinetic energies must be identical.

3.a)

Scalar

3.b)

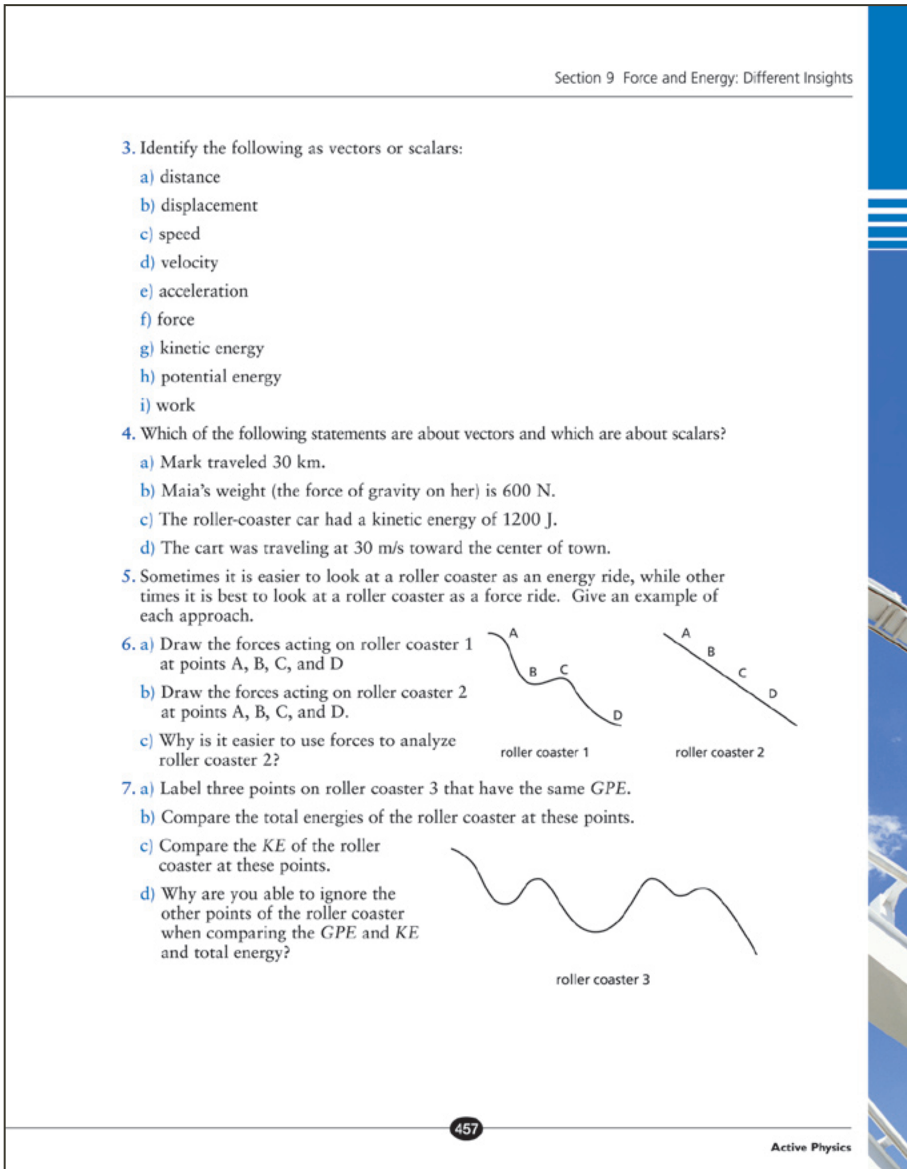
Vector

3.c)

Scalar

3.d)

Vector


Section 9 Force and Energy: Different Insights

3. Identify the following as vectors or scalars:
   a) distance
   b) displacement
   c) speed
   d) velocity
   e) acceleration
   f) force
   g) kinetic energy
   h) potential energy
   i) work
4. Which of the following statements are about vectors and which are about scalars?
   a) Mark traveled 30 km.
   b) Maia's weight (the force of gravity on her) is 600 N.
   c) The roller-coaster car had a kinetic energy of 1200 J.
   d) The cart was traveling at 30 m/s toward the center of town.
5. Sometimes it is easier to look at a roller coaster as an energy ride, while other times it is best to look at a roller coaster as a force ride. Give an example of each approach.
6. a) Draw the forces acting on roller coaster 1 at points A, B, C, and D
   b) Draw the forces acting on roller coaster 2 at points A, B, C, and D.
   c) Why is it easier to use forces to analyze roller coaster 2?
7. a) Label three points on roller coaster 3 that have the same *GPE*.
   b) Compare the total energies of the roller coaster at these points.
   c) Compare the *KE* of the roller coaster at these points.
   d) Why are you able to ignore the other points of the roller coaster when comparing the *GPE* and *KE* and total energy?

457 Active Physics

3.e)

Vector

3.f)

Vector

3.g)

Scalar

3.h)

Scalar

3.i)

Scalar

4.a)

Scalar

4.b)

Vector

4.c)

Scalar

4.d)

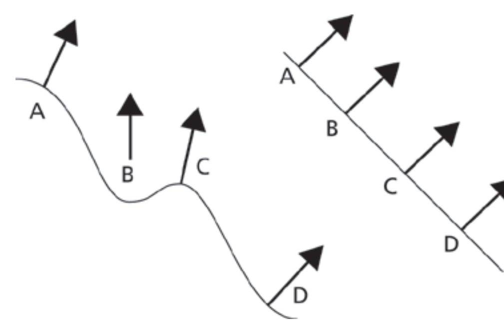
Vector

5.

When you are interested in the speed of the roller-coaster car at any point on the track, it is usually easier to look at the coaster as an energy ride. The speed depends upon the kinetic energy of the car, which depends upon the *GPE* at that point and the total energy to start the ride. If you are interested in the forces acting, or what your apparent weight may be at a certain point, it is often best to consider the roller coaster as a force ride. When going around a horizontal loop, the speed remains constant, so energy will not explain how the force varies in direction.

6.a)–b)

See diagram below:



6.c)

Forces are easier to use in analyzing roller coaster 2 because the direction of the force and the speed are constantly changing.

7.a)

Students' answers will vary. Any three points that are on the same plane will have the same *GPE*.

7.b)

The total energy will be the same.

7.c)

The *KE* will also be the same at these three points.

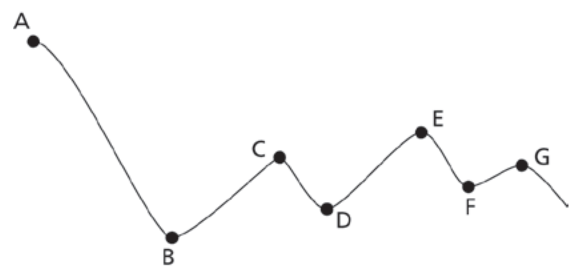
7.d)

Conservation of energy determines the *GPE* and *KE* of the roller coaster at all points independent of path if there are no losses.

SECTION 9 QUIZ

4-9d **Blackline Master**

1. The diagram below shows a roller-coaster car traveling on a frictionless track. As the roller-coaster car travels from point A to point G, which of the following quantities remains the same?



a) The normal force on the car
b) The rider's apparent weight
c) The car's gravitational potential energy
d) The car's total energy

2. In *Question 1*, at which point will the car have the greatest speed?

a) E
b) B
c) G
d) D

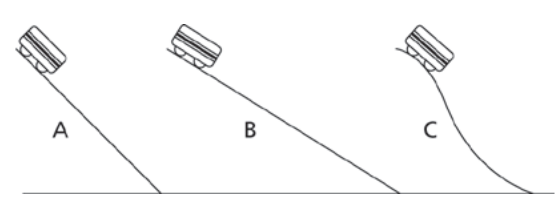
3. In *Question 1*, all the curved sections of roller-coaster track have the same radius. At which point will the normal force on the coaster car be the least?

a) A
b) G
c) E
d) D

4. Which of the following quantities is a scalar?

a) energy
b) force
c) weight
d) acceleration

5. Three equal mass roller-coaster cars are shown on three different frictionless slopes. All the cars start from rest at the same height. Which statement below correctly describes the cars at the bottom of the slope?



a) Car A will arrive at the bottom first with the greatest speed.
b) Car B will arrive at the bottom first with the greatest speed.
c) All three cars will arrive at the bottom at the same time with the same speed.
d) All three cars will arrive at the bottom with the same speed, but at different times.

SECTION 9 QUIZ ANSWERS

1. d) Neglecting any small losses, the total energy (*GPE* plus *KE*) as the car moves along the track remains the same.

2. b) Because point B is the lowest point on the track, it is the point where the roller-coaster car will have lost the greatest amount of *GPE*, which will be converted into *KE*. At all other points, some of this *KE* will have been used to increase the *GPE* of the car to bring it to a higher level.

3. b) The normal force at the top of the curves will be less than the normal force at the bottom of the curves. In addition, the normal force will be least where the car is traveling the fastest. For the top of the curves, point G is where the speed is greatest, so the normal force will be the least.

4. a) Energy is a scalar quantity because it is the capacity to do work, regardless of the direction in which work is done. Weight (mg), force (ma), and acceleration ($\Delta v/\Delta t$) are all vectors because they all involve the direction in which the mass moves.

5. d) By conservation of energy, all three of the cars will have lost the same *GPE*, so they will have the same *KE* at the bottom of the slope. Because they have the same mass, all three will have the same speed at the bottom. The differing slopes will provide different accelerations, causing the car on the steepest slope to have the greatest acceleration and thus reach the bottom first.