Vehicles in Motion

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Learning by Design Project

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Dedicated to the principals, assistant principals, science coordinators, and others who helped us identify participating teachers and who allowed those teachers the latitude to experiment with our units in their classrooms.

A Note about Learning by Design (LBD)

Janet Kolodner (Dr. K)

The LBD™ *Apollo 13* unit was designed to introduce you to many of the skills you need for learning science through design and for communicating with others what you've learned. You've measured, observed, made arguments, designed experiments, collaborated with others, borrowed their ideas and given your own advice, asked questions, tried to answer them, applied what you learned to solving new problems, and tried to explain what happened when your solutions didn't work exactly as you had planned.

This is what science is about, and these are the things scientists, engineers, architects, and even managers, do everyday. They use what they know to try to address problems and challenges that arise. They raise questions and investigate areas they know little about. When they discover flaws in their proposed solutions, they go through cycles of trying to explain what might be problematic or misunderstood, asking new questions, investigating again, coming up with better solutions, trying those out, and so on. As they move through the cycle, two important things happen: (i) They propose better and better solutions to problems or answers to questions, and (ii) they come to better understandings of the concepts and skills involved in addressing their challenge — they learn.

Learning by Design™ (LBD™) is modeled after these kinds of real-world activities. LBD™ organizes classroom activities to give you opportunities to apply what you are learning and to help you recognize whether you understand those answers well enough yet. You'll have the kinds of experiences that will prompt you to ask questions and to want to find answers. We also make a special request of you. In addition to trying your hardest, we want you to spend time reflecting on what you've done so as to identify the strategies you've used and how well they worked, the concepts and principles you used and are learning, and ways you could have done better. Why? Because research on learning tells us that such reflection will make it easier for you to reuse what you're learning later on, when you're in a new situation solving a different problem.

Your experiences during the *Apollo 13* unit were designed to give you introductions to the whole set of skills involved in learning science. Our plan in that unit was to put you in situations where you could begin to discover some of the difficulties of doing science well; to understand the need to learn the skills for doing and learning science; to understand the need for communication skills, collaboration skills, and design skills; and to begin to learn those skills.

Now, we hope, you're ready for a bigger challenge, and this unit presents you with one that you'll be working on for six to eight weeks. You'll be designing a vehicle that can carry a load over a rugged terrain. It's a big challenge and one that will require you to learn quite a bit about forces, friction and motion. You'll have to learn how to measure distance and speed, and interpret graphs that hold these data. And you'll have to learn how those things can be influenced and changed.

Six or eight weeks is a long time, and we know you can get bored or overwhelmed by something that is too big a challenge. So we've divided the unit into four parts. This will allow you to focus on important science and to build up your skills early. We then ask you to apply what you've learned and put it all together for the grand challenge.

You'll be using the skills you began learning during the *Apollo 13* unit, and you'll be developing further expertise at using those skills. We don't expect you to be expert at any of them right now, but we do want you to pay attention to all of them. LBD gives you a chance to develop important science process skills -- like designing your own experiments and making careful measurements -- and other important thinking skills while you are learning science. These skills will be important any time you need to collaborate, learn something deeply, solve a hard problem, address a difficult challenge, make a decision, or communicate the reasons for a decision you've made.

Have fun!

Dr. K.

Vehicles in Motion

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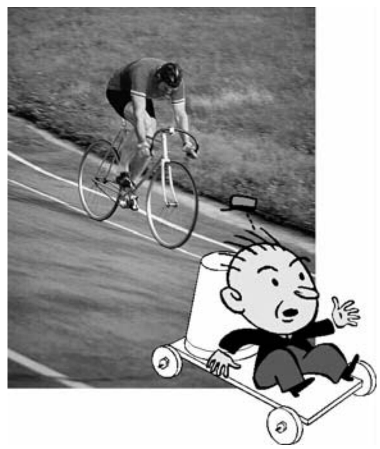
Introduction



The Antarctic Challenge

Antarctica, located at the South Pole, is still considered the "unknown continent". It is very cold and for the most part, uninhabitable. However, Antarctica is very important to scientists. The continent's ice, rocks and fossils help explain earth's early history. They could offer evidence for continental drift, extinct or prehistoric organisms, and trends in climate conditions like global warming. The continent also holds a vast amount of wealth in rock and mineral deposits. Unlocking these deposits could benefit the whole world by making some rare resources more available for all kinds of uses.

Special equipment must be designed for the expeditions that work in the hostile and remote environment of Antarctica. The vehicles needed there are very different from the cars and buses we use to get around town. Antarctic expedition vehicles must be able to travel in many different conditions, including a wide variety of terrains and surfaces. The vehicles also have to be simple to maintain: the harsh temperatures can cause many breakdowns, and there are no service garages out in the field. The sturdiness and reliability of a vehicle may make the difference between a mission's success and failure, or even the difference between life and death. Scarce energy resources means that vehicles and equipment must be very energy-efficient. Therefore, vehicles for Antarctica must be designed to move well in different conditions, over different terrains, and while going long distances with their limited power sources.

Your class will be a task force for an R&D firm that will give advice on how to design a prototype utility vehicle for Antarctic exploration. To begin your work, you will build and experiment with models of cars. You will start with a basic plan for a vehicle body, and you'll modify and refine it so that it can travel long distances over different terrains and conditions, reporting what's necessary for success. You will also build, test, modify and improve three different propulsion systems as possible power sources for the vehicle.

As you discover the constraints on your vehicle's motion, figure out how it works, and revise the vehicle's design to overcome these limitations, you'll be learning about the laws underlying motion — not just how your vehicle moves, but how anything can be made to move. What you discuss about vehicles in motion can be applied to everything in the known universe and is fundamental in understanding physical science.

Your task force (the class) will be divided into smaller investigation and design groups. Although each group will develop its own ideas for the best model vehicle, it is very important to remember that this is a collaborative effort, and your entire task force is working toward a common goal. Good communication and sharing of ideas is necessary and expected.

in Motion

Objectives of the Unit

In *Vehicles in Motion*, you will learn about forces and motion, in particular the ins and outs of getting things to move and keeping them moving, in the context of designing, building, and testing model cars. By the end of this unit, you will understand, demonstrate, and be able to discuss the following physics concepts:

- Newton's First, Second, and Third Laws of Motion
- Friction, gravity, air resistance
- Mass, weight, inertia, load
- Air pressure, propulsion, thrust, torque
- Acceleration, velocity, speed
- Combining forces, net force, direction of force

As well, you will get better at several process skills you began learning in earlier units and begin learning some others:

Science:

- "Fair testing"
- Gathering information
- Measuring and observing
- Designing experiments
- Graphing
- Asking questions, conducting investigations and inquiries

Design:

- Breaking down a problem into parts
- Identifying criteria and constraints
- Designing for structure, behavior, and function
- Iterative designing, building and testing
- Designing for optimization
- Documenting the design process
- Understanding devices
- Fabricating and building things
- Reasoning with cases
- Using the LBD cycle to learn

Collaboration and Communication:

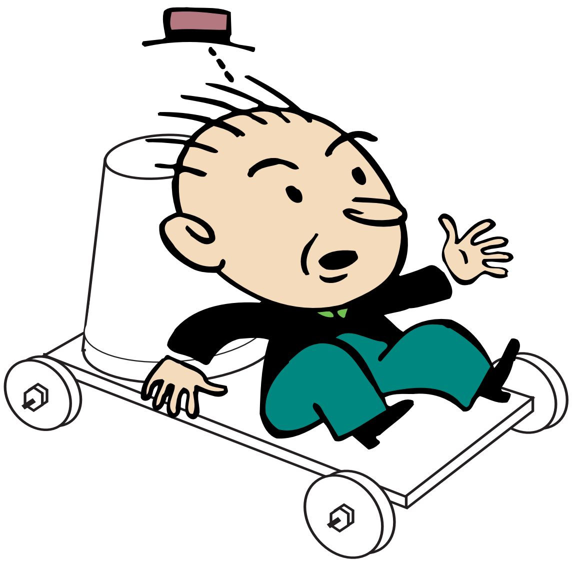
- Working with a group
- Presenting to an audience
- Drawing meaningful diagrams, sketches, and illustrations
- Learning from your own experiences and those of others through gallery walks, pin-ups, and whiteboards

Decision Making:

- Making and justifying decisions
- Backing up an argument with data
- Making comparisons

Model Car Challenge Overview

To gain an understanding of the issues involved in solving the Antarctic challenge, you will design and build a model car that goes over hills, on its own power, and then travels as far and straight as it can beyond the hills. You will do this work in stages: (1) getting your vehicle to coast as far and straight as possible; (2) adding a "balloon engine" and configuring it to travel as far as it can; (3) experimenting with two other propulsion systems and (4) then designing the best system to meet the challenge.



1. Coaster Car

Your first challenge is to design and build a vehicle that can coast in a straight line as far as possible. You will be given plans for a basic "coaster car" and a ramp that it can run down. You'll build and test this basic car and then refine it to improve its performance.

You will collect data as evidence to show that your design works better than the original. You will also use these figures and observations to tell why your car works better than the original.

2. Balloon Vehicle

Your next challenge is to configure a balloon propulsion system that will power your car to travel the greatest distance possible over flat terrain. You will be given plans for building a basic balloon vehicle. You'll conduct experiments and collect data to find out what factors affect the balloon car's behavior. You'll then create an improved balloon car, based on those experimental results, refine it over several iterations, and then get to test it on the final test track with hills.

3. Rubber-Band & Falling-Weight Cars

You'll get plans for two new propulsion systems. After building one or both, you will design a hybrid system that combines the best traits of each, and test it first on a flat and then on a hilly test track.

4. Over the Hill

Your final challenge is to change the size of wheels and gears of your self-propelled cars so that it can go over a 5-cm and a 10-cm hill and then continue on the greatest distance. You then will present this design in class presentation, and write a report on how your design changed over time.

At each stage, your team will present its findings to the entire class. Each time, you will need to:

a. Describe how your car works, with emphasis on the improvements made;
b. Provide reasons for your design decisions;
c. Show the data you gathered from experiments that helped you in your design decisions; and
d. Demonstrate your vehicle's performance.

Car with a Mission

Products

For *Vehicles in Motion*, you design and build a series of cars with different wheels, gears and systems for moving the car over a test track. This work includes:

Section 1: Build and test coaster car; write report of test results; give class presentation
Section 2: Build and test balloon car; give class presentation on car; write design report
Section 3: Build and test a rubber-band or falling-weight car, and then build a hybrid design
Section 4: Build the best propulsion for your car; give final class presentation and car demo; write a final report giving advice to Antarctic expedition vehicle builders

You will hand in documentation from your Design Diary for each section of work that you do.

Product Testing

In each section of the unit, you will test the cars you design and build, while learning about forces and motion. Sometimes you will design and run experiments to find which product features most affect your car's performance. You will be keep records of these product tests, design efforts, and what you are learning in your Design Diary.

Presentation

You will present your ideas and results in a series of pin-up sessions and gallery walks. In some of these presentations, you will describe your car, its performance, the design decisions you've made, and the science that supports and explains them.

Assessment

The assessment of your work for Vehicles in Motion will be based on six main items:

- work in groups
- the presentations you make
- your understanding and application of science ideas and experimentation skills
- design process and performance of your car
- homework and documentation
- quiz and test results

The science ideas you will be asked to understand and use in your explanations include:

- Newton's Three Laws of Motion and the other physics and science concepts listed on p. 7

The technology ideas you will be asked to know and explain include:

- how your cars work
- how you got your car to do its best

Getting "Messing About"

Why "Messing About"

Your main *Vehicles in Motion* challenge is to design and build a model car that carries a load as far as possible over a hilly terrain. You're doing this so that you can make good recommendations for designing a vehicle for use in the Antarctic. But before you can do that, you need to understand the challenge well enough to have some idea how to go about addressing it. That's what <u>messing about</u> is for. Before you actually start designing your car, you will study car motion by <u>messing about</u> with toy cars available in stores. We want you to examine several types of existing toy cars and figure out how they work. Watch them perform and identify good and bad points in their designs. This, we hope, will give you ideas, help you identify what you need to learn, and allow you to be an effective case-based reasoner.

The Questions

Your main question in this activity is simple to ask but hard to answer: "What makes and keeps a vehicle moving?" To find out, you will observe as much as you can about the toy cars that you and your classmates bring into class. Try to explore several issues about those cars.

1) Structure — The <u>structure</u> of a vehicle involves its frame and parts, how the parts join together to make up a whole car, and how the parts interact. Structure is something you can see when the car is at rest. What do you notice just by looking at the car — from above and underneath? How was the car designed? What materials were used? How was it built?

2) Behavior — The <u>behavior</u> of a vehicle is what an observer sees when the car is running. How far does the car run? In what directions? How fast? What do you notice about its performance when you stand far away? What do you see when you look up close?

3) Mechanisms — We call the working parts of a device that allow it to run its <u>mechanisms</u>. Which parts help each car to behave the way it does? What are its mechanisms? Each mechanism has a <u>function</u>: its reason or purpose. What function does each mechanism you've identified carry out?

4) Subsystems — A <u>subsystem</u> is the group of parts or mechanisms that carry out a common function. What subsystems do the toy cars have?

5) Design decisions — Designers choose the functions a product must do. They then choose structures and mechanisms to achieve each function, and figure out ways of connecting subsystems to each other. Can you infer or guess what design decisions were made when each car was first being designed?

Started
With Toy Cars

The Activity

1. In class, join your team, and bring your toy vehicle into a defined “pit area”.

2. Before the messing about activity begins, briefly introduce the following facts about the car, if you know them: cost, estimated date it was made, and user for whom it was designed. This short talk should last no more than a minute.

3. While keeping in mind not to damage the vehicle, first look over each toy to see how it works. Make notes and sketches on your Messing About observation sheet. Then, use the car, making sure you stay within your pit area and don’t interfere with other teams. Take notes on the structure, behavior, mechanisms of each device, and ideas you think might be useful with your own designs.

4. When you are finished with your car, get permission and swap toys with another team. Take notes based on close observation of those cars, too, and describe their behavior after you use them. Continue examining cars until your time runs out. Ask for additional “Messing About” pages as you need them.

*

* This is an icon for the Design Diary.

5. Teams will report on their observations to the class, using drawings and notes, and in some cases demonstrations, so that the entire class can benefit from the study of as many toy cars as possible.

Homework: *What Have We Learned?*

For homework, complete any remaining work on your Messing About Observation sheets. Also, do the following on a separate sheet of paper:

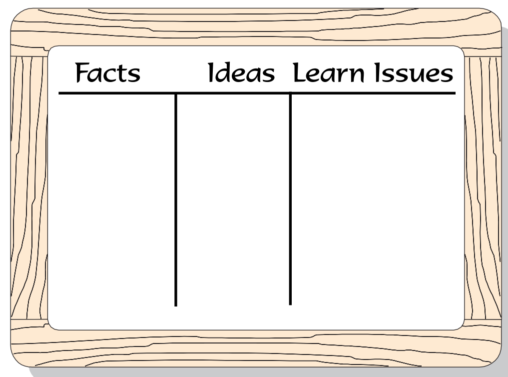
1. Consider the toys you worked with today.
    - Group the toys into categories or groups, based on things they have in common. Give each category a name.
    - Explain how the items in the categories are alike. Then tell how these are different.

2. Think about two aspects of toy vehicles — what makes them roll (wheel-and-axle subsystem) and what makes them move (propulsion subsystem):
    - What about the wheel-axle and propulsion systems were similar in the toy cars you used? What are some key differences?
    - Propulsion systems can make a toy move. What different propulsion systems did you see? Which relied on the user to make the car move? Did any store energy that was used to move the car at a later time?

Whiteboarding
What Do You Need to Learn?

To address the Antarctic vehicle challenge, you need to learn about how to make things move. But what particular ideas from science, technology and design do you need to learn to do this?

Think back to the toy cars you recently messed about with. What questions did you come up with about how they work and how to make them work better? What observations did you make that suggest things you might want to explore further?



Whiteboarding provides a way to think through key issues and organize the questions you need to explore during this or any *Learning By Design*™ unit. This is the same activity you did when designing parachutes in Apollo 13. First, you look over the answers to your "messing about" homework about the toy cars. List "Facts" and questions about motion that you need to consider in more detail. After noting what you already know, propose "Ideas" for addressing the challenge. Then identify things you need to learn ("Learning Issues") in order to decide which ideas are worth following up on and doing.

As you come up with ideas, keep in mind the goals of the challenge:

- making a vehicle travel a long distance
- making a vehicle travel over hills of varying sizes
- making a vehicle that can travel on different surfaces

About Whiteboarding

Whiteboarding is a classroom notetaking method invented by Dr. Howard Barrows to help medical-school students learn science by talking about treating patients described in essays that they read. Dr. Barrows' approach to education, called Problem-Based Learning (PBL), has students investigate, research, and diagnose some 200 cases to get a good science foundation. Learning by Design™ is very similar to PBL, but changes PBL's approach to make it more appropriate for middle-school use.

Dr. Barrows make several suggestions about how to use whiteboards when you're trying to solve a hard problem:

- After doing some basic "Messing About" investigations, write down the things you know about the challenge in the "Facts" column: What constraints must you design for? What resources do you have available? What still needs to be explained? In what situations does it have to work?

• Based on what you already know and what you found out while messing about, list possible solutions that come to mind in the "Ideas" column.

• Then consider: How can you tell which idea is best to follow? This can be hard since you don't know all the things yet that you need to know to address the challenge. What ideas do you need to learn more about to make things work? Try to choose the most important things and do them first.

• Turn some questions you wrote down into science investigations.

• Learn more about each question through reading, doing experiments, asking experts, or selectively using the Internet. It's usually a good idea to divide up responsibility for answering the questions among your group or class.

• After you've had a chance to investigate some of your questions, come back together and share what you've learned, but in a special way. Using the Ideas list as a guide, identify what everybody now knows about each idea. During this discussion, several things will probably happen: You'll throw out some ideas. You'll add some new ideas to the list. You'll add facts to the Facts list. And you'll add new questions to the "Learning Issues" list.

• After this, you have to decide as a group how to move on. There may be more investigations you need to do to learn more about learning issues. Or, you might be ready for the challenge.

• As you come up with solutions, revisit the whiteboard from time to time. Go over the answers to the questions listed under "Learning Issues." You've learned more about as you've addressed the design challenge -- list new facts, ideas, questions and learning issues to your Whiteboard.

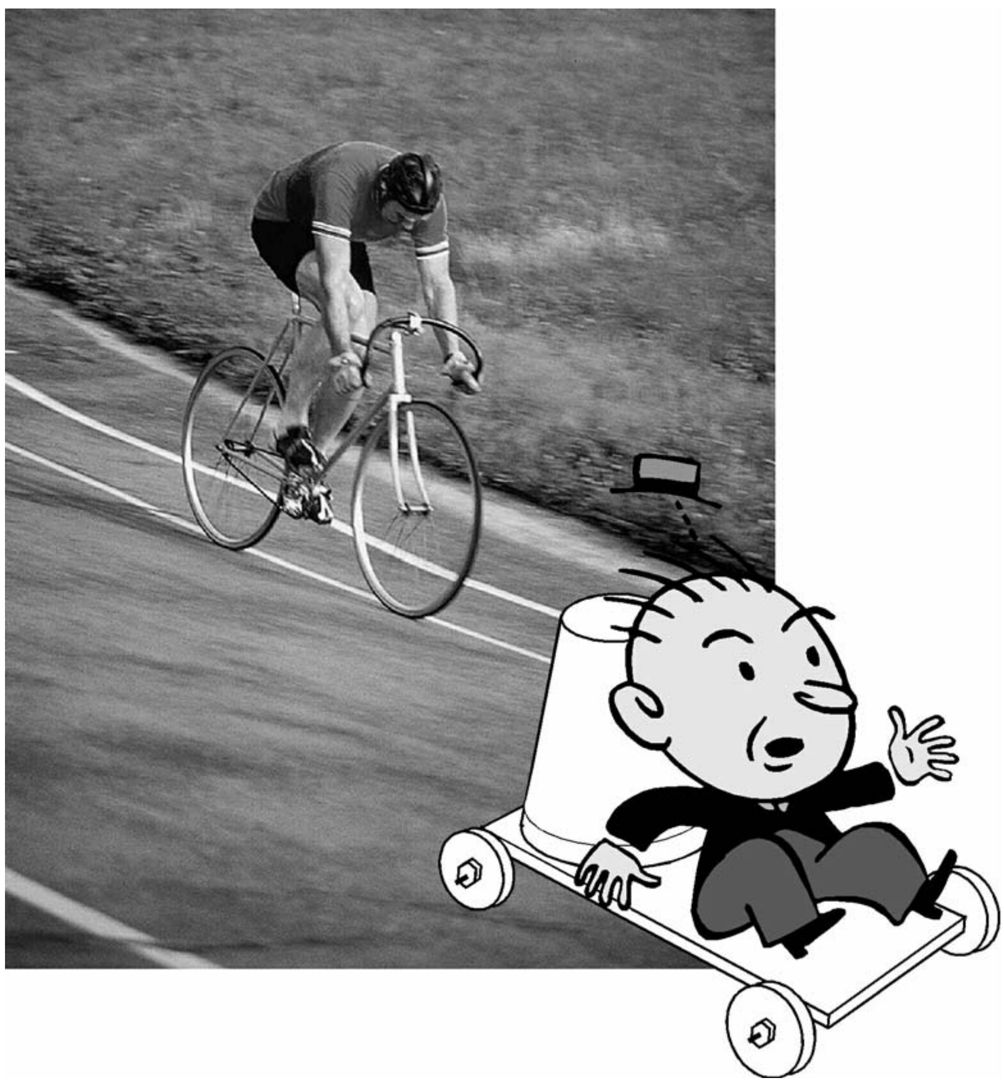
• When the design challenge is complete, reflect on what you have done. This includes your use of whiteboarding, how it helped and how using whiteboards might work better. Look for new ways of using whiteboards that the PBL folks didn't consider.

You may want to use something like a whiteboard to keep track of options when you are solving your own problems and making personal decisions. One 6th-grader just introduced to whiteboarding thought it would be great for her dad because he had a lot of problems keeping track of everything when he had to make decisions.

Dr. Barrows also suggests that in earlier *Learning by Design*™ units, your teacher will play a big role in helping you do whiteboarding to help you get good at it. Your teacher will help you turn your construction and how-does-it-work questions into science and design questions. Over time, you'll get better at doing this yourself -- then your teacher will help less and less.

Vehicles in Motion
Section 1

The Coaster Car



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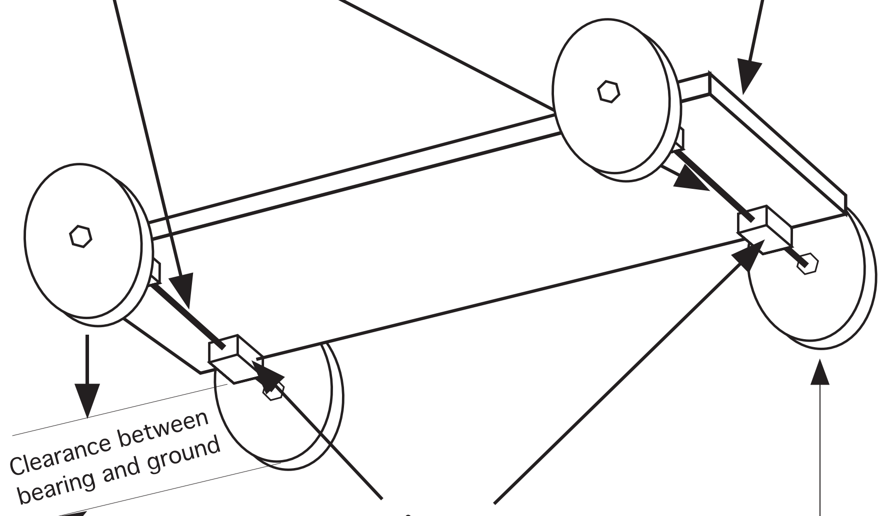
Coaster Car

The coaster car pictured below is a simple vehicle without a system for making it move. It is just a flat body (called a chassis) with wheels and axles and other items like bearings and tape to hold these things together. You will be given instructions for making this basic, run-of-the-mill, unpowered “coaster car”. After building it, you will conduct performance tests by running your coaster car down a cardboard ramp. You will then get some chances to redesign and improve your coaster car to make it travel straight and coast as far as possible.

Coaster Car Parts and Terminology

Axle -- round shaft that holds wheels attached to it. In some cars, the axle stays still while the wheels rotate. In others, the wheels are fixed to the axle, and both rotate together when the car moves.

Chassis -- (pronounced CHA-SEE) the body of the car. It is the main structure or frame to which other parts are attached.



Clearance -- distance separating two things. The distance between the lowest part of the car body and the road is the clearance of the car with the ground.

Bearings -- hold things like axles in place, while allowing them to rotate with little friction.

Wheels -- round disks that allow a vehicle to roll rather than slide down a road

Challenge

Products

The goal of the Coaster Car Challenge is for you to make a vehicle that can travel as far as possible after going down a ramp. You can do this in two ways: (1) by improving the way you build and put together the car and (2) by changing its design. You will also turn in several reports about this work.

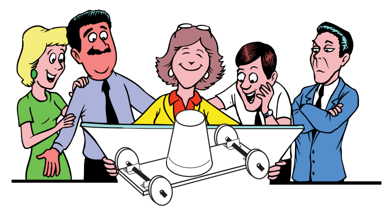
Product Testing

To determine how well your design improvements work, you will conduct tests and collect data on how far your car coasts. These tests you design and plan must be fair. When reporting your results, you will be asked to tell why you think your tests were fair. You will use the Design Diary's "Testing Your Product" sheets for this work.

Project Presentations

You will be giving several short presentations showing your car's performance and your design thinking and reasoning in gallery walks. You will choose how to display the data you collect to make an effective presentation. These presentations should include:

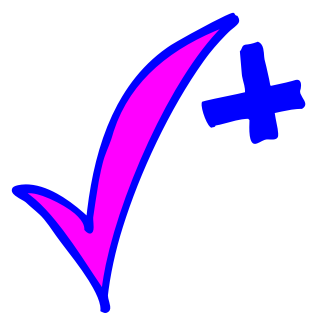
- data from your tests;
- sketches of the various car designs tested; and
- reasons for changes in your designs or construction methods;
- science ideas that supported your design decisions.



Assessment and Objectives

Your team's design work will be assessed during the unit by your teacher. These ideas relate to *National Science Education Standards* that have been developed. Your homework will be reviewed by your teacher. There will be quizzes and tests on this section's science and technology ideas. Here are some you will need to show that you understand:

- How your coaster car works, in terms of form and function
- How to test your car's design and show improvements in your design
- Showing your experimental data in different ways
- Identify needs and think about criteria and constraints when designing
- Newtons Three Laws of Motion on balanced and unbalanced forces
- Describe forces acting on an object when still or in motion
- Understand systems and their parts or sub-systems
- Concepts: Force, speed; velocity; friction; net force; acceleration
- Identify stages and reflect on steps taken when using the LBD™ Cycle



Now, on to building your first Coaster Car.

Section 1: Addressing the

Designing and Building Your First Coaster Car

Your main goal in Section 1, which will take you about two weeks to complete, is to build a coaster car and then improve its design so that it can travel down a ramp and coast as far as possible. You'll learn about friction, gravity, and how forces affect motion while doing that. The coaster car will serve as a foundation for the propulsion systems you'll design and attach later. Those propulsion systems will work best if the coaster car goes straight and far.

Your teacher will provide you with materials to build your car. You will learn about how these cars work, how to test them, and how to improve their design.

Don't worry if the first versions of your coaster cars don't work very well. You can learn a lot from something that doesn't work the first time. Remember, you do not have to invent something completely new, but rather improve on an 'okay' car whose design may have room for improvement.

Here are some of the activities you will be doing:

- Test what you've built and analyze the results;
- Identify and learn about science concepts that will help you improve your car;
- Change your design based on what you've learned and your test results;and,
- Share your ideas with others.

Procedure

1. **Build and Use Your First Coaster-Car and Do a Gallery Walk** -- You will follow instructions for building your first coaster car, and then mess about with them to see how they work, and then report to the class in a Gallery Walk. Note: Review *Apollo 13* for pointers on how to do gallery walks, and how to make the sharing of sketches and test data with others work better. If your device didn't work, don't worry about it. Show the class what you tried, explain what happened, and share your thoughts on why. You'll have more opportunities in coming days to improve upon your design.

• Gallery Walk Notes

2. **Do a Second-Pass at Improving Your Car and Do a Gallery Walk** -- With the ideas you've gotten from others and new ideas of your own, improve your car and then show others what new things you've learned.

• Gallery Walk Notes

3. **Learn about Force and Friction to Debug your Cars** -- You'll be reading about fforces and friction, how to debug and improve your car, and net force to gain a better understanding of your coaster car. Then you'll do another Gallery Walk on what you've learned about improving your car thus far. You'll describe the pros and cons of your current bearing system, and share "tricks of the trade" that you've learned in building them, and any design rules-of-thumb you've uncovered or read about.

• Design Rules of Thumb

Coaster-Car Challenge

4. **Redesign and Rebuild Your Cars, Test Them Again, Pick Up Some Design Tips, Redesign Your Wheels-and-Axles and Share Findings** - You'll next work at conducting fair tests and taking good measurements while improving your car design. Then you'll get some tips for improving your designs and decide what kind of wheels and axles you want. Then, you will use your new ideas to improve your car, or even start over again and build a new coaster car from scratch. You may have a Gallery Walk or Pin-Up session where you'll share ideas you have tried.

> • Testing My Design

5. **Force, Net Force, Velocity, Acceleration and Your Car**-- You'll have done lots of building, observing and repairing. You'll next be learning about the science that explains and predicts how coaster cars perform. You will create Motion Storyboards to analyze the forces and acting on your car. You will uncover how they affect the motion of your car, and you will be able to describe motion in terms of force. Then you will form a class panel that will answer questions you might have about your car and how it works.

> • Gallery Walk and Pin-Up Notes

6. **Redesign, Rebuild, Iterate, and Hold Gallery Walks** -- After collecting ideas from your walks and readings, you'll plan and make changes to improve your car and put your results in your "Testing My Design" Diary pages. Then you may do a Pin-Up or conduct a Gallery Walk, where you will talk about and show data on your new design ideas.

7. **Summing Up, Transition, a Look at Your LBD™ Cycle and Whiteboarding** -- You will have some questions and a quiz near the end of the unit to help you assess how well you understand the materials. Having had lots of experience with cars, you'll be ready to write up Product Specifications that you think your car should meet. Finally, you'll get a chance to look back on how you have been working at *Vehicles in Motion* by reviewing the LBD™ Cycle, and you'll end with a Whiteboarding session that focuses on what you've learned, new ideas for your final car, and revising learning issues.

> • Testing My Design
>
> • Gallery Walk and Pin-Up Notes
>
> • Product Specifications
>
> • Whiteboarding Summary

Coaster Car Build

Outline of the Coaster Car Building Instructions

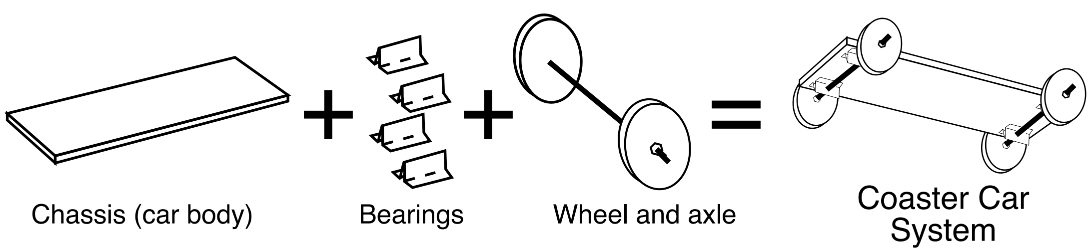
The following four pages of instruction for building a coaster car are divided into six parts:

A. Introduction to Building a Coaster Car
B. Materials You Will Need
C. Choosing Your Car's Bearings
D. Helpful Information and Explanations
E. Attaching the Bearings to the Chassis
F. Connecting the Wheels to the Axle

A. Introduction to Building a Coaster Car

A coaster car is the simplest of vehicles — it has a body and wheels with axles attached to it. A well-designed and built coaster car should be able to move easily when given a slight push and should seem to travel without any brakes on. Coaster cars do not have their own propulsion system.

You will be making a coaster car, which is made up of three basic parts or subsystems:
a. a chassis or body;
b. a pair of axles with two wheels each; and,
c. bearings to hold axle or wheels in place while letting them spin freely.



Note: Bearings are made with straws, not those picturred above.

B. Materials You Will Need

Your teacher will give you the following materials to build your coaster car.

Materials List

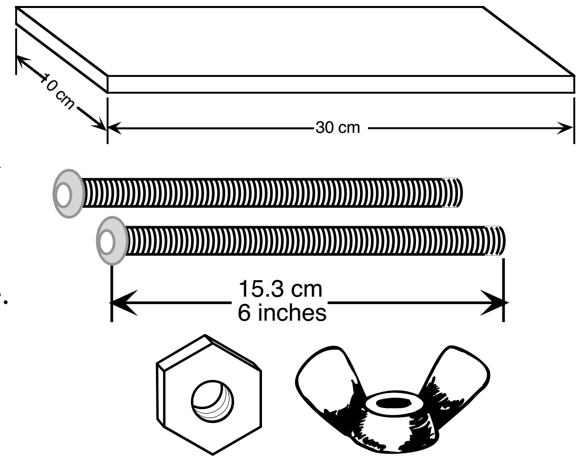
1	piece of 8x30 cm foamcore or cardboard	2-4	1/4" thread wing nuts
2	6 inch carriage bolts, coarse 1/4" thread	1	roll masking or other tape
4-6	1/4" thread regular nuts	2-3	plastic or paper straws

ing Instructions

C. Helpful Information and Explanations

The following are some facts that might help in using the tools and materials you need to make a coaster car.

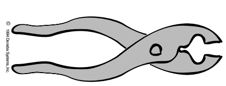
- The car's chassis or body can be made of any firm, light thin material, like foamcore, cardboard, or plastic.
- Carriage bolts are threaded shafts with a cap at one end that serve well as car axles.
- A **regular nut** is a six-sided piece of metal, with threads through its center, used to hold or fasten things in place. A **wingnut** is a similar kind of nut that can be tightened with the fingers.

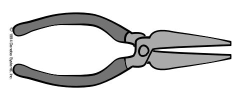


Nut Wingnut

Help in Using Adjustable and Needle-nosed Pliers

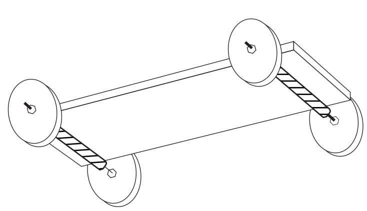
- Pliers are like a pair of strong hands that give you a firm grip on something without hurting yourself when you squeeze hard. Adjustable pliers have short jaws and can be set to grab narrow or wide objects. Needle-nosed pliers have longer jaws that help you reach hard-to-get objects.





Adjustable Pliers

Needle-nosed Pliers



Coaster Car Build

D. Connecting the Wheels to the Axle

Fastening a wheel to an axle can be done in a number of ways: welding, gluing, and just jamming parts together snugly (called “press fit”) can work in a number of applications. One way to fasten wheels to an axle uses nuts and a threaded axle. Two hexnuts are placed on either side of a wheel and then are tightened together. Using pliers to tighten the hexnuts firmly against the wheel and to lock the wheel in place on the axle. An easy-to-tighten wingnut can be used on the outside side of the wheels, instead of a regular nut.

<u>Directions for fixing a wheel near the end of the axle with the cap on it:</u>

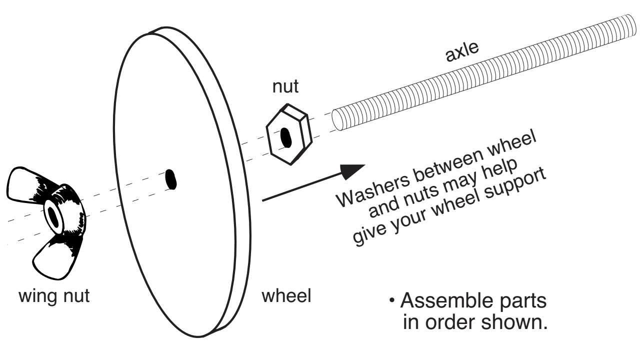
D1. Thread a regular nut or wingnut along the length of the carriage bolt, so that it rests next to the bolt’s cap.

D2. Slide a wheel into place on the axle so that it rests snugly against this nut.

D3. Spin a hexnut so that it presses against the other side of the wheel.

D4. Grab the hexnut with a pair of adjustable pliers and turn the wingnut with your hand. Tighten the two in opposite directions to lock the wheel in place between them.

D5. Check that the wheel is firmly held so that the axle and wheel turn together.



• Assemble parts in order shown.

• Tighten nuts onto wheel with your hand and a pair of pliers, so that the axle turns when the wheel is rotated.

Note: You may use “wing nuts” instead of regular ones to secure the wheel firmly to the axle. Washers may be placed between the wheel and nut.

<u>Directions for placing and fixing a wheel near the open end of the axle:</u>

D6. Put one hexnut on the threaded axle by turning it in place.

D7. Slide the wheel after it until it is pressed against the first nut.

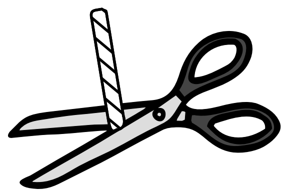
D8. Spin on a wingnut or regular nut. Tighten with pliers in the usual way.

ing Instructions (cont.)

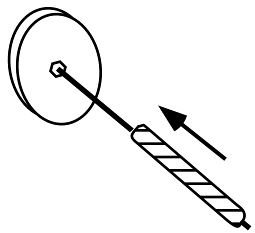
D. Attaching the Bearings to the Chassis

D.1 A **bearing** holds something in place while allowing it to move freely in certain ways (like rotating). You will use a straw for your bearings, as pictured below. As you test your car's performance later, you may decide to smodify the bearing to improve performance.

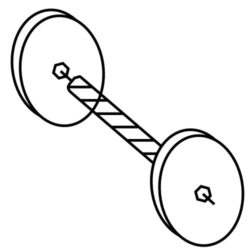
D.2 Your next step is to attach the bearings to the chassis. Use masking tape to attach the bearings and axles to the chassis. Some of you may find it better to attach the whole wheel assembly to the chassis, as pictured below.. On the other hand, some of you may prefer to tape the bearings to the chassis first, then construct the wheel and axles system through th straw. There may be other methods you discover. The choice is yours and it may lead to



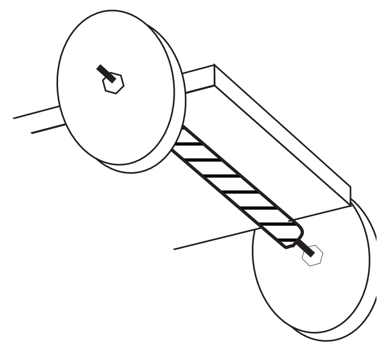
Cut straw so it is slightly wider than chassis

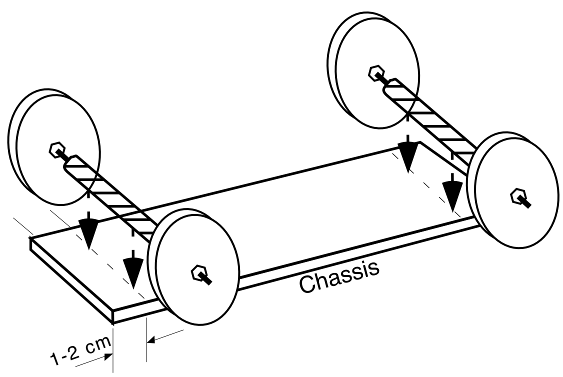


Slide straw on to axle



Mount second wheel





Testing and

Overview

You've built your first car and made some small design decisions in construction. Very good. You now need to find out how well it works, and what you can do to improve it. In order to do this, you will need to measure your cars performance by doing tests.

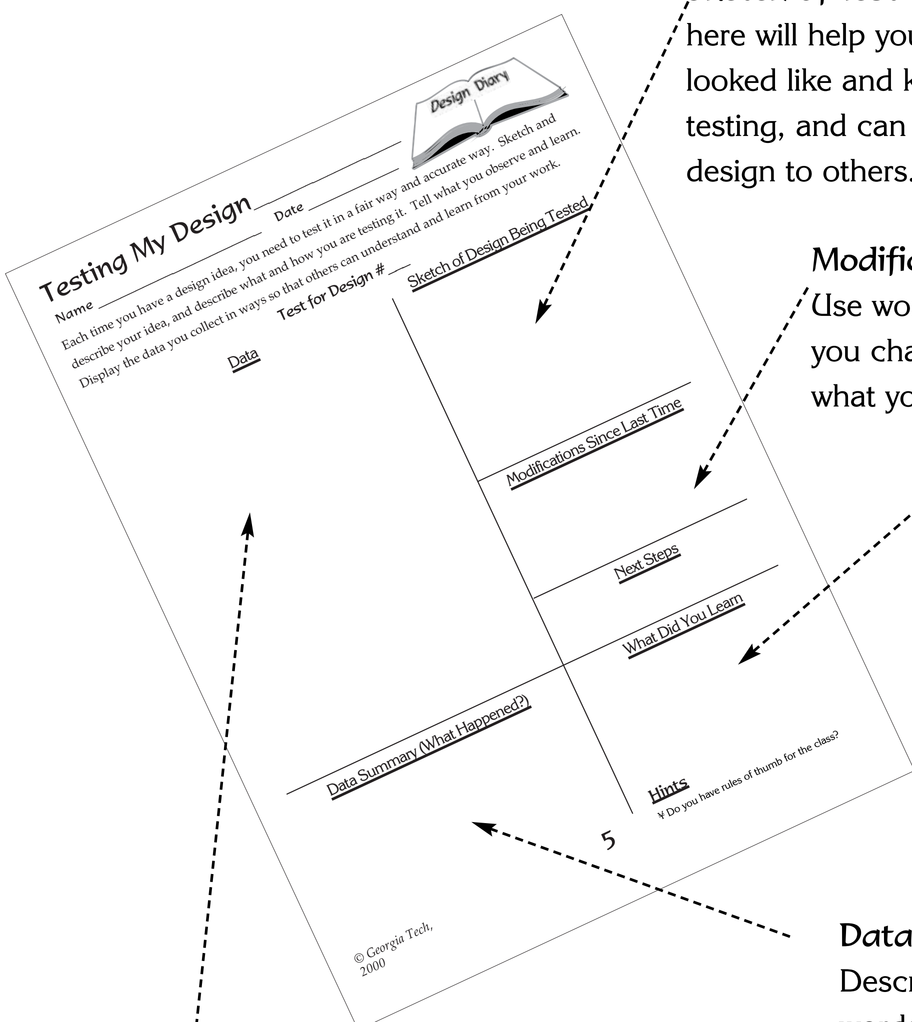
When doing design, it's not always easy to know whether you're making progress or not. Some car problems are not related to the car's design, but rather, to *how* you built the car — maybe you taped something poorly, or didn't tighten a pair of nuts well. How can you tell the difference?

One good way to avoid this problem is to run tests, lots of tests. This is where good science skills can help. You'll have to figure out what to measure and how to measure it accurately. You'll have to learn to carefully examine your car and its mechanisms. You need to figure out how things work and what might make things work better. You'll also need to compare and contrast your car system with those of others in the class.

Refining Your Car

Keeping Good Records

Throughout *Vehicles in Motion*, you will design, test, and redesign your cars. You'll want to keep track of what you've tried and tested and what you've learned along the way. Such records will help you to explain to others why you made the design decisions you've made. "Testing My Design" sheets provide you with a tool for keeping those records.



Sketch of Test Car — A simple sketch here will help you recall later what the car looked like and key design features you were testing, and can help you describe your design to others.

Modifications Since Last Time — Use words to describe the features you changed in your car. Then tell what you plan to do next.

What Did You Learn — You are doing tests so that you can make design decisions. Tell what you learned here, based on your tests, and design decisions your test results support.

Data Summary — Describe here in your own words what were the important observations and findings you gathered while collecting your data.

Data — Write down the data you collect here. Showing data in a way that is clear to others is the sign of good science skill and understanding. You can present your data in charts, tables, maps, graphs, or formulas. You might find other ways to display data as well.

What is "Force?"

The word "force" is probably familiar to you. People use it every day, and most everyone has an idea what it means. What do *you* think it means?

My Definition of Force

Share your definition with the class. See if you can all agree on a good statement of the meaning of "force."

In science, words are defined by how you observe or measure the thing you are defining. How would you measure a force on an object? To make it simple, just think about pulling a coaster car.

My Way To Measure Force

How could you measure how hard you are pulling?

Discuss your measurement methods as a class, and see if you can improve those methods.

The Science of My Car

Soon, you will learn the full scientific definition of "force," but that definition has many parts. We can use a simpler definition that will be good enough for now.

> *"Good Enough For Now" Physics Definition of Force*
>
> A force is **a push or a pull on an object.**

Can you think of an example of a force? Try to think of some real situations where objects are experiencing forces. Make a list of all the ones your class comes up with. In each case, be sure to write down the force. In some cases, there might be more than one force.

Every Force Has A Direction

A push or a pull is always in a particular direction. You can show the direction of the force by drawing a picture of the object with a labeled force arrow. The label reminds you which force you are describing.

Rules for Drawing Labeled Force Arrow Pictures

1. The arrow points in the direction of the push or pull

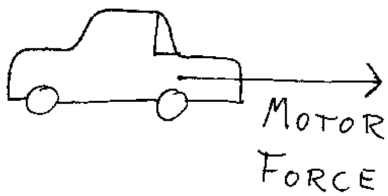
2. The length of the arrow gives an idea of the size of the force (big force = long arrow; little force = short arrow)

3. The label describes what caused the force

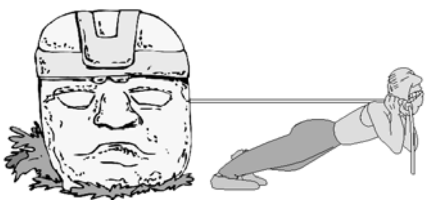
Examples of

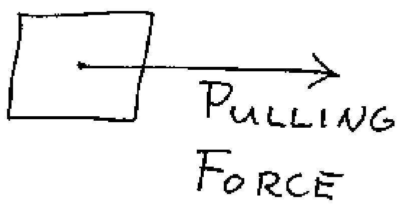
Here are some examples of force arrows.

Situation | **Labeled Force Arrow Picture** | **Force Description**



The car's motor exerts a force that pushes the car forward.



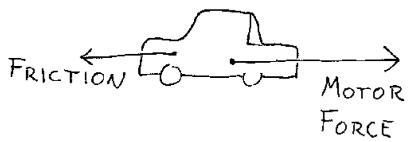
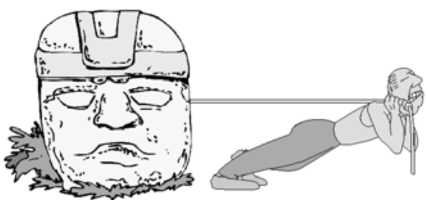
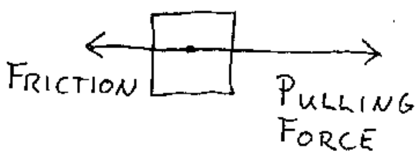
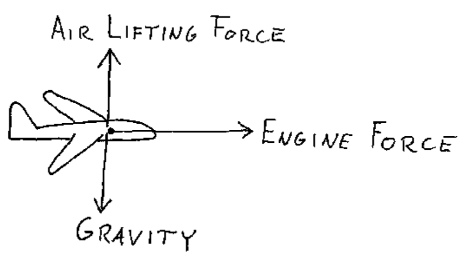


The person exerts a force that pulls the object along.

The airplane's engines exert a force that pushes the plane forward.

Often (in fact, most of the time) there might be more than one force involved.

Force Arrow Diagrams

Situation	Labeled Force Arrow Picture	Force Description
		1. The car's motor creates a force that pushes the car forward. 2. Friction with the road creates a force that slows the car down.
		1. The person exerts a force that pulls the object along. 2. Rubbing against the ground causes friction that slows the object down.
		1. The airplane's engines create a force that pushes the plane forward. 2. The Earth's gravity pulls the airplane down. 3. Force of air on the wings pushes the airplane up.

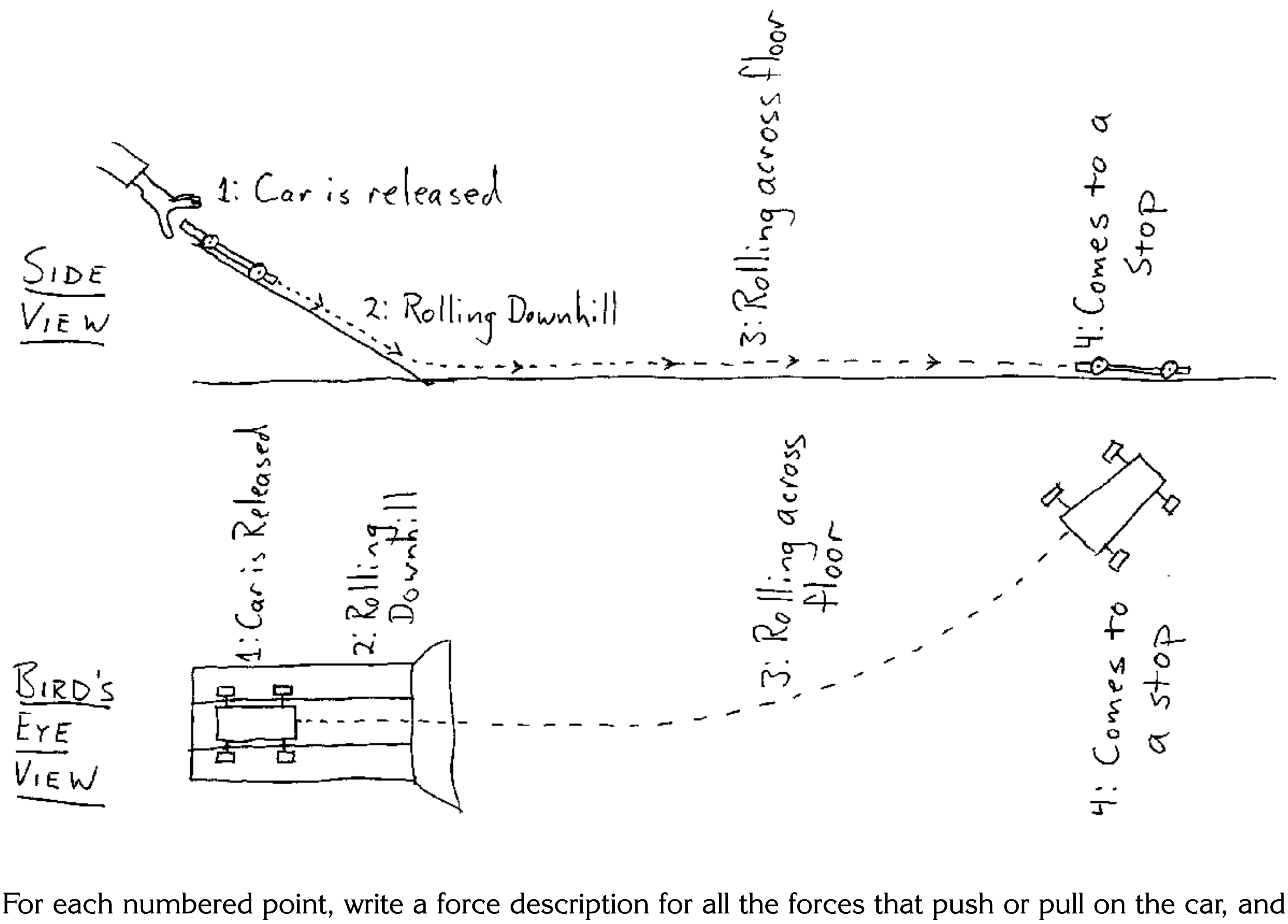
Force Arrow Pictures

As a class, come up with some labeled force arrow pictures for each of these situations:

1. The book support activity
2. One of your tape experiments. Draw the force arrows for when the tape was "holding" and another for when the tape was letting go.
3. Your parachute while it was falling.
4. Some of the toy car situations you explored when you were Messing About
5. The man pulling the big stone head in the picture on the previous page.

For each picture, also write a description of the forces involved.

This is a picture of the path followed by a coaster car.



For each numbered point, write a force description for all the forces that push or pull on the car, and draw a labeled force arrow picture.

Your Turn Now

Reflection Questions

1. Find some real world examples of objects that are experiencing forces. Draw labeled force arrow pictures and write force descriptions for each one. Be sure to find examples of each of these cases:

◊ objects that are moving (3 examples)
◊ objects that are at rest (3 examples)
◊ objects that are just starting to move (2 examples)
◊ objects that are coming to a stop (2 examples)

Share your pictures with the class.

2. Draw a picture of the path your coaster car followed in one of your trials. Pick 6 points along that path. Draw a labeled force arrow picture and write a force description for each point.

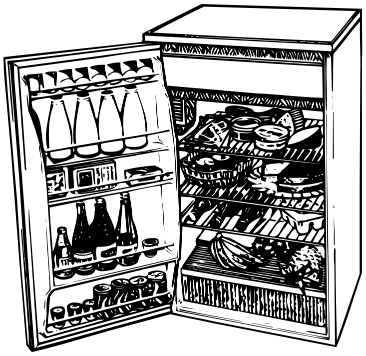
3. From the situations on page 27. what if . . . .

a. . . .the object the person is pulling is heavier. Redraw the labeled force arrow picture.
b. . . .the airplane is going slower. Redraw the labeled force arrow picture.
c. . . .the car has its wheels locked up so they skid instead of turning. Redraw the labeled force arrow picture.
d. . . .the car in the drawing went in a straight line instead of a curve. Redraw the labeled force arrow picture.

Friction is

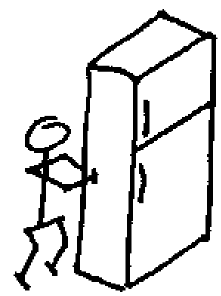
A Heavy Case of Friction

Imagine getting a summer job working for a moving company. You observe that some crews know how to do their job a little better than others. They take pride in doing their work with the least amount of effort. One such crew of two movers must move a refrigerator out of a kitchen with a smooth vinyl floor, then through a carpeted room, and finally out the apartment door. One partner is suddenly sent to another job. His co-worker is left to move the fridge by himself. How can one person move this heavy appliance? Here is how one lone mover did his job: "I knew I had to drag the fridge across the floor – it was too big for me to lift and carry. So, I put a small piece of carpet under the fridge to make it easier to slide across the vinyl floor. When I got to the carpeted room I had to use a dolly (a special cart with wheels) to help me move it to the front door."



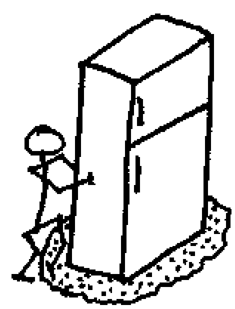
Mover Uses Force

Refrigerators are big and they are heavy. This mover must apply a lot of force to make the fridge move, so he uses a large push or pull to do his job. The fridge not only experiences forces from the mover, but it also experiences forces from the floor. Draw force arrows on the refrigerator, to the right, showing all the forces and the direction in which they act. Do not forget to label your arrows.



Mover Reduces Friction

It will be easier to move the fridge across the floor if the mover pushes harder on the fridge. However, he can only push so hard…there's a limit to the force the mover can create. If he places a carpet under the fridge, he finds that the fridge moves easier too. Again, draw force arrows on the refrigerator, to the right, showing the forces when the mover uses a carpet underneath the fridge. What will be different about this drawing from the one above?



a Force

As you have probably figured out, there is less friction between the fridge and the floor when the carpet is used. Friction is a force that is created when objects that are touching slide or roll past one another. If the friction acting on an object is high, it is tough to slide or roll it past another object. However, if the friction is low, the easier it is to slide or roll it past another object. Draw two examples of situations where an object experiences friction. Label your drawing with a force arrow that describes the direction and size of the force of friction in that situation.

Example 1 **Example 2**

The mover is also trying to create low forces to help him do his job. He created lower friction by using the carpet and then using a rolling cart. Another way to reduce friction is to use lubricants like oil. We use oil in car engines to lubricate the moving parts so that they slide and move easier. For the two examples of friction you came up with, list a way you could reduce the friction in each, and then a way you could increase the friction in each . Also, for each, provide a situation when this would be desirable.

Example 1

Reduce the friction by…

Desirable when…

Example 2

Reduce the friction by…

Desirable when…

Example 1

Increase the friction by…

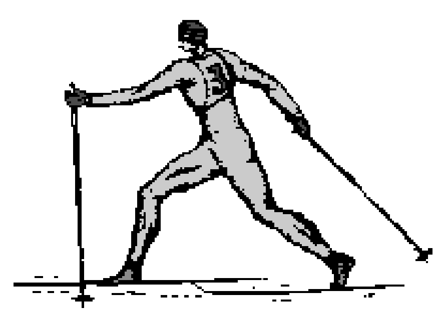
Desirable when…

Example 2

Increase the friction by…

Desirable when…

In the three pictures below, draw force arrows showing the friction in each situation.



Friction is a Force, continued

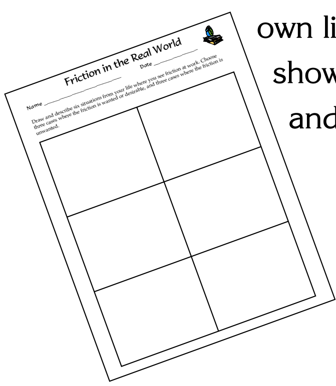
Forces of Friction Homework

As you can see in the heavy mover case, when two objects slide or roll against one another, each slows down and heats up the other. Both slowing down and heating up are caused by friction.
Here are some familiar cases involving friction:

A. A toddler falls on his knees while playing and ruins another pair of pants.
B. A girl riding a bicycle slams on her brakes to avoid a dog in front of her.
C. You squirt oil into the wheels of your bike to stop its squeaking.
D. You rub your hands together to keep them warm on a cold day.
E. You are washing dishes and wear rubber gloves while trying to grip wet, soapy glasses and plates.

Questions to Answer

1. Sometimes you want friction to happen. Which of the five cases above involve desirable or "good friction"?
2. Other cases of friction are unwanted. They happen, but we try to create conditions where as little of this kind of friction gets made as possible. Which of the five examples involve undesirable or "bad friction"?
3. Think up or look for cases where friction is at work in your own life. Use the "Friction in the Real World" sheet to show three cases where friction is desirable and helpful and three cases where friction is unwanted.



Reviewing your Initial Tests

Questions and Suggestions

Here are some questions to think about and suggestions for testing your design ideas.

Did you develop "fair tests" of your ideas? Your tests of different car designs need to make fair comparisons. For example, if you use a test ramp, did you set your vehicle in the same place and height on the ramp? Was the test ramp always in good condition? Another example: Did you do enough trials for each version of the design? Did you change any design partway through the trials? Did you compare a worn out car versus a new car? Does that make a difference? Note anything that you might do better next time you do testing.

Taking **good measurements is critical in testing.** Always decide what you need to measure before running your experiment. Do practice runs of a test before capturing data you will later report. Make sure to write down numbers, the units you measured in, and your reasons for this choice.

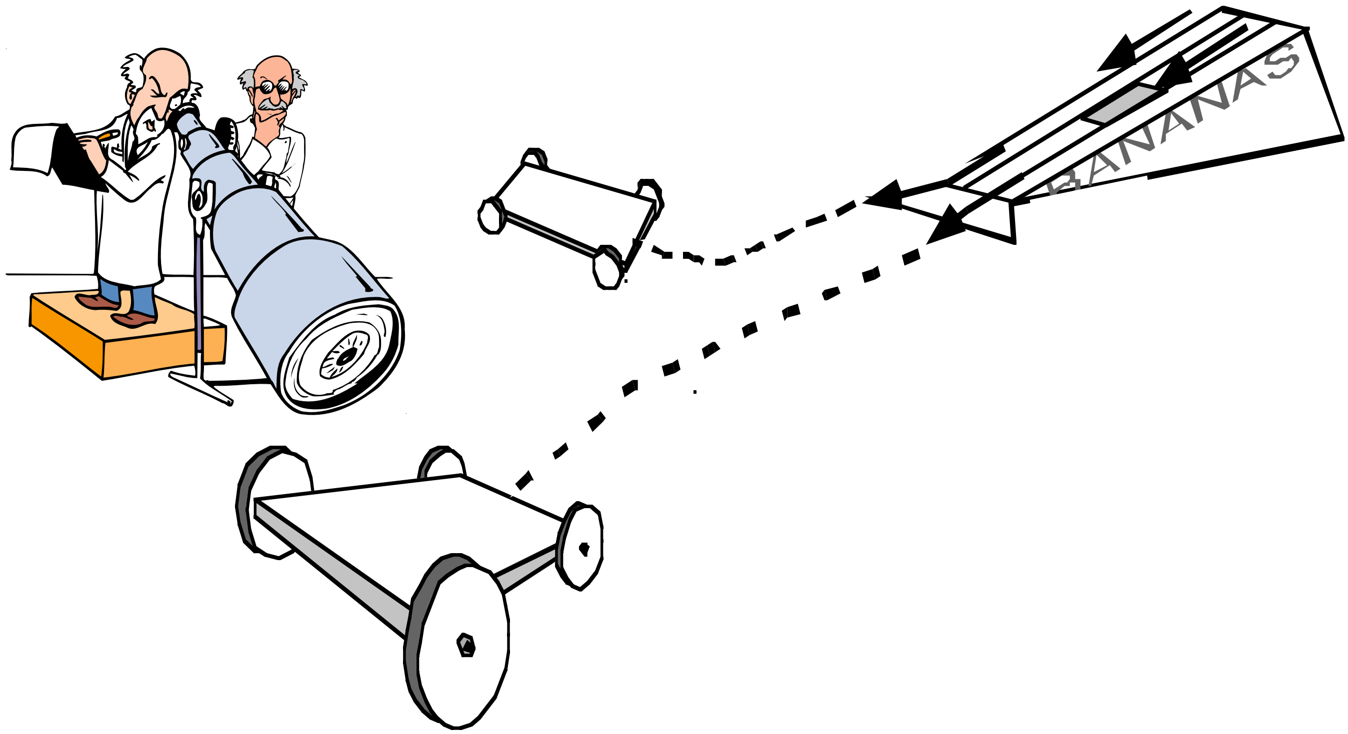
Did you develop tests that help you evaluate your design? Be clear about the things you want to find out, and develop tests that help you learn those things. Remember, good designers will **re-design and re-test designs many times** to come up with the best idea possible. Good scientists will re-design and run an experiment many times to understand better what they are studying.

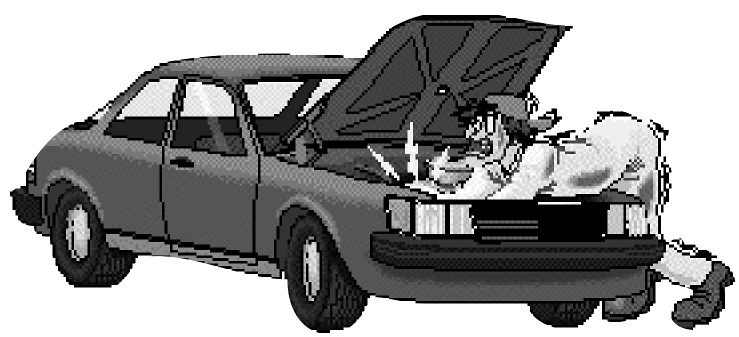
Your project will be assessed on how well **the results of your tests affected your design**. Your tests should help you find out things that lead you to change your design or give you good reasons for staying with a design choice. When you re-design your vehicle, make sure you explain why the change was necessary, and also **re-test the new design as carefully as you tested the old design.** Good tests will also help you understand the science that explains how and why your product works as it does.

Keep these suggestions and questions in your mind as you conduct the next set of tests. Each test should help you to make a future design decison, so make sure you are getting quality feedback from your tests. Continue to use your Testing My Design sheets to record your design changes and test results. You will need to reference these sheets in order to complete future activities and homework.

Debugging
Up-Close Car

Why do some cars go further and straighter than others?
Coaster cars perform differently for two main reasons: (a) the way they were designed, and (b) the way they were built.





You are going to try to discover what is keeping your car from performing at its best. You will be acting a bit like a scientist, a bit like a private eye, and a bit like a car mechanic. Is poor construction ruining your vehicle's performance? Is the way you connected the car's parts affecting how it runs?

Your Cars Inspections

Here are four ways to examine your cars. Whichever techniques you choose to use, write down your observations and offer reasons why your car performed the way it did on your observation sheet.

A. Looking for Wear

Cars that create lots of friction don't travel very far when they run. Yet when the car is in motion, friction is often hard to notice. Sometimes the car might produce a squeaky sound. (Have you heard of this phrase, "The squeaky wheel gets the grease"?) This sound is caused by two parts rubbing together — a source of friction! Over a period of time, friction can also cause wear on the car's parts or body that you can observe. Listen and look for signs of friction and wear. Describe them with words on your observation sheet and draw them on a sketch of your car. Suggest changes to your car that could reduce or eliminate this source of friction.

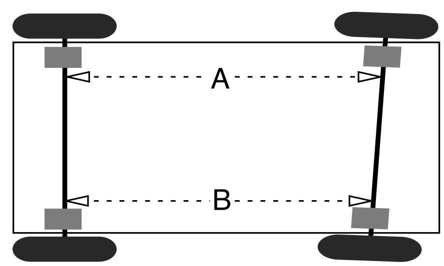
B. Wheel-Spin Test

You can always take your car for a run on the test track to see how well the wheels and bearings perform. A quicker way to test these parts is to turn the car upside-down and do a "wheel-spin test".

Here's how you do it. Hold the body or chassis of your car upside down with one hand, and with the fingers of your other hand, spin one wheel. Make careful note of what you observe on your sheet. How does it spin, and for how long? What do you hear? Compare the performance of the front and rear wheel systems. After you have studied your own car, compare your car's wheel spin results to that of other teams. [<u>Puzzler</u>: How could you make sure your different spin tests were the same every time? How could you improve the way you do this quickie inspection?]

C. Parallel Axle Inspection

With your car turned upside down, inspect by eye and take measurements to see if the car's axles are parallel or not. Use a ruler to check the distances between the axles at different points are equal. Adjust the placement of your bearings and axles if needed.



Make sure that distance A and B between the car's two axles are the same to insure they are parallel.

D. Two-Car Comparison

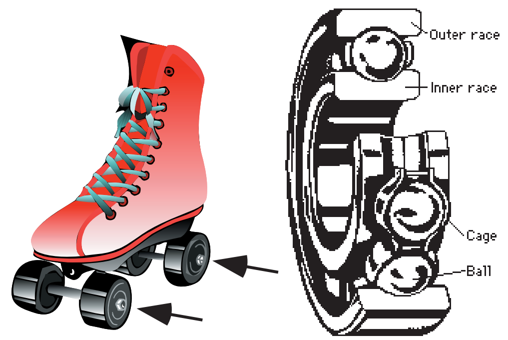
Take two cars with the same design but with very different test results. Record the path that each car travels for a number of downhill tests. Note carefully differences in performance, including distance travelled. Examine both cars side by side, looking for what's different about their construction.

Try to think of other ways you can inspect your cars, and suggest them to the class when you review your findings.

Bearings

Introduction to Bearings

Many products have moving parts that rub against each other. This rubbing results in friction that causes parts to heat up, slow down, and wear out. In order to make such mechanisms move more smoothly and with less friction, designers use bearings.



Most roller skates use ball bearings to improve performance.

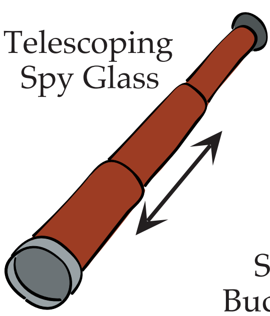
Bearings have two main design criteria or functions: to control motion and to reduce friction. Sometimes the heat from friction is so great that the parts melt together. The amount of friction generated depends on the materials involved, the loads they carry, their speed, and the shapes of their surfaces.

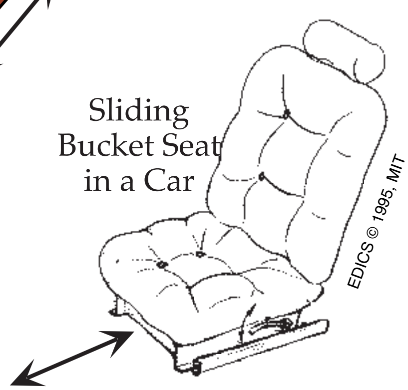
A well known kind of bearing that uses small metal spheres is called a <u>ball bearing</u>. These can be found in products like roller skates and bicycles. With ball bearings, rolling balls are put between two rotating metal surfaces so that the surfaces won't have to slide against each other. Ball bearings are used when low friction and long life are important design criteria. You do not find them used with low-cost products because they are expensive.

Back-and-Forth Sliding Bearings

<u>Sliding bearings</u> are the most common type of bearing and are usually inexpensive to use. They involve two relatively smooth surfaces sliding along one another. Below are some devices that have sliding bearings -- can you predict where the wear in the sliding bearings will appear after the devices have been used for a while?

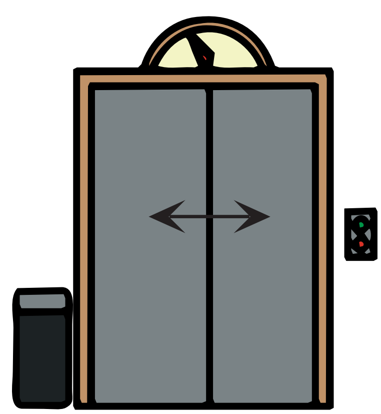
Telescoping Spy Glass





Sliding Bucket Seat in a Car


Sliding Switch

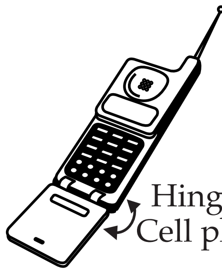

Sliding Doors of Elevator

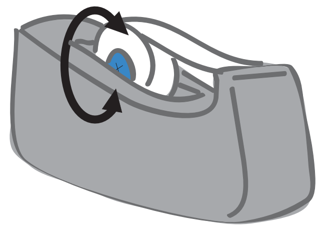
Fact Sheet

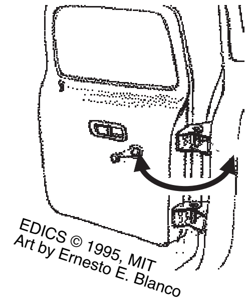
Rotational Bearings

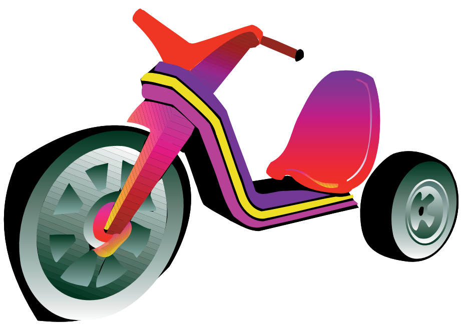
Sliding bearings that move in an arc or circle are called rotational bearings. They are inexpensive to make and can get somewhat dirty without failing. Where is the wear, in each example?

Four Sliding Rotational Bearings

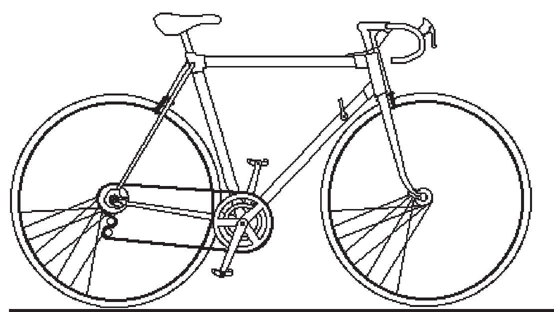




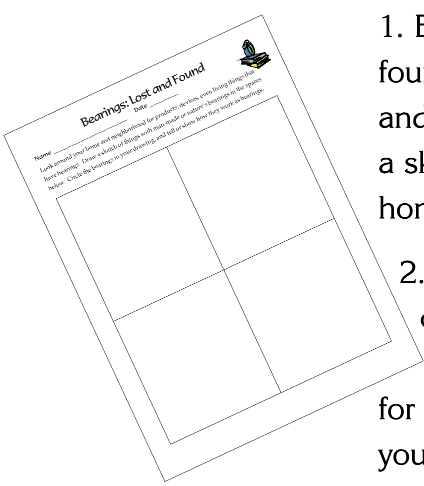




Inexpensive plastic tricycles usually have sliding rotational bearings, while a professional tour bicycle and rollerskate usually have more expensive ball bearings. Can you point out places on each where you think there are bearings?



Homework



1. Bearings are friction-reducing parts that are usually found in mechanical devices. Look around your home and neighborhood for things that have bearings. Draw a sketch of them with the bearings circles on your homework sheet entitled Bearings: Lost and Found.

2. On the back of your homework sheet, make two columns and write out what you think are the criteria and constraints of a good bearing system for your model differences and for the Antarctic car you will be designing.

Making a Better

The building instructions you were given for making your first Coaster Car left plenty of room for improvement. The Factsheets on bearings that you read and others are provided to help you make other decisions. The following are some key features of your coaster car that you might want to redesign:

- bearings (what materials; what shape; what size; how much axle-road clearance);
- wheels (how large in diameter; what material; what surface; treads for wheels or not);
- axle (what material; smooth or with threads); and,
- axle-wheel system (axle spin freely with wheels attached or should the wheels spin freely on a fixed axle; 4 short axles, one for each wheels, or 2 long axles, 2 wheels per axle).

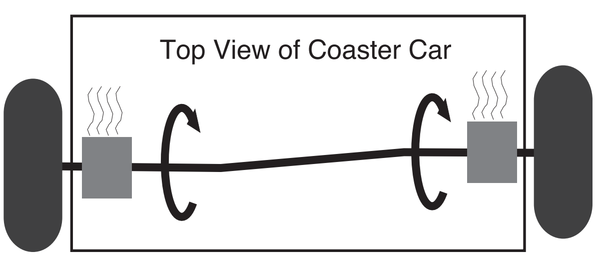
Other changes might also have a big impact on car performance. Feel free to make design improvements allowed by time and by your teacher. Whatever you do, it will be important that you test your ideas so that you can present clear reasons backed up with test data when you explain your redesign work to the class.

Studying toy cars that work well or other products with wheels may give you new ideas for how wheels, axles, and bearings can work together. What follows are ideas to help you in doing this.

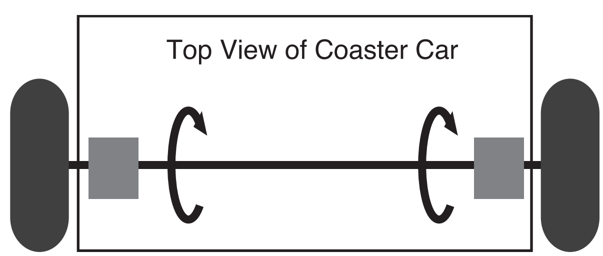
Tips for Redesigning with Bearings

Designers don't do everything through trial-and-error or doing experiments. Sometimes they use design rules of thumb to guide them in what they decide to create. Four design rules-of-thumb you might want to keep in mind when redesigning your coaster car bearings include:

1. The materials used for making the bearings should slide against each other with little friction.
2. The fit of bearings with what they hold must not be too tight or too loose. There should be enough "play" or clearance to allow an item to slide or rotate freely, without excessive movement.
3. The alignment of bearings must be carefully adjusted (see picture below). Bearings should be even with one another so that the axles can rotate freely.
4. Always design with a pair of bearings -- not a single bearing, or 3 or more bearings. Three or more bearings are hard to line up, and can cause too much friction.



Bearings that don't line up create lots of friction and heat when the axle rotates



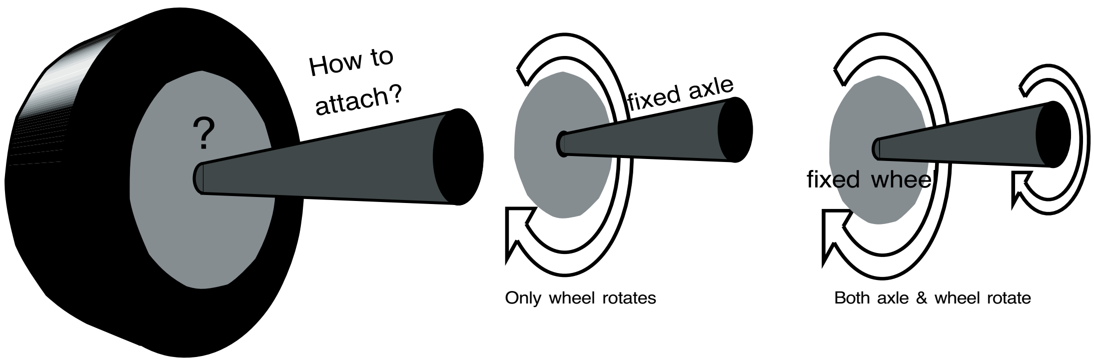
Bearings with good alignment have less friction

Car by Design

Choosing a Wheel-and-Axle Subsystem

You and your design team may have already thought about this, but there are two ways designers of coaster cars can have wheels attached to an axle. They are:

1. Wheels locked tightly to axle — when the car moves, the axle-and-wheel system turn together as a unit. This is how your original design worked.
2. Wheel spins freely on fixed axle — when the car moves, the wheels spin, but the axle does not move. This is called a fixed-axle system.



Be ready in class to point out where you think there will be friction in the two systems shown above. *Hint:* To answer this, try to visualize which parts will slide against each other. From this, you might be able to say which will result in less friction. Make a prediction with a reason for which system will work better. Run tests to find out if your prediction is right.

Bearings for the above two wheel-and-axle systems are constructed and work differently from one another. You have seen three bearing systems for the first approach in the building instructions on page 15. What kinds of bearings would work for the first-spinning wheels approach? How could you test this? Do you remember seeing toy cars with fixed axles and free-spinning wheels? What approaches did the designers of these cars use to reduce friction?

Homework

How much of your coaster car's workings do you understand? What can you explain to others? For homework, draw a diagram of the car. Point out and label the different subsystems you see operating in it. Explain how each works by showing the parts (structure), how they connect to one another, and how what forces make the mechanisms move. Label key components, and describe what you think the role and function of each is.

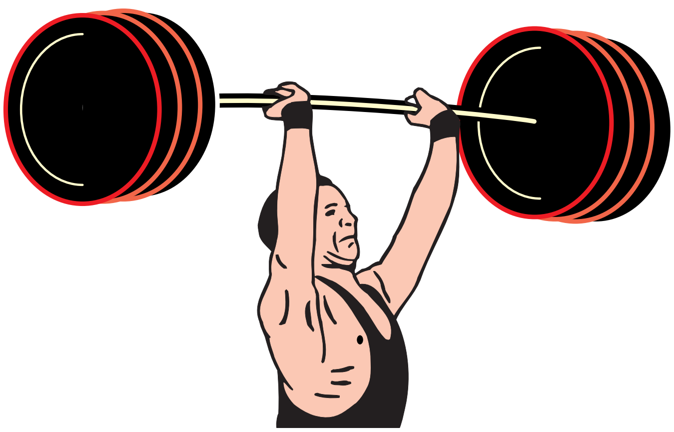
Where Do Forces Come From?

Earlier in this section, we defined a force as "a push or a pull." We said that it was a good enough definition, but that we would make it better over time.

At that time, you probably imagined personally grabbing hold of something and pushing it around. You might not have even thought much about that mental image since it is so obvious, but it is an example of a very important point that has to be part of a good definition of force.

A Better Science Definition of Force: A force is **a push or a pull** that comes from an **interaction between two objects.**

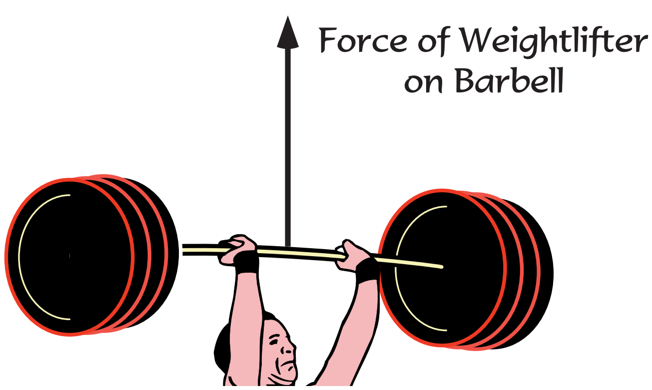
Many (but not all) interactions happen because the objects are touching. Here are a couple of examples:

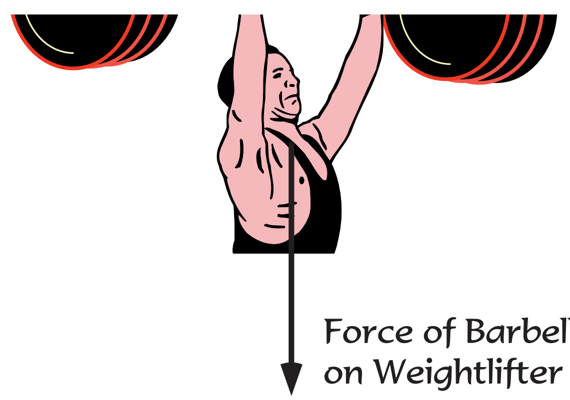


The weight lifter is interacting with the barbell by touching it. We can imagine a force on each object that is part of that interaction:

◊ Force on the barbell: The weight lifter exerts an upward force on the barbell by pushing to lift it.

◊ Force on the weightlifter: The barbell exerts a force on the weightlifter, because of its weight, pushing down on him.

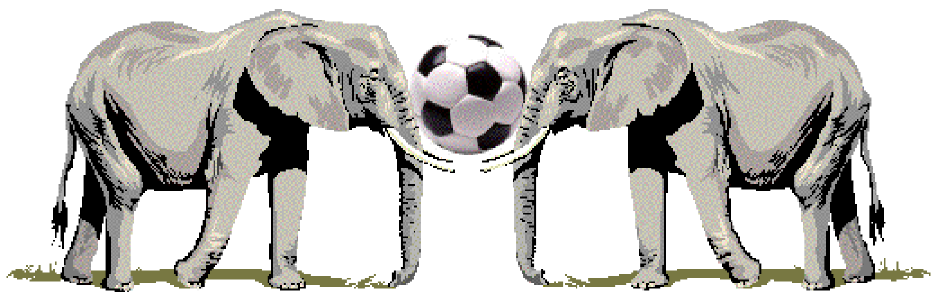




More About Forces

You Try It

How many "touching" interactions can you see in the elephant picture? As a class, make a list of them all. What forces happen because of those interactions? Which objects do the forces act on? Draw force arrow pictures for each object.



There are a few examples (but not very many) of forces that can happen at a distance, without touching. Gravity is an important one. If you throw a ball up in the air, the Earth's gravity pulls it back down even though the Earth is not touching the ball. We should add gravity to the force arrow picture of the barbell.

If you haven't already done it, add gravity arrows as needed to the elephant and soccer ball picture.

More About Forces

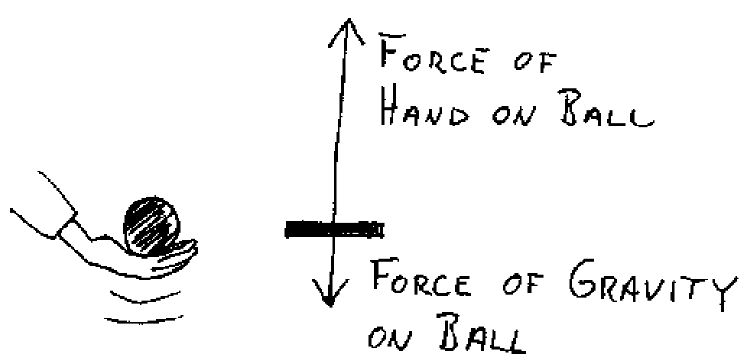
This definition of force contains a very important rule of thumb for forces:

Force Identification Rule of Thumb

Since all forces come from interactions, if there is no interaction then there is no force.

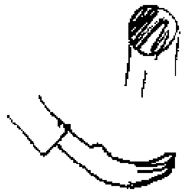
Here are a couple of examples:

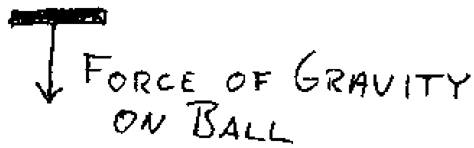
While you are throwing the ball, it is interacting with your hand. You exert an upward force on the ball, and gravity exerts a downward force on it.



Continued

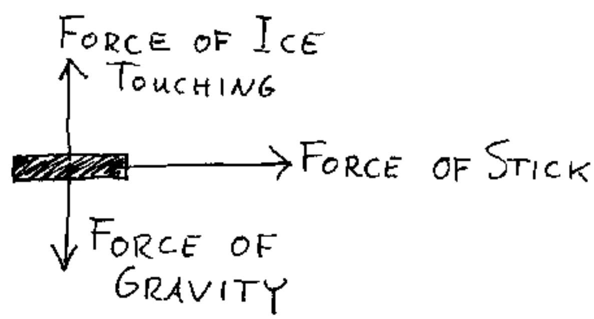
While the ball is flying through the air, it is not interacting with your hand since it isn't touching your hand. That means that the upward force goes away and only gravity is left.



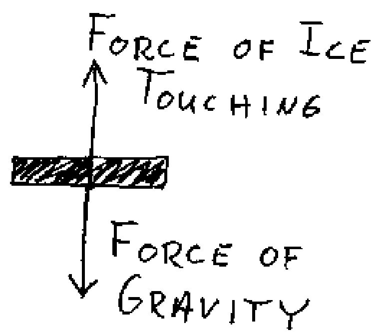


When the hockey player hits the puck with her stick, the puck is interacting with:

◊ the stick
◊ the ice
◊ the Earth (gravity)



After the puck leaves the stick, the only interactions left are with the ice and the Earth.



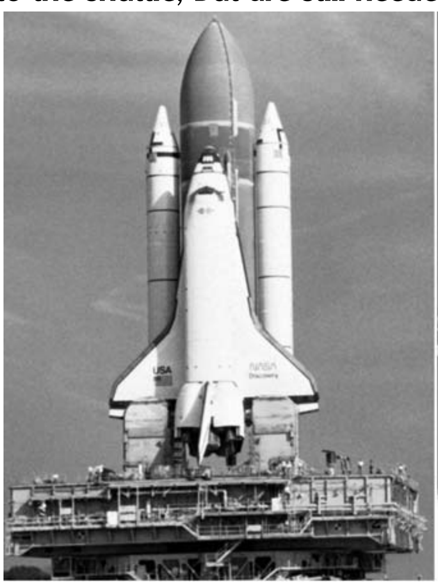
As a class, return to the examples and force arrow pictures that you did before with the "good enough for now" definition of force. Identify the interaction that causes each one. It helps a lot if you draw a picture of your example. If you can't find an interaction to go with a force, then it is probably not a force after all. Revise your list and force arrow pictures to get rid of those. If you see any interactions that you missed before, be sure to add those forces.

Seeing Systems

You have just learned that bearings come in all shapes and sizes. Some bearings are cheap while others are expensive. Some slide while others use rolling. All bearings aim to lessen friction for certain kinds of motion, while restricting other kinds of motion.

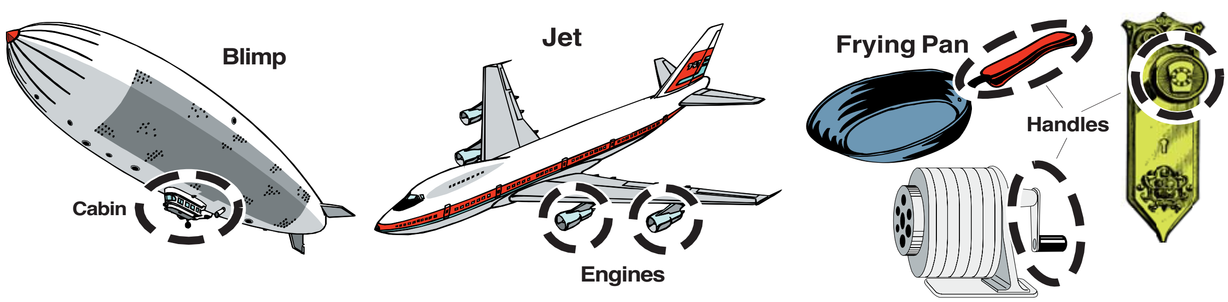
In the car you have built, the bearings help give with the wheels and axles of your car the capacity to coast. When different parts of a device (wheels, axles, bearings) work together to serve some function (coast), those parts make up a <u>sub-system</u>. A sub-system is a system within a system. The coaster car has two wheel-axle sub-systems in it. What other sub-system does your car have? What function does it serve?

The shuttle spacecraft is made up of many different systems that help make it work. Which ones do you see or can you identify in the pictures below? Are there sub-systems that are not even attached to the shuttle, but are still needed for it to operate? (Hint: Think back to the case in <u>Apollo 13</u>.)



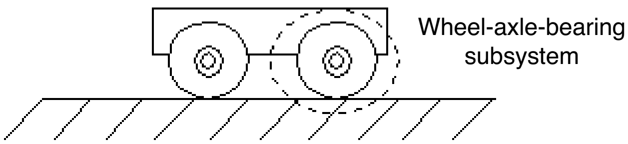
How many different sub-systems can you pick out in this picture of the space shuttle? On a separate sheet of paper, make a sketch of the shuttle, and then draw a circle around three subsystems you've identified. Come up with a question you could investigate about each.

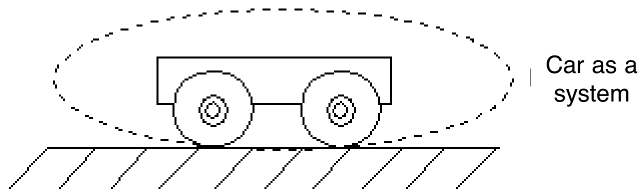
Just like a spacecraft, a car is a system made up of smaller sub-systems. Sometimes you might focus on one system while ignoring the others. It helps to "see" a sub-system by drawing a boundary around it. This dotted boundary line, or system balloon, tells others how you understand the way a device works, by grouping parts of a device with a shared function together.



in a System

Picking out the sub-system can be important because it can help you focus on key parts of a complex design and ignore the rest. Drawing the system balloon can help you study a car more easily and help you figure out better how it works. If you want to study how friction is affecting your car's performance, you would draw a circle around the wheel-axle-bearing sub-system and then focus your attention on it, and things forces that affect it what's inside the balloon. If you want to study what makes your car go down the hill when you launch it, you need look at the effects of gravity on the whole car, and so would draw a circle around the whole car. You only would then study the forces from outside that circle that were acting on what is inside the circle.

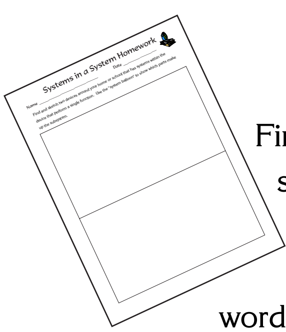




If you wanted to study how much of a load your car could handle, what would you put a circle around and then study?

You've seen systems in the Apollo 13 unit. Remember the parachute challenge you solved for it? If you wanted to investigate what makes a parachute slow down, you might want to focus your attention by drawing a dotted balloon around the parachute cloth or canopy .

You could then ask, "What forces are acting on this 'chute?" The circle would remind to concentrate only on that part of the whole device. Suppose that you wanted to investigate whether the parachute passenger would survive upon hitting the ground. What subsystem would you study, and around what would you draw your circle?

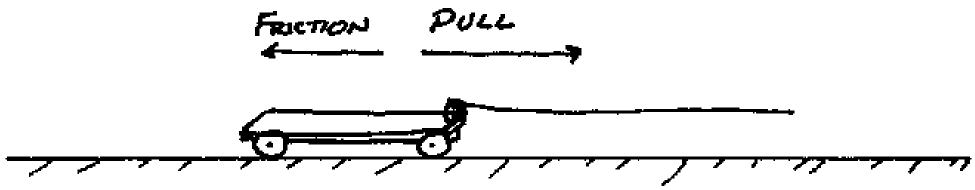


Homework

Find two examples of objects around your house that have systems inside of a larger system. Make a sketch of each example onto your "Systems in a System" activity sheet. Then draw a dotted balloon at least two of the subsystems and describing in words what they do.

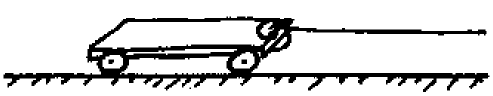
Combining Forces

You have been looking at and discussing situations where objects experience forces. You have learned how to label forces with force arrows, and you have probably noticed, in many situations, that forces occur simultaneously. For example, let's say that we have a coaster car with a string tied to it. The string is used to pull the car across the floor. During this event, the car experiences a force of propulsion from the pull and a force of friction from the floor.



Obviously both of these forces have an effect on how the car moves. If you pull hard on the string, the car will move forward more quickly. If you make the surface of the floor very rough or sticky, the car will resist moving forward. When these types of changes take place, we need to change the force arrows that represent the forces. On the two sketches below, draw new force arrows on the car according to the changes indicated above each sketch. Remember that the length of the arrow communicates something about the size of the force.

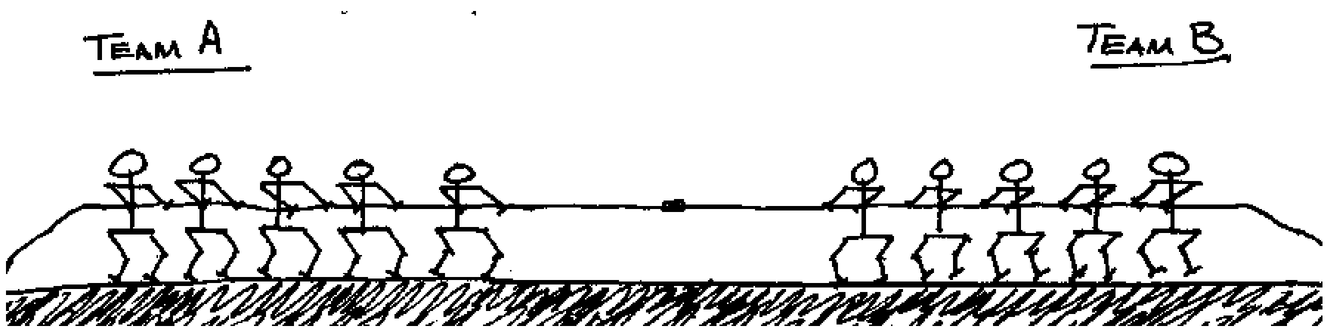
<u>Increase the pull on the string</u>



<u>Increase the friction from the floor</u>

and Net Force

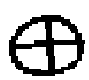
Identifying the forces acting on an object in a situation is important, but you also need to understand what these forces do together. Let's look at a familiar event…Tug-of-War. The object we will focus on is the rope. Team A and Team B are matched up. Each team has 5 members. Let's say that each participant in the Tug-of-War pulls on the rope with the same amount of force. Therefore, each team member represents **one unit of force**. In this picture draw force arrows that accurately show the forces acting on the rope. *Hint: The length of a force arrow represents the size, or magnitude, of the force. How does each team's force compare in size?*



Force Diagram Tips

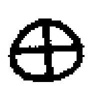
1. When we draw force diagrams or pictures, we only focus on **one** object. Even though there may be several objects involved in a situation, <u>we can only draw a force diagram for one object at a time.</u> In our Tug-of-War situation, we have many objects: the rope, the teams, and the individuals. However, for now, we are only concerned with the forces on the **rope**. *In a force diagram, only draw forces acting on* one single object.

2. When we draw force diagrams for objects, it is not necessary to draw a detailed picture of the object. You can draw a simple sketch, or you can use a special symbol to represent the object.



Near the symbol, indicate what it represents. However, be sure to leave plenty of room to draw the force arrows.

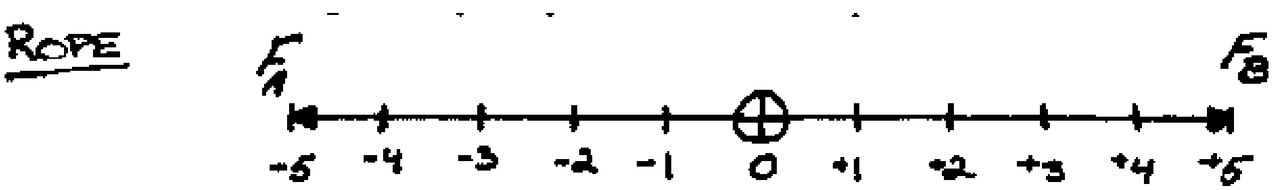
ROPE



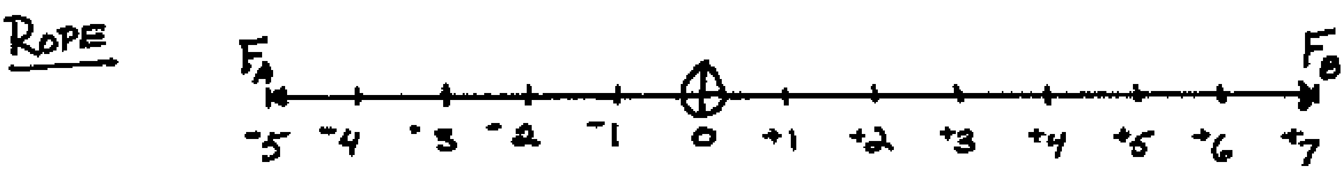
Combining Forces

Here is the force diagram for the Tug-of-War using the symbol.

If Teams A & B have the same number of members, pulling equally as hard, then the force arrows should be the same length. You can use a ruler or draw the force arrows along a number line using the object symbol as the zero point to make sure that the arrows are correct.



Let's say two people join Team B so that they have 7 members now. Notice how the diagram changes.

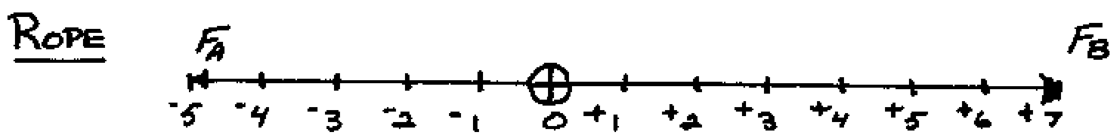


How would it change if Team A also **lost** 2 players? Draw the new diagram below.

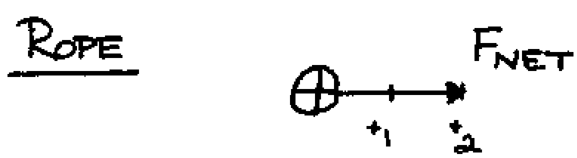
and Net Force, continued

In these situations with the Tug-of-War, can you predict what the outcome would be? If one side pulls with 2 more units of force than the other what would happen? You probably have guessed, correctly, that the team with the greater total force would win the match. The question is why? Many people assume that the greater force from one side wipes out or eliminates the smaller force so that it is the only force acting on the rope. Forces do not behave like this. Both teams have an effect on the rope, and the rope experiences both forces throughout the match. In order to correctly predict what will happen when an object experiences many forces we draw a **net force diagram. A net force is the force acting on an object as a result of adding together** all **the forces pushing or pulling on the object**

The net force diagram can be drawn only *after* the original force diagram has been drawn. Let's return to the Tug-of-War. Team B has 7 members and Team A has 5. Each team member represents a unit of force. The force diagram would look like this:



If we treat the arrows like integers on a number line, +7 and –5 combine to equal +2. So in the end, when we combine all the forces acting on the rope, the rope acts as if it was only experiencing a force of 2 units toward the right. We draw and label this diagram like this:



This would be the **net force diagram** for this situation.

Now you try. Create a force diagram and then a net force diagram for Team B having 6 members and Team A having 3 members

<u>Force Diagram</u> <u>Net Force Diagram</u>

Combining Forces

On a separate sheet of paper, create the Force Diagrams and the Net Force Diagrams for the following situations.

1. A coaster car is pulled with 7 units of force but experiences 3 units of frictional force in the opposite direction.

2. A parachute falls to the ground with 5 units of gravitational force but experiences 1 unit of air resistance force (known as drag) in the opposite direction.

3. Create a situation and draw the force diagram for an object that has a net force of 3 units to the left.

4. Create a situation and draw the force diagram for an object that has a net force of 1 unit in a down direction.

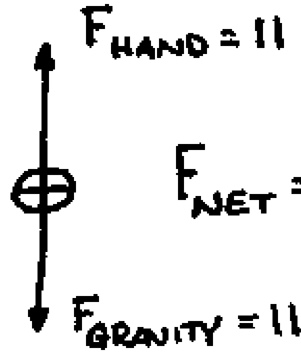
5. A ball is held in the flat hand of a person. The force of gravity is 11 units, and the force from the hand underneath the ball is 11 units.

Discuss these situations as a class before you continue reading. Check your answers with your classmates and your teacher.

Net Force and Motion

Did you notice something unique about the last situation listed above? It was probably very easy to draw the force diagram, but difficult to figure out what the **net force** diagram looked like. Since both forces are equal in size and opposite of each other, there is no remainder, or net, force to act on the ball. What do you suppose the reaction of the ball is to this type of situation?

The ball remains in the person's hand. We do not see the ball move or change its position. The forces acting on the ball balance each other, and therefore, **there is a zero net force**.



and Net Force, continued

Try to write a statement that explains the relationship between zero-net-force and the ball's motion. Discuss the statements you and your classmates create.

Try to think of two situations where an object has all of the forces balanced to produce a zero net force. Draw and label the force diagrams below.

Combining Forces

If the person holding the ball were to remove their hand from under the ball, we know that the ball would begin to fall toward the ground. That's because the forces are no longer balanced. The force of gravity in this example was stated as 11 units. The force from the hand was also 11 units. But, once the hand is removed, only air resistance is pushing up on the ball. This force is much less than 11 units. Let's say it is only 2 units. Draw this force diagram and then draw the net force diagram.

Try to write a statement that explains the relationship between the ball's motion and the existence of a net force acting on the ball. Discuss the statements you and our classmates create.

The net force acting on the ball is 9 units in the down direction. So now when there is a net force we see the ball change its motion (going from resting to moving). When the hand moves away, the ball begins to fall, but isn't something about the net force changing too? Try to write a statement that explains the connection between forces that are balanced or unbalanced and changes in an object's motion.

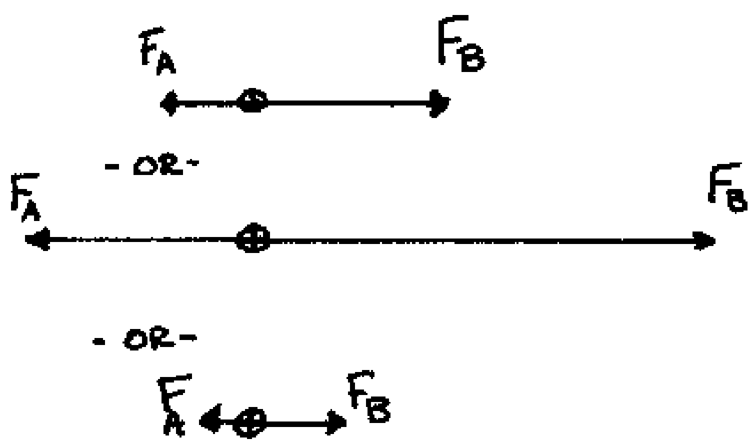
and Net Force, continued

Important Information About Force Diagrams

You have been reading about how to draw good force diagrams. You now know that it is important to make sure that the lengths of the force arrows accurately represent the size of the force. We have told you to use rulers and/or number lines to help you draw force arrows. These are good practices, but it is not always necessary to use such specific lengths. You can draw force arrows without worrying about the exact length of the arrow.

We draw force diagrams to discover and analyze all the forces acting on an object. We want to know not only what forces are present, but how they compare to each other and how they affect the object. In the Tug-of-War, let's say that Team B has 8 members and Team A has 4.

Team B has twice as much force as Team A. However, we can draw force diagrams of many different sizes, but **the arrows must accurately represent the forces involved**.



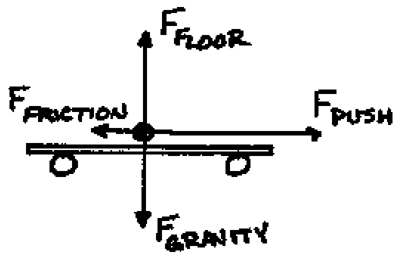
All of these diagrams are legitimate diagrams because the force arrow of B is always twice as long as the force arrow of A. If Team B were to add 4 more people, what would change about the force diagram? Below, draw what this diagram would look like **without** using a number line. Try to draw the force arrows correctly relative to each other.

Is your force arrow for Team B 3 times the length of A? Should it be?

Combining Forces

More on Net Force Diagrams

Many times an object experiences forces that are not always opposite to one another. For example, your coaster car experiences force in many directions as it is pushed or pulled across the floor. Remember, forces are created when two objects interact.



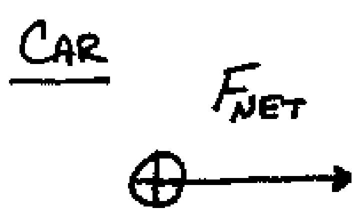
The car experiences…

- a push forward (interaction between the hand and the coaster car)
- some friction backwards (interactions between the floor, bearing, axles and car)
- gravity pushing down on the car (interaction between the earth and the car)
- a push up from the floor (interaction between the floor and car in a vertical direction)

This last force may seem confusing…how can the floor be pushing on the car? You will learn more about this force later. For now, think of it this way, if the floor did not resist the force of gravity, then wouldn't we see the car falling through the floor?

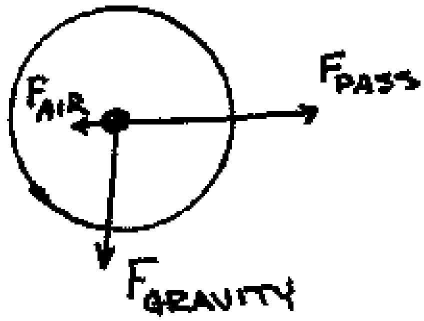
We know that in order to understand what might happen during this situation, we use the force diagram to draw the net force diagram. Look for arrows that are opposite of each other and determine how much of the large arrow is left over when you combine the effects of each arrow.

Car, Net Force Diagram
The upward force of the floor and the downward force of gravity cancel each other out, and the push is larger than the friction. The result is a good estimate of a net force to the right that is a little smaller than the force from the initial push.



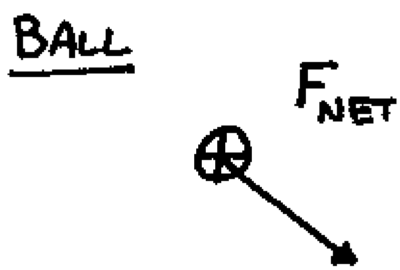
and Net Force, continued

<u>Ball, Force Diagram</u>
Think about a basketball being passed using a chest-pass. Again, we see all kinds of forces in different directions.



The ball experiences…
- a push forward (interaction between the hands and the ball)
- gravity pushing (interaction between the earth and the ball)
- a small push backwards, air resistance (interaction between the air and the ball)

<u>Ball, Net Force Diagram</u>
The force from the push pass is opposed by a small force of air resistance. Gravity has no opposition. The net force is forward and down at the same time, so the net force arrow represents both of those directions.



<u>Your turn….</u>
Draw the force diagram and net force diagram for the following situation: A parachute falls toward the ground, but there is also a large left to right wind that seems to be blowing the parachutist toward the right as he/she falls. Discuss your drawing with your classmates and teacher. Try to decide what the correct drawing is through class discussion.

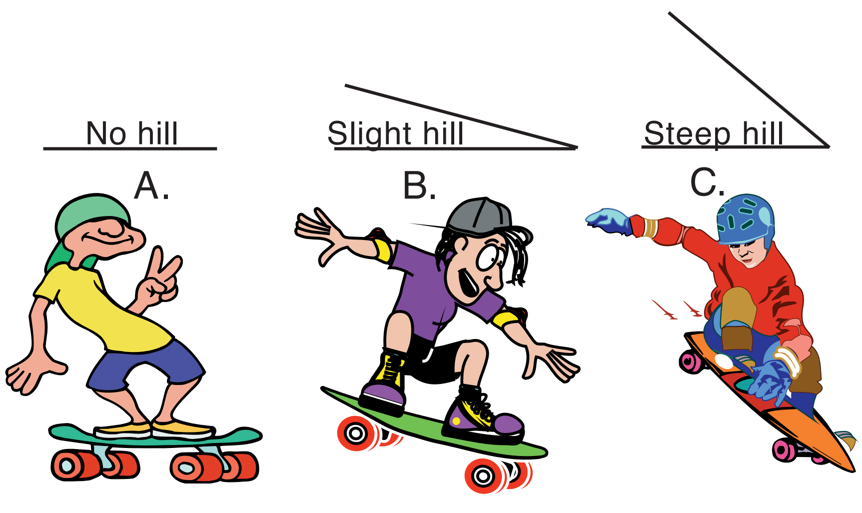
The Science of Coaster Cars:

Earlier, you studied what makes a coaster car slow down. But what makes your coaster car move in the first place? What is its engine? What gets it going? The answer is that the coaster car has help from the outside.

Some toys run on their own power -- they have batteries included, a wind-up spring, or a stretched rubber band. Others, however, require children to give them a forceful push to get the vehicle moving. But will the push be the same every time? If one car gets less of a push than a second car, is it fair to compare two cars' coasting abilities?

Another approach, the one you used, is to put the coaster cars on a sloped ramp and let gravity move them. Why is that a fairer way to test coaster cars? And how does this work?

Let's look at the familiar case of a skateboard going down a hill, where gravity helps make the board and rider move.

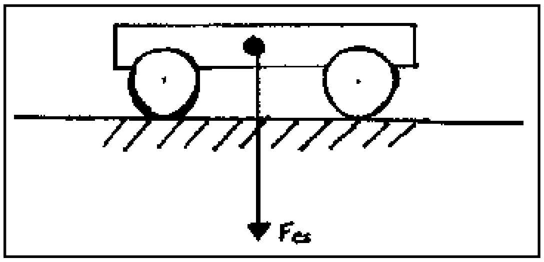


Different slopes yield different net forces that either
move or don't move the skateboarders forward

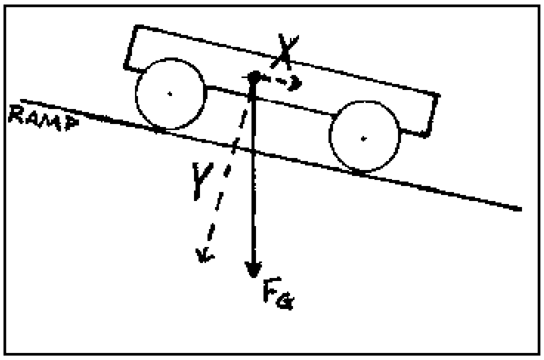
In situation (A), the skateboard doesn't move (unless the boarder pushes off with his foot, or gets pushed). When a skateboarder is on flat terrain, all of the force of gravity, or weight, is directed straight down -- none is directed forward. The skateboard doesn't move because the ground is in the way. (Actually, the downward force of gravity is canceled by the force of the ground pushing up!) When on a slight hill (B), a small amount of gravity pulls the boarder forward. The steeper the hill (C), the greater the forward force from gravity to go down the hill. Everybody knows this but why does it happen? We'll zoom in and look at coaster cars more closely to explain.

How Gravity Works as an Engine

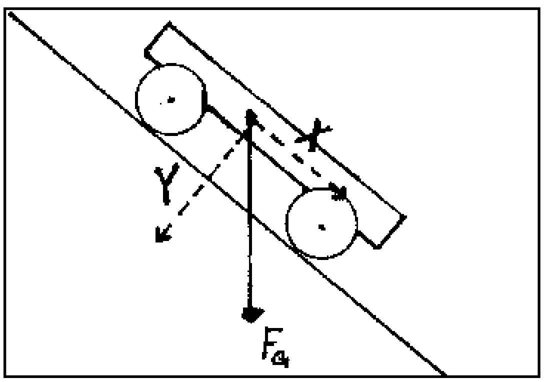
Imagine a coaster car on a ramp. The force that propels the car down the ramp is gravity, and gravity always pulls toward the ground (or floor) no matter what the slope of the ramp might be. However, we know from experience that if we increase the slope of the ramp, the car will roll faster down the ramp, just like the skateboard on a steep hill. Let's look at the coaster car in three situations to see why the slope of the ramp makes a difference even when the direction of the gravitational force is always the same.



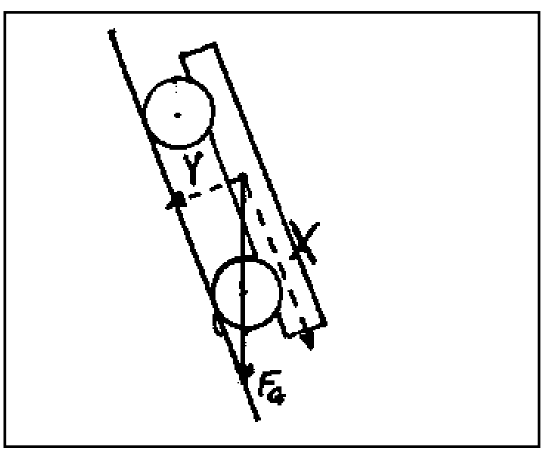
Gravity (force arrow F_G) pulls down on the car. No portion of the force acts in the direction you would like to see the car move…forward!!



Gravity (F_G) is still pulling down, but now we divide that "pull" into two portions. X is the portion of gravity that pulls the car down the ramp. Y is the portion of gravity that pulls the car into the ramp's surface. Notice that the length of the force arrow for the gravity (F_G) has not changed. That's because the force of gravity pulling on the car has not changed because it is the same car.



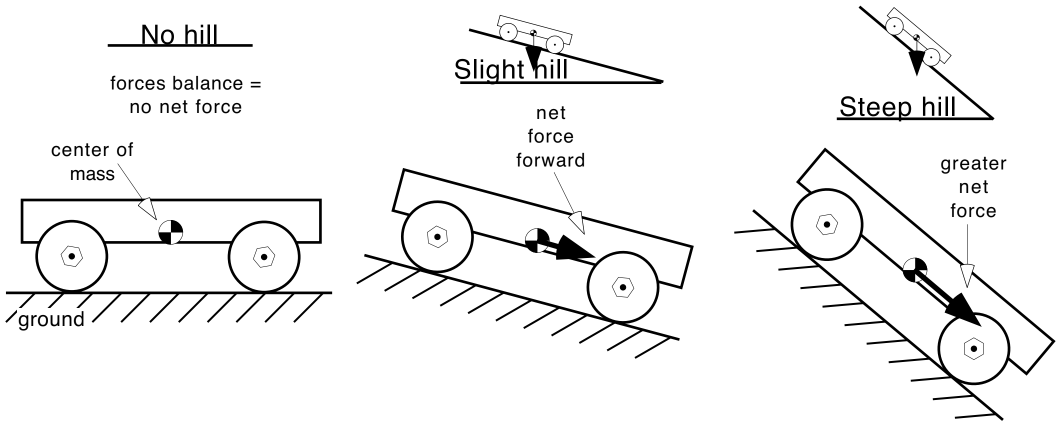
Notice the changes from the diagram before. With the steeper ramp, the X portion of the gravity is larger than it was before, and the Y portion is smaller. So, a larger portion of the gravitational force is pulling the car down the ramp, and a smaller portion is pulling the car into the ramp. Notice that the length of the force arrow for gravity (F_G) still has not changed.



With a very steep ramp, a majority of gravitational force (F_G) pulls the car down the ramp (X), and only a small portion goes to pulling the car into the ramp's surface (Y).

Net Force and

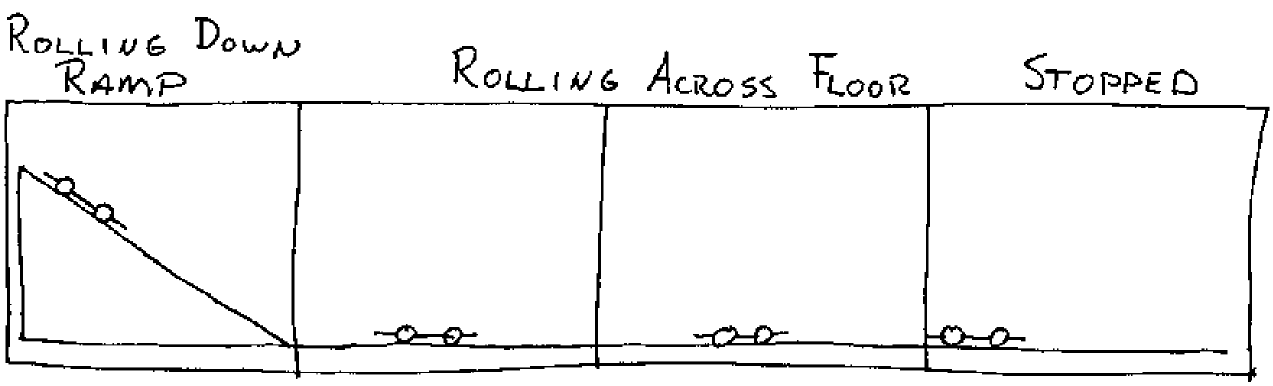
A Review So what is the net force acting on the coaster cars when they rest on flat land or “hit the slopes”? The figure below shows the net forces on the cars -- and shows that gravity acts in a similar way on the car as the skateboarders.



Extra Mile Question
How would you have to position the ramp to maximize the amount of gravity used to pull the car down the ramp and minimize the amount of gravity used to pull the car into the ramp? Write your answer below and discuss this with the rest of your classmates.

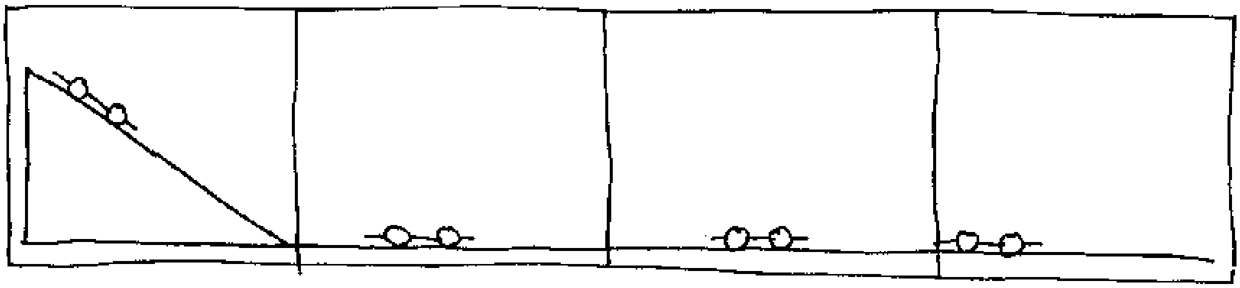
Your turn...

You've seen several examples now of identifying forces from interactions and using them to find the net force. Try it with your coaster car problem. The picture below is a side view of the ramp and floor that your car is rolling along. It is divided into four sections. We call these types of pictures Motion Storyboards. For each section in the Motion Storyboard, draw force arrows on the picture that match the forces acting on the car.



my Coaster Car

Now, use your force arrow pictures to help you decide on a single arrow that shows the *net force* on your car in each section. Make sure the class agrees on what these pictures should look like.



Reflection Questions

1. What if . . .
a. The ramp was steeper? Redraw your pictures to show the forces and net force in this situation.
b. There was more friction when the car rolls across the floor? Redraw your pictures to show the forces and net force in this situation.
c. The car was heavier? Redraw your pictures to show the forces and net force in this situation.

2. Think of a personal situation where you were moving and experiencing forces. For example, you might have been roller skating, or playing football, or slipping on a banana peel in the cafeteria. Tell a story about this experience by drawing pictures like the ones for your car. Draw one series of pictures that shows all the different times when you experienced forces. Then draw another series that shows the net force on you at each of those times. Share your stories with the class. Make sure everyone can agree on the forces as well as the net force.

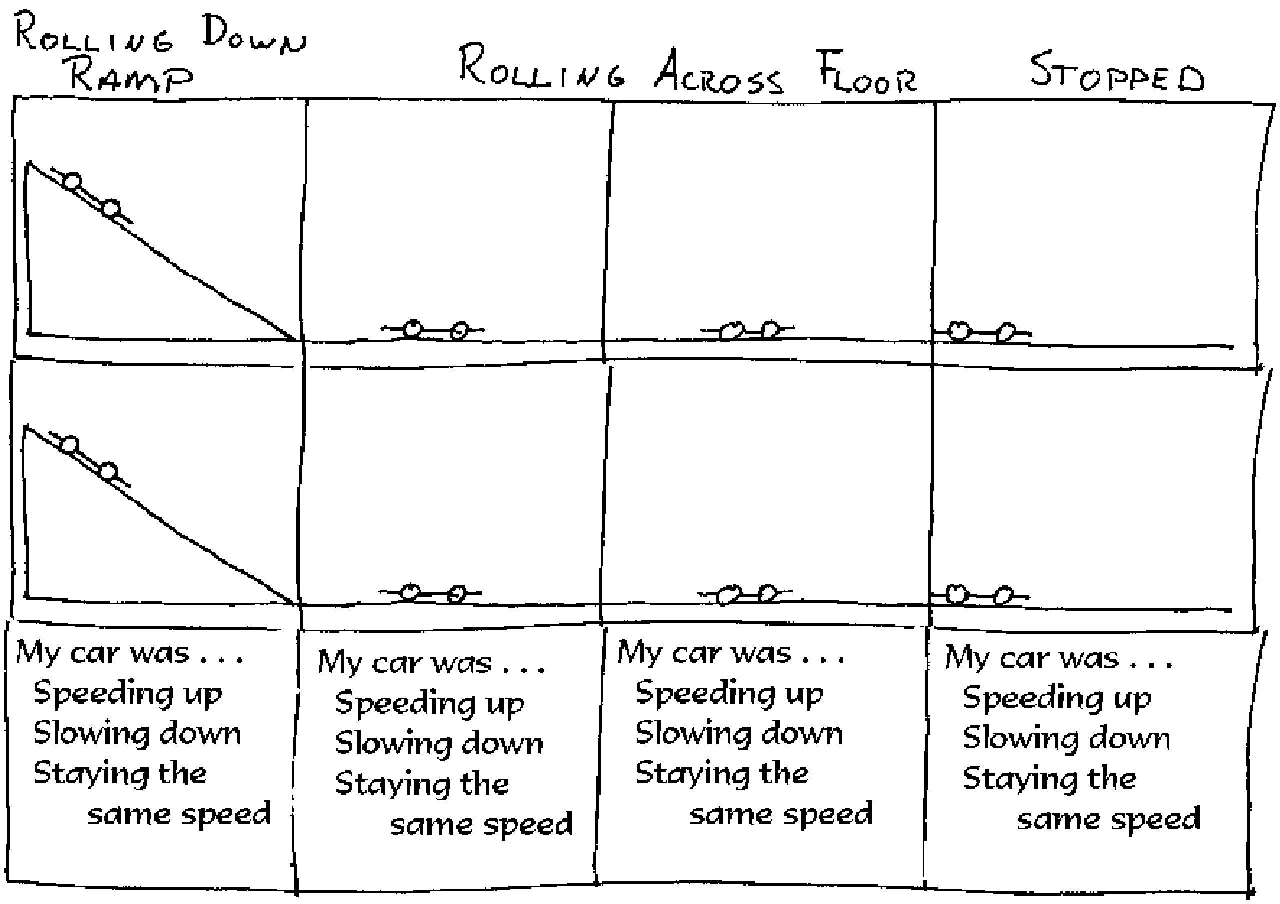
Your Car's Motion Storyboard

Look at the "Testing My Design" sheets you have created, and create a motion storyboard for each that describes the forces acting on your car for each design. Remember, as you made changes to the design, you changed the forces acting on the car .... mostly the friction. Make sure that your Motion Storyboards accurately show the differences between designs. (Hint: the directions of the forces might be the same, but what about the size of the forces from one design to another?). Create these storyboads on separate pieces of paper...you will have to add rows to them later on.

Discuss your storyboards with your group members. You might have to present your storyboards in a poster session. Look for differences and similarities between your storyboards and those of other students. How might studying and dicussing other storyboards and design help you?

How Does Net Force Affect

You just thought about the forces that your coaster car was experiencing and how they combined to make a net force on the car. Recopy those force arrow and net force pictures onto the frames below.



Now think about how your car was moving as it traveled over the test track. Was it speeding up, slowing down, or staying at the same speed? Circle your choice for each frame.

What direction was the net force when the car was speeding up? What about when it was slowing down? Which force was mostly responsible for the speeding up or the slowing down? Was it gravity, friction, or some other force?

My Car? Force and Motion

Reflection Questions

1. How far did your car coast from the bottom of the hill to the point where it stopped? Suppose that you could cut the friction force in half by oiling the bearings in your car. What do you think the new coasting distance would be? Draw a new picture to show the force arrows and net force for this case (you might need to add some extra boxes).

2. Suppose you found an even better kind of oil that made the friction 1/10 of what it was to begin with. How far do you think the car would coast with the new oil?

3. You can't ever get rid of friction. It is always going to affect your car. But imagine a world where you could make friction go away. Suppose you found a perfect kind of oil that made the friction force zero. How far do you think your car would be able to coast with the perfect oil? Explain your answer using a force arrow picture and a net force picture.

4. Think of a situation where you were experiencing forces. For example, you might remember riding your skateboard or falling down in the cafeteria. Draw a sequence of frames like the one on the previous page that shows the force arrows, shows the net force diagram, and describes how you were moving.

5. Think of some situation when you were experiencing forces while moving. You might recall a time you were riding a skateboard or your bicycle, or a time when you slipped and fell. Draw a picture like the one on the previous page that shows how the net force on you was related to your motion. Does the story told by your pictures match the forces you remember feeling?

Zero Net Force and Motion:

Gravity is what made your car speed up. If there were no gravity, then the net force on the ramp would be zero. Your car would never have started moving or sped up. If you took your car and ramp far out into space, the car would just sit on the ramp and not move.

Friction is what made your car slow down. If there were no friction, then the net force on the flat part of the track would be zero. Your car would never have slowed down. It would have coasted forever.

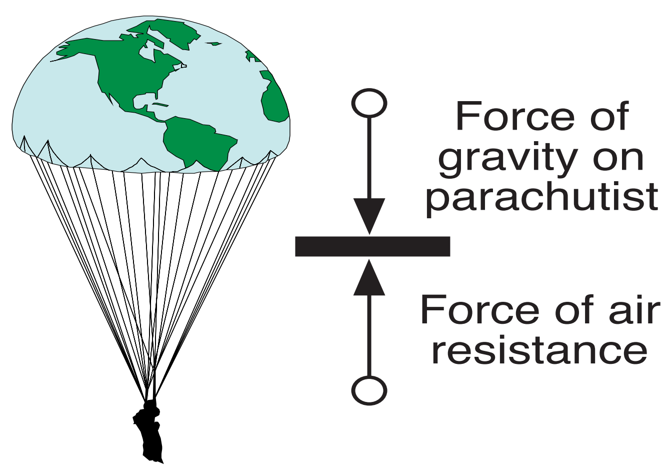
In both cases, the net force does not cause motion. It causes the existing motion to change. Is this consistent with the story your pictures told on the previous two pages?

Best Definition of Force

A force is **a push or a pull** that comes from an **interaction between two objects**. The **net force** on an object causes its **motion to change**.

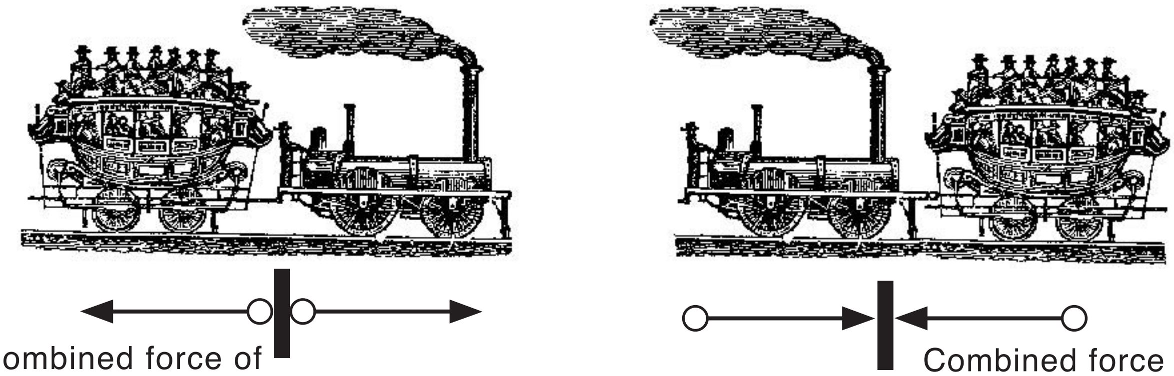
But zero net force is not the same as zero force! Zero force means that there are no forces persent, but *zero net force* means that all the forces acting on an object balance each other out..

After the initial jolt of the parachute opening, the parachutist travels at a constant speed until landing. Two main forces are at work here — gravity and air resistance. Gravity pulls to speed up the parachutist, while resistance pushes to slow her down. Once these forces are in balance, the person travels downward at an unchanging (or terminal) speed. So it is possible to have zero net force acting on a object and the object will be in motion.



A Better Definition of Force

Look at a second case below. Once the train reaches its cruising speed, the "push" from the engine is matched by the combined forces of air resistance, friction of the bearings, internal friction in the engine and gears, and the rolling friction of the wheels.



Whether the engine is pushing or pulling does not matter -- the forces balance in either case.

As a class, return to the examples you came up with using the "good enough for now" definition of force. For each one, decide on the direction of the net force and explain how it affects the motion of the object.

Reflection Questions

1. Come up with two examples of zero net force for moving objects. Explain them using force arrow pictures.

2. Come up with two more examples in which the net force is not zero. For each one, explain how the motion changes using force arrow and net force pictures.

3. How could you make a coaster car travel at a constant speed without touching it? You are not allowed to add anything to the car. You may want to think about changing what is outside the car system. In other words, design a testing environment where a coaster car can travel without speeding up or slowing down. Explain how your solution works using force arrow pictures and net force.

4. Does the net force on an object have to be in the same direction it is moving? Give an example that illustrates your answer. What happens to the motion of the object in this case?

Vocabulary for Motion

Speed is a rate or measure of how fast something is travelling; the distance something travels over a period of time. Faster speed means you go farther in the same amount of time than a slower speed. The speed limit on many highways is 55 miles per hour (88 kilometers per hour). A speed of 30 meters/sec signifies that some object will travel 30 meters in one second of time.

Velocity is a measure of how fast something is travelling <u>and</u> in what direction. Velocity differs from speed in that velocity also communicates direction. When the weatherman reports that the wind is blowing from the northwest (NW) at 10 miles (16 kilometers) per hour, he is expressing the wind's velocity — it's speed (10 miles/hour or 16 km/hour) <u>and</u> its direction (NW).

Average Speed and Velocity A car's speedometer shows the speed the car is going at each moment. To calculate the <u>average</u> <u>speed</u> and <u>velocity</u> of a car, you need to know the distance between the starting and ending points and start and end times. The path traveled is not considered. Consider: If we know when somebody left home for work, when they arrived on the job, and the distance between work and home, then you can calculate average speed and velocity. If you include the direction of travel from home to work, you can calculate the velocity. See below for an example of this with numbers:

$$\text{Average Speed (S)} = \frac{\text{Total Distance Travelled}}{\text{Total Time of Trip}} = \frac{D}{t}$$

Average Velocity (V) = Average Speed (S) and a direction

When figuring averages, you lose details of the story of travel — like how much of that time was spent traveling in bumper-to-bumper traffic, how much was spent waiting at stop lights, and how much was spent speeding along the highway.

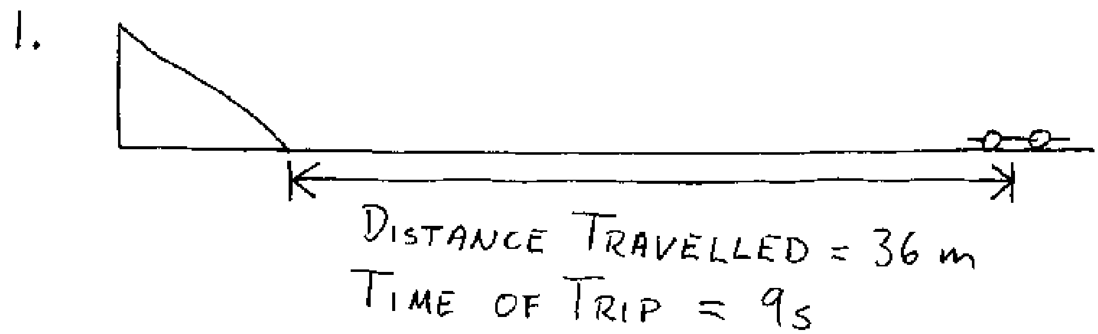
A second example using numbers: If a vehicle travels 6 meters in 12 seconds, what is the average speed of the vehicle?

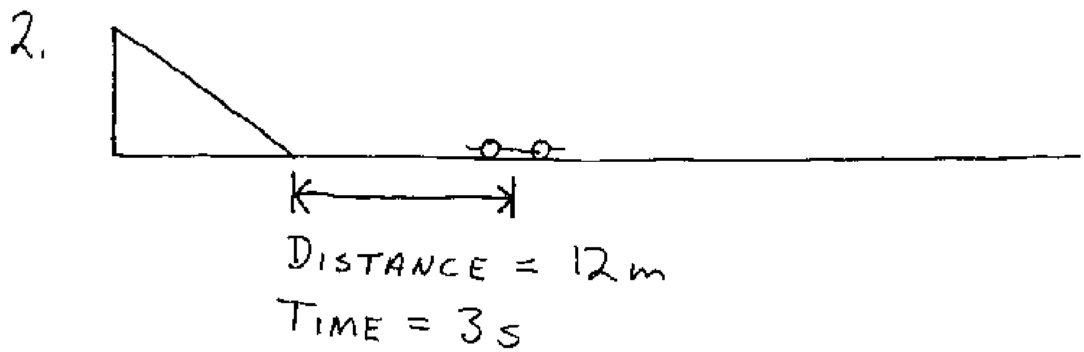
$$\text{Speed} = \frac{\text{Distance}}{\text{Time}} \qquad S = \frac{6\text{ meters}}{12\text{ seconds}} \qquad S = .5\text{ meters / second}$$

The calculation above is of the average speed because only distance and time are available for doing the math work. Without the direction of travel, you cannot calculate the average velocity.

An Experiment to Measure Motion

When something moves, it has a velocity. But your car doesn't have a speedometer. All you can measure easily is the distance it travels. Can you just look at the one that goes the furthest? Which of these two cars is faster? Give your gut reaction before you calculate the average speed.

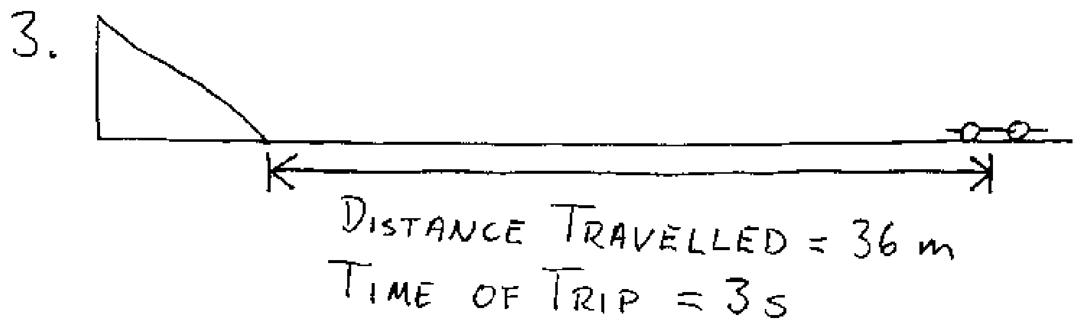


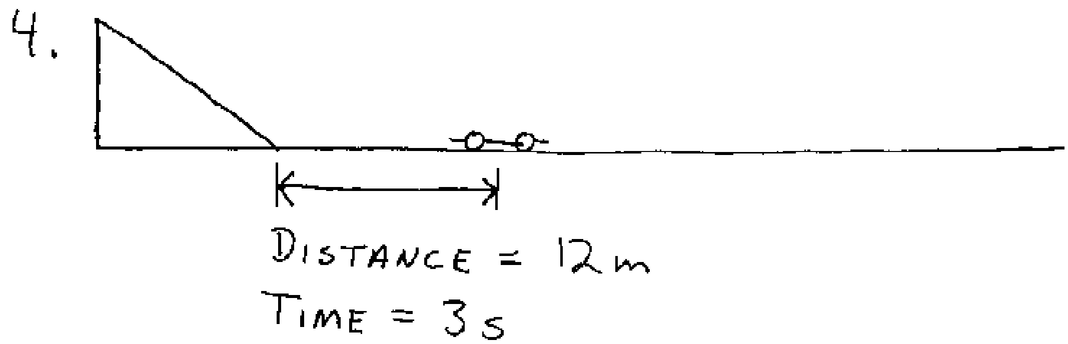


Can you explain why their speeds came out the way they did? With your group, make up a story that would explain why cars 1 and 2 performed the way they did. You might think about differences in the construction of the cars, or in the testing environment, or some other factor. Draw force arrow and net force pictures that illustrate your story, and share them with the class.

An Experiment to Measure Motion

Now which of these two cars is faster?





Explain why the velocities turned out differently this time. With your group, make up a story that would explain why cars 3 and 4 performed the way they did. You might think about differences in the construction of the cars, or in the testing environment, or some other factor. Draw force arrow and net force pictures that illustrate your story, and share them with the class.

Continued

Design a Velocity Experiment

Design an experiment that would allow you to use distance traveled to compare the velocities of two cars. Be sure to use the design procedure that you used with parachutes as well as the same design diary pages. Don't forget to identify variables you need to control and ways of making your procedure reliable. Use the "my Experiment" sheets that your teacher supplies you with to recird your data.

Try out your experiment, comparing your car with one from another group. See if your results agree with your gut feeling about which one was faster? Look for design features that might help explain why one car was faster or why one car traveled further than the another.

Reflection Questions

1. How could you rewrite the definition of force using velocity?

2. What if . . . .

   A. the bearings in your car had more friction? How would the average velocity be affected? Use force arrow diagrams to help explain your answer.

   B. the ramp was steeper? How would the average velocity be affected? Use force arrow diagrams to help explain your answer.

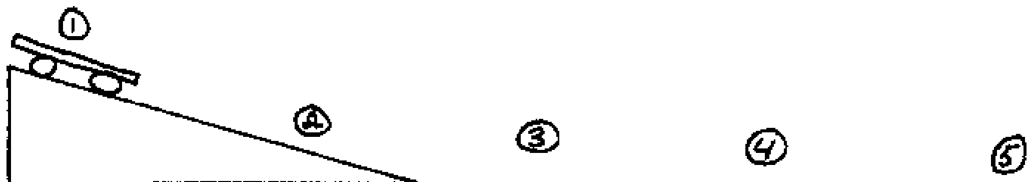
   C. you tried the experiment on a different floor and found a larger average velocity? How might the floor be different? Use force arrow diagrams to help explain your answer.

3. What do you think is the most likely explanation for the behavior of cars 1 and 2? Describe an experiment you could do to test your idea. How would you explain the behavior of cars 3 and 4? Describe an experiment you could do to test that idea as well.

Acceleration: A Change

In all likelihood, you have heard the word acceleration throughout your life. What does this word bring to mind? Being in a car that must dart quickly out into traffic, an amusement park ride, or maybe sprinting forward to pass your friend in a foot race? These are all examples of acceleration. There are many more that are similar to these examples, but there some others that may surprise you. With your teacher, try to come up with a list of 10 good examples of acceleration.

Once again, let's look at the coaster car traveling down the ramp. Assume that the event we are looking at begins with a student holding the car at the top of the ramp. We will examine 5 locations on the Motion Storyboard. At point 1, assume that the car is being held still, at points 2, 3, and 4 assume the car is coasting, and at point 5 assume the car has come to a stop. Draw the force and net force diagrams and describe the velocity at each point.



Force Diagram					
Net Force Diagram					
Velocity	a. increasing b. decreasing c. stays the same	a. increasing b. decreasing c. stays the same	a. increasing b. decreasing c. stays the same	a. increasing b. decreasing c. stays the same	a. increasing b. decreasing c. stays the same

1. Now, circle the points where you think the velocity of the car is changing. Look at your responses in the velocity row of the chart. Can you see any relationship between the direction of the net force arrow and the way the velocity is changing? Discuss this with your classmates and teacher.

2. When there is a net force (positive or negative), what always seems to be happening to the car's velocity?

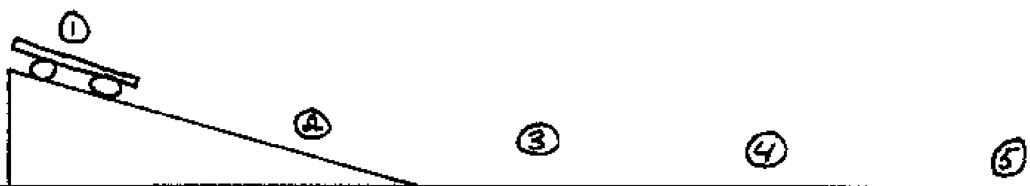
3. What about when there is a zero net force? What is happening to the velocity?

in Motion

Anytime an object's motion (velocity or speed) is changing (increasing, decreasing, or changing direction) we say that the object is experiencing **acceleration**. Yes, that's right, even slowing down is considered to be an acceleration in science. If it helps, you can refer to this type of acceleration as *negative acceleration*. However, pleasedo not call it deceleration.

Go back to the list of 10 items your class thought were good examples of acceleration. Check them against the description of acceleration we have provided here for you.

Now, let's return to our Motion Storyboard. Like with the previous drawing, fill in the chart below the drawing, however, this time, include whether the object is experiencing an acceleration. Remember, at points 1 and 5 the car is at rest. Review you responses with your class and teacher.



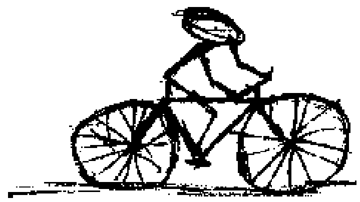
Net Force Diagram					
Velocity	a. increasing b. decreasing c. stays the same	a. increasing b. decreasing c. stays the same	a. increasing b. decreasing c. stays the same	a. increasing b. decreasing c. stays the same	a. increasing b. decreasing c. stays the same
Acceleration Yes or No					

We have established that when an object experiences a change in its speed or velocity, the object is experiencing an acceleration. On a seperate piece of paper, sketch and explain 4 instances or situations where an object experiences acceleration. Try to come up with a variety, avoid choosing examples where all are "speeding up".

As a class, write a statement that describes the relationship between a change in an object's motion and the existence of a net force on that object.

Acceleration and

Let's consider a more familiar situation…riding a bike. We will examine the motion of a person riding a bike down a long, flat street. Each box in the ACTION column has a description of the motion at that moment in time. Read the first 2 as examples, and then fill in the columns next to each picture. Check your answers with your classmates and teacher when you have finished.



ACTION	Acceleration, Y or N	Force Diagram	Net Force Diagram
Standing still, not pedaling	NO	F_N F_G	$F_{NET} = \emptyset$
Begins to pedal, increasing speed	YES	F_N $F_{FRIC.}$ F_{PEDAL} F_G	F_{NET}
Stops pedaling, coasts, decreasing speed			
Begins pedaling again, increases speed			
Pedaling, maintains a constant speed, not slowing or speeding up			
Coasts again, speed decreases			
Applies brake, speed decreases quickly			
Bike is stopped, no pedaling, no brake			

Net Force

The analysis of the bike rider illustrates that when accelerations occur, net forces play a role. Look at your previous statement about the relationship between "changes in motion" and "net force". If you haven't already, rewrite the statement using the word acceleration. What is the relationship between acceleration and net force? (Your previous statement might be incorrect. It may be necessary for you to alter the statement so that it is more correct than it was before.) Work on it as a class and discuss several possibilities. We'll return to the statement again later.

Your Car's Motion Storyboard - Revisited

1. Return to the Motion Storyboards that you have created for your coaster car. Add two rows to the bottom of the storyboard. In the first added row, identify what is happening to the speed of the car (speeding up, slowing down, no change). In the second row, identify where acceleration is taking place.

2. Examine your storyboards and your current design. Can you see design featurtes which may be responsible for poor performance? List out the problems you seem to be having with your car. Discuss them with your group. You will be engaging in a special activity (on the next page) that will allow you to collaborate with your whole class in hopes of improving the designs of every car in the class.

Coaster-Car Chat

Photo used with permission

Car Talk®

One of the most popular shows on National Public Radio is a call-in program called *Car Talk®* for people with questions about their sick cars. Every weekend, the stars of this show, two brothers named Tom and Ray Magliozzi, take questions from people from all over the country with automobile woes. (Their nicknames are "Click and Clack: The Tappet Brothers" -- do you know what a tappet in a car does?) These two hosts know a thing or two about cars and run a well-manicured car-fix-it shop in Cambridge, MA, called *The Good News Garage*. You can listen to selections from the *Car Talk®* show on the Internet at: http://cartalk.cars.com/.

A Coaster-Car Chat Panel and Session

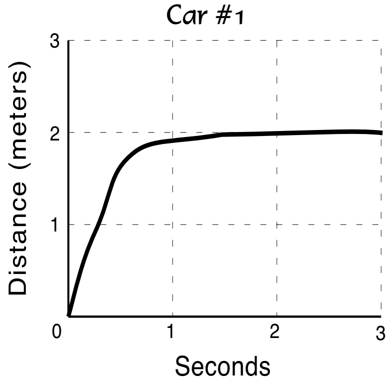
In class, you may run one or more Coaster-Car Chat sessions, using something like the "call-in" format heard on the National Public Radio program. Each design team will nominate a member to join the Coaster-Car Chat panel. Anyone in the class with a toy-car problem can then "ask the experts" for help and advice about their vehicles. Requests can focus on getting a car to work, making it work better, or finding out how it works.

To prepare for the Coaster Car Chat session, questions should be submitted to panelists one day ahead of time. Panelists may consult with others who have done this challenge or use email to contact other classes who may already have done or are currently doing this working. They may read books, consult with each other, and consult with outside experts. Any way of getting answers to questions is allowed (as long as it is safe and legal). Experience helps! Panelists may also want to listen to the radio program if possible to get a sense of how Tom and Ray run their show.

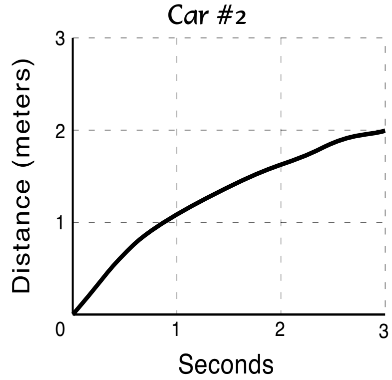
Questions for the panel might be based on actual test data. Here are some figures and a graph for two cars. Things that could be asked include: Which car went farther? Which car might have the problem of wheels rubbing against the side of the car's body? Which car might have bearings with too much friction? What could cause this?

Time	Distance (m)
0.5	1.6 meters
1.0	1.9 meters
1.5	2.0 meters
2.0	2.0 meters
2.5	2.0 meters
3.0	2.0 meters

Car #1



Car #2

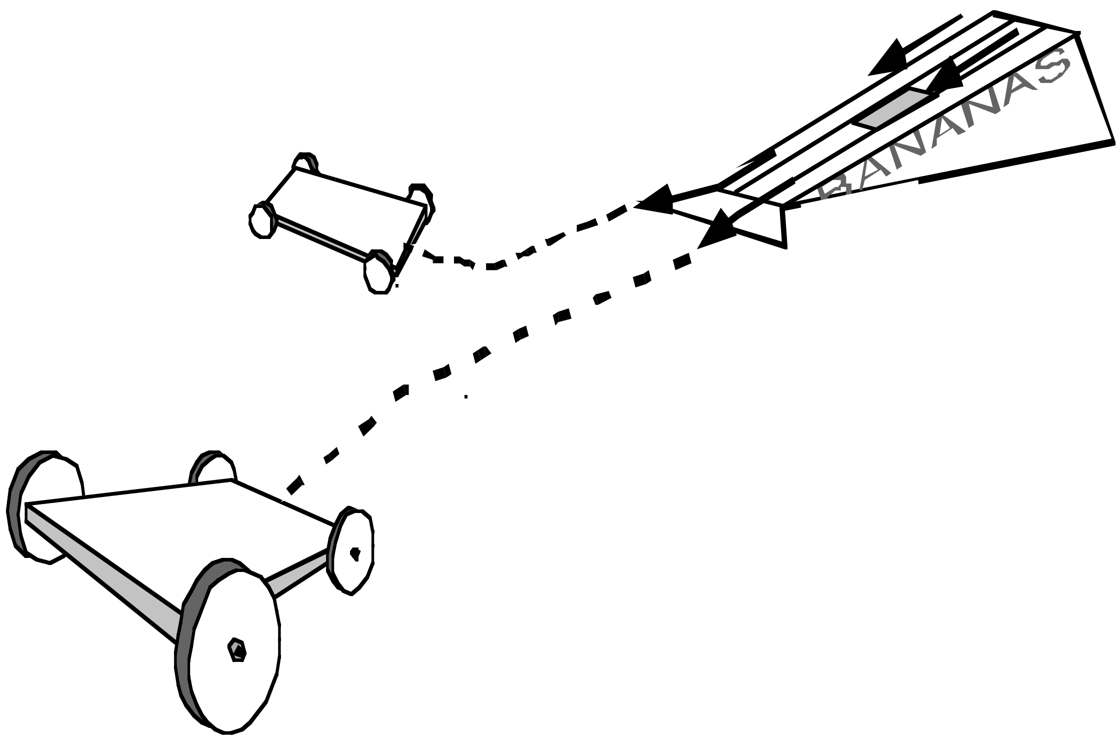


Time	Distance (m)
0.5	0.7 meters
1.0	1.1 meters
1.5	1.4 meters
2.0	1.6 meters
2.5	1.9 meters
3.0	2.0 meters

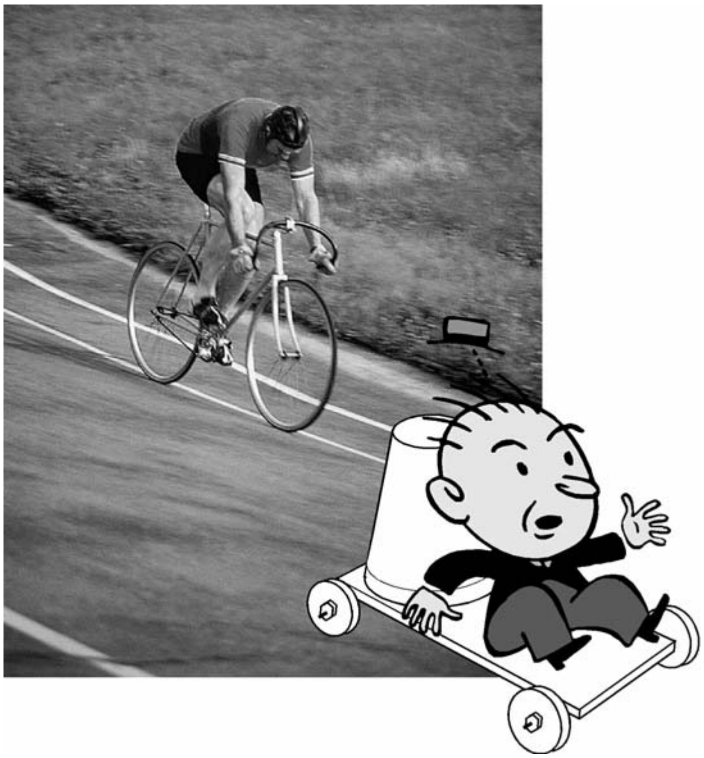
Build Your Best Coaster Car

You have some *real* design experience, you've explored some of the science issues governing your car's motion, and you have collaborated to share information and ideas with your classmates. Now it is time to show what you've learned. Create a plan for designing your best coaster car. You may want to show your idea in a pin-up. make sure that you justify any design idea or feature with experience and/or data. Share your plan with your classmates. Look to incorporate the knowledge they have shared with you.

Run your coaster cars and have a gallery walk to look at the final designs. See if you can figure out why one or two cars might be out performing the rest. Or, it might be the case that all of the cars perform fairly equally. Do your best, and have fun!!



Review and Summary
Section 1 Coaster Cars



1. In your own words, describe the overall challenge you are facing in *Vehicles in Motion*, and how your study of model cars helps you in meeting that challenge (no more than two complete sentences).

2. Use a drawing, diagram and words to describe how your coaster car works. Label all parts and tell their functions. How do the parts interact with each other?

3. Write a paragraph describing the plans for running an experiment where you compare two coaster cars. Give details and explain why your tests are as fair as possible. What are some things you cannot control?

4. Describe the role friction plays in determining the effectiveness of your bearings. What influences how much friction your bearings produce? How can you change that level of friction?

5. Write out your best description of how forces and motion are related.

6. In the movie Titanic, the female star falls from the edge of the ship and is caught by the guy. He stops her fall by grabbing her arm. If you haven't seen the movie, imagine a cliff-hanging scene where someone reaches out and grabs another by the hands or feet to keep them from falling a long way down. Use drawings and words to explain how at this moment, the net force is zero.

7. Name and sketch two things with bearings in them. Draw circles where you think the bearings are located. Tell whether the bearings use rolling or sliding bearings.

8. Use force arrows and sketches to show two examples of forces canceling themselves out. In the real world, forces are usually invisible. How can you tell when the forces acting on something cancel out exactly?

9. From memory, draw the LBD Cycle. Which step is the most important for you in doing a design challenge. Defend your choice by telling why.

10. Give an example of where your design team built upon the idea of another group in your design work.

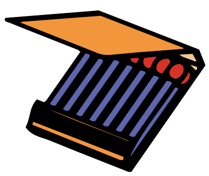
Problem Specifications

What does your

The design of products is both an art and a science. Designers have to understand what users want and like (marketing), how to make things (manufacturing), how products work (science and engineering), and how to make products effective and usable (product design).

To know whether what they create works well enough, designers list how a product *must behave* and things it *must do* to be a quality product. Such product specification lists describe what the item must be able to do and must be testable. Specs are a more detailed version of product criteria.

Here are what some product criteria and product specifications for four everyday products might have looked like while being designed and developed.

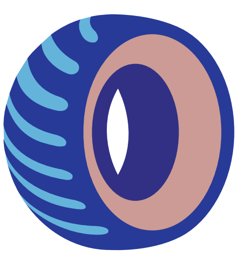


Safety Matches

Criteria	Specifications
• Holds lots of matches in small space	• Holds 20+ matches in 2x3 cm space
• Matches lit easily	• Matches light with a 0.1 N force down.
• Keeps matches from getting wet	• Keeps matches dry 20 minutes after 10 drops water are placed on the cover.

Audio Tape

Criteria	Specifications
• Can hold lots of tape without tangling	• Holds 30-120 minutes of tape
• Does not take up much space	• Must fit in shirt pocket - 5.7x10 cm
• Light in weight	• 90-min tape less than 60 grams in mass
• Stackable	• Can stack 20 cassettes without toppling
• Durable, hard to break	• Drop from 10 meters without breaking



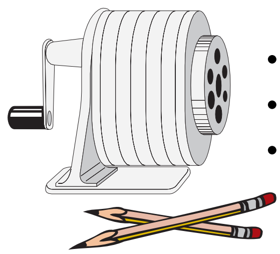
Car Tire

Criteria	Specifications
• Gives good grip on wet or dry road	• Can stop an empty car going 55 km/hr (35 mph) on a dry road in 14 meters.
• Tires easily removed for replacement	• Can be replaced by mechanic in 10 min.
• Use in cold or hot temperatures	• Useful in temps from -50° C to +140° C
• User can tell when tire nearly worn out	• When worn out, tread lines disappear

tion

and Whiteboarding

car need to do?



Criteria	Specifications
• Collects wood shavings from shapening	• Holds 15 cc of pencil wood shavings
• Handle is easy to turn	• Handle requires 3 Newtons to turn
• Creates a pencil with a sharp point	• Sharpens pencil to .1mm diameter point
• Can sharpen pencils of different sizes	• Has guide that supports pencils with a diameter from 4mm to 14mm

Pencil Sharpener

Notice two things about each list of specs. First, specs include numbers with units of measure listed, unlike product criteria. Second, specs are not only <u>testable</u>, but <u>doable</u>. All of the measurements listed can be done in a lab or other testing area.

Now You Try

<u>Product List</u>

portable fan, drill, bathroom scale, zipper, bicycle lock, whistle, mousetrap, wallet, safety razor, cell phone, tape dispenser

• Product Specifications

You can write product specifications for almost anything that has ever been made. Pick two products and write out what you think were their specifications when they were being designed. Use the "Product Specifications" page from your Design Diary. Make sure that the specs you write are <u>specific</u>, that you or anyone else could <u>test</u>.

You are writing product specs for a reason.

Soon you will be writing product specifications for your own vehicle. By defining how your car should perform, in detail, you will be able to test it to see how close you are getting to your goal.

Product Specs for Your Vehicle

For homework, you will use another "Product Specification" Design Diary page. On the left-hand column of this sheet, write out the general criteria a vehicle must meet to do the final Over-the-Hill challenge. Then, write those specs down in the right-hand column of the Design Diary sheet. During your next day's class, get together with others to discuss your lists. Try to agree on what are the key specifications for a good design.

It's also a good time to list and begin gathering other sources you will need to get needed information you need to continue. What are the names of books, people with experience, or sites on the Internet, that might help you understand more about cars or different terrains and surfaces?

Finally, go back to your original Whiteboard, and update it with the new things you know, your new ideas, and new questions you have.

Vehicles in Motion
Section 2

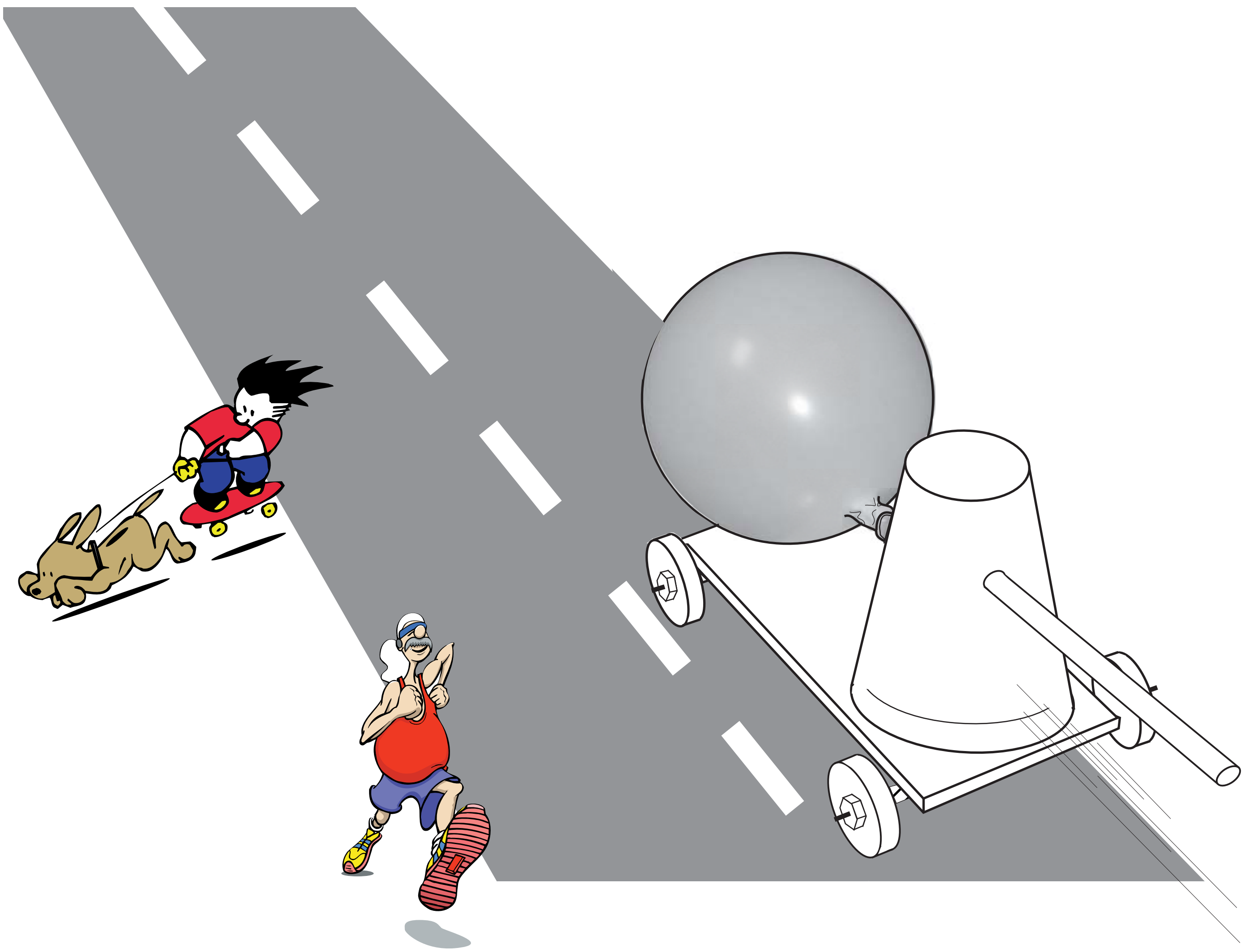
The Balloon Car

Section 2 Table of Contents

Balloon-Car

The Challenge

Your next challenge is to configure a balloon propulsion system that will power your car the greatest distance over flat terrain. You will be given plans for a basic balloon-car vehicle, and your team will build it and then refine its design. You will conduct experiments and collect data to support your design decisions and ideas and learn more about how forces cause motion.



Challenge

Product

For the Balloon-Car Challenge, you will add a propulsion system to your coaster car so that it can travel under its own power. You will be given starter plans for a basic balloon-and-straw system. You will build it, run experiments to find out what affects and can improve the performance of your balloon car, and report results to your class. You'll redesign your balloon propulsion system based on the results of those experiments.

Gallery Walk Presentation

When you reach the end of Section 2 of *Vehicles in Motion*, you will give a Gallery Walk presentation where you will report results of experiments, show drawings and notes from your design work, and conduct a test-run demonstration showing how well your current vehicle performs. Your car should be able to travel under its own power on a flat floor.

Your presentation should include:

- a description of your design process, including your design decisions;
- the reasons for design decisions you made;
- data from the experiments you conducted;
- the science ideas that supported your decisions; and
- sketches of the various cars you tested.

Assessment and Objectives

Your design work and collaboration will be assessed throughout *Vehicles in Motion* by your teacher. Your presentation will be reviewed by your classmates and teacher, and your presentation will be given a score. You will also take a quiz on the science and technology ideas presented in this and the previous section, which are part of the objectives set by the *National Science Education Standards*. These include:

- How net forces change motion
- Predicting and calculating how forces combine, and how forces act on an object
- Designing experiments for testing cars and displaying test data in different ways
- Evaluating technological products, and predicting performances of different balloon cars
- Identifying stages of technological design; for example, steps you use of the LBD™ Cycle
- Thinking about and analyzing systems, and subsystems, as with your car and balloons
- Using the following terms with understanding: speed; velocity; acceleration; mass

Section 2: Addressing the

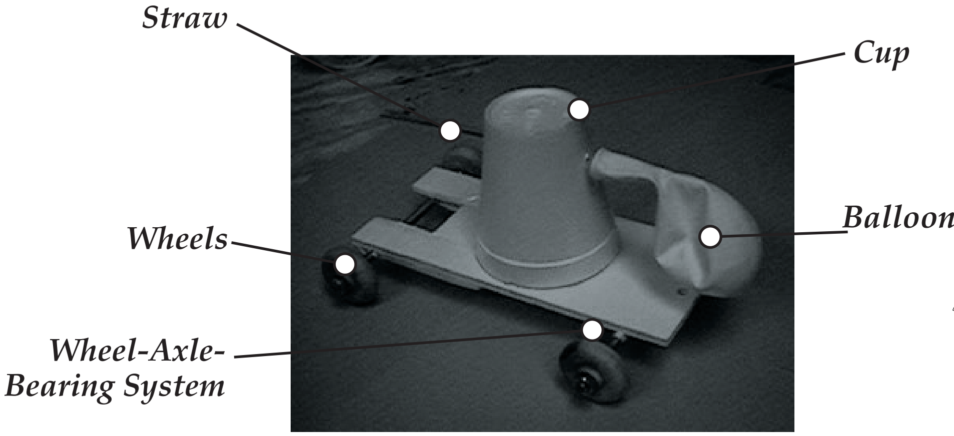
Your main goal in Section 2 is to build a balloon car and then improve its design so that it can travel on its own along a path as straight and as far as possible. You'll learn about how balloons work, about changing the forces and loads on your car, and Forces in Pairs, Net Force & Acceleration, and Force of Propulsion. The balloon car will be one of the propulsion systems you study that make your car move under its own power. You'll work on the Balloon-Car Challenge for about 10-15 days. Here is the sequence of activities you will be following for Section 2:

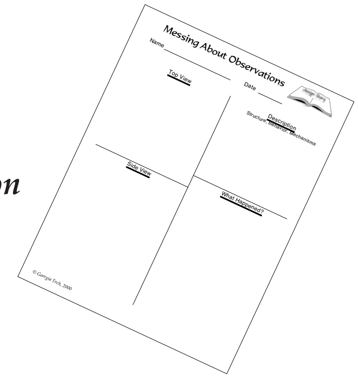
Procedure

1. Construct and Mess About with a Balloon Car: You'll first build a basic balloon car from plans you're given, and then mess about with several balloon-and-straw engines. Hopefully, you'll get ideas about how to design a balloon car engine so that your car will travel a long distance. You'll want to try out several different balloon-and-straw engines and compare them to each other. You'll make predictions before you try out each engine, and use "Messing About Observation" pages as needed.

2. Class Review of Messing About and Whiteboarding: You've already investigated some changes to your balloon car and predicted the effects on your car's performance. Sometimes you were right, sometimes wrong. It's time now to develop and record ideas you have about how to improve your balloon car's performance. Remember, you want to make your balloon car go as far as possible using the materials you have available. As in the parachute challenge, you'll be doing whiteboarding as a class to develop those ideas and to identify what you still need to learn. To prepare for whiteboarding, work with your group to make a list of design changes that you think might effect your balloon car's performance. Feel free to include some that you tried and some that you haven't tried yet. Use the photo below of a balloon car and its parts to help you make your list. It might remind you about different parts of the balloon car that you haven't considered changing yet. Can you predict, for each of the changes you are thinking about, how they will affect the car's performance? Do you know everything you need to know to predict how to design your very best balloon car? You'll need to do some additional investigations to find out for sure if the changes you're thinking about are good ones. List ideas on the whiteboard, generate a set of things you still need to learn to make your balloon cars as good as they can be. Finish up by selecting a set of variables that your class thinks are the most important ones affecting a balloon car's performance.

Balloon Car Challenge





Balloon car with labeled parts. Which parts might you redesign or change to make a better balloon car?

3. Learning About Forces n Pairs and the Force of Propulsion -- You spend some time with your teacher learning more about how forces are created and how they act to make your balloon car move forward. Some pages in the book and some homework questions will help you understand how the balloon car works. It will be up to your class to investigate how to make it work better.

4. Running Experiments, Reporting to the Class in a Poster Session, and Evaluating Your Experiments -- You will return to the whiteboard and identify the design features you will focus on in some experiments. Choose one variable in the car's design and run an experiment to find out the affect of it on potentially to three key measures of a balloon car. Use "My Experiment" Design Diary pages to help you design your experiment, collect data, and reflect on what you find. Remember that answering a "how" question will tell you more than simply answering a yes/no question. Design a way to display your data and conclusions in a Poster Session. You'll review the work of your classmates and discuss possible Rules of Thumb for a balloon car. During this time it is important to pay close attention to the experimental tactics of your group and your classmates. Make sure that tests are fair and verify that everyone's procedures are sound.

5. Another Round of Experiments: It's possible that the results of your first experiment weren't good enough to derive a rule of thumb. Perhaps you didn't control some variable well enough. Perhaps your measurements weren't accurate. Or maybe you didn't run enough trials. If your peers weren't satisfied with your results, go back and improve your experiment, and run it again.

6. Net Force and Acceleration & Motion Storyboards – You will again discuss in more detail the forces involved in moving your balloon car. You will look at the special relationship between Net Force and Acceleration. You will see other examples, and create your own examples, of how this relationship. Then, you'll review your experiments to create Motion Storyboards that depict the Net Force and Acceleration for the balloon car in each of your experiments.

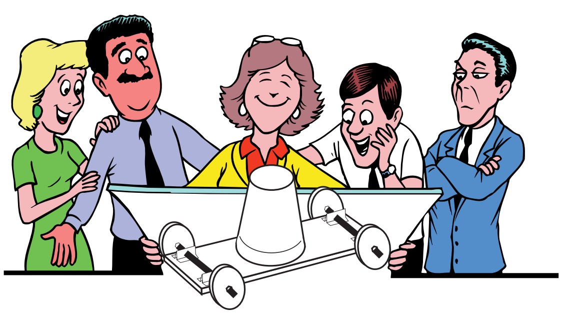
Addressing the Balloon

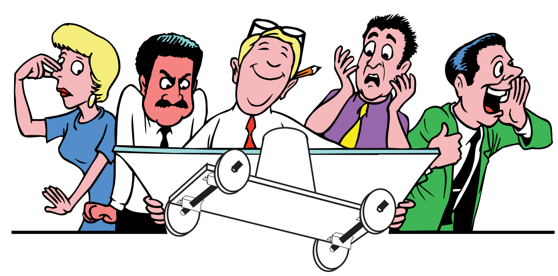
7. Design: It's time now to work as a team to design your best balloon car. For each alternative you've each thought of, make predictions about what will happen if you construct the car that way, and think about whether the balloon car rules of thumb suggest a better way. Let each person present his or her design and explain his or her predictions. Choose one of those designs, or even better, plan a new design jointly based on the best of everyone's design plans. Draw a poster of your group's best design, and explain why you think it will work better than any other design.

8. Pinup session: Present your design plan to the class. Be clear about why you made each of your design decisions. Be sure to ask other students questions about their design decisions. Advice and questions from others are almost always a help.

9. Trial and Refinement: You might want to refine your design based on discussions during the pinup session. Feel free to do that, but make sure you show your changes on your "Testing My Design" sheet, and explain there why you are building and testing a different design than the one presented in your pinup. Construct your balloon propulsion system and try it out. Use "Testing My Design" sheets to record your results. For each refinement you make in the car or its propulsion system, use a new "Testing My Design" sheet to record the new design decision and the results of your trials. After each deign, complete a Motion Storyboard describing the force and motion of your design.

10. Gallery Walk, plus Iterations: After one or two iterations, hold a gallery walk to show the class what you've constructed and how it performs. How close is your balloon car to the one you described in the pinup? Explain any differences to the class; make sure they understand why you made the changes. Do another iteration or two after the first gallery walk, whatever time will allow, and then get ready for another Gallery Walk. Make sure your car works well for this presentation.





Car Challenge (continued)

11. Design for Three Competitions – Your teacher will offer, potentially, three competitions to run your best balloon car through. A Distance Competition, measuring how far you car will travel across a flat, smooth floor; a Tug-of-War Competition, measuring how the net force your car creates holds up against the net force of other cars; and a Stall Load Competition, measuring your car's ability to carry loads. After the Stall Load Competition, you'll explore how mass affects the motion of things.

12. Competition, Final presentation to the Class and Test Run on a Hilly Track: You will give a final presentation of your balloon car and summarize the differences between your initial plan (presented in your first pin-up) and your final design, with reasons explaining why you made the changes that you did. You will then predict how well you think it will run on a track with a 5-cm and a 10-cm hill, and test it twice on this hilly track. You'll report what you saw and tell why you think the car performed the way it did.

13. Summing Up and Whiteboarding -- You will have some questions and a quiz at the end of the unit (page 90-91) to help you assess how well you understand the materials. You'll end Section 2 with a Whiteboarding session that focuses on, "What more do we need to learn about propulsion systems?"

Balloon Car Build

Outline of the Balloon Car Building Instructions

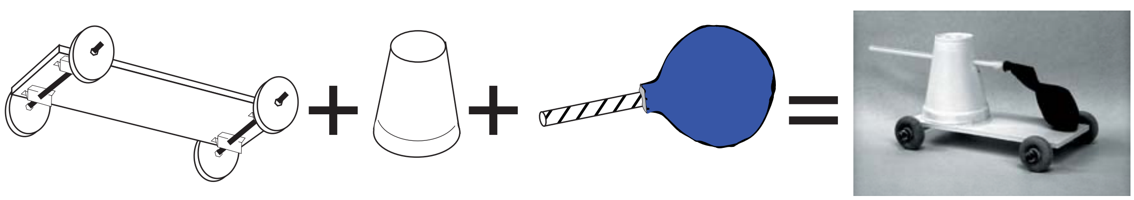
These three pages of building instruction are divided into seven parts:

A. Introduction to Building a Balloon Car
B. Materials You Will Need
C. Using a Glue Gun
D. Attaching the Straw to the Balloon
E. Cutting Holes into the Cup to Hold the Balloon
F. Attaching the Cup to the Coaster Car
G. Inflating the Balloon and Controlling the Air Inside

A. Introduction to Building a Balloon Car

You will be making a balloon car system, which is made up of three basic parts:

a. a coaster car;
b. a styrofoam cup attached to the top of the coaster car; and,
c. a balloon with a straw glued to its end so that it holds air when inflated.



Coaster Car   Cup   Balloon-Straw   Balloon Car System

To make the car run, you blow up the balloon, hold it in a special way so that the air does not flow out (see page 54 for these instructions), and then release it. If everything is built well and the parts are sized well, the car will move under its own power. You will eventually do experiments with different propulsion systems you design, with the goal of making the best vehicle for the challenge. You can begin "messing about" and doing informal experiments with your car right after you build it. Record all testing on the Design Diary's "Testing Your Design" sheets.

B. Materials You Will Need

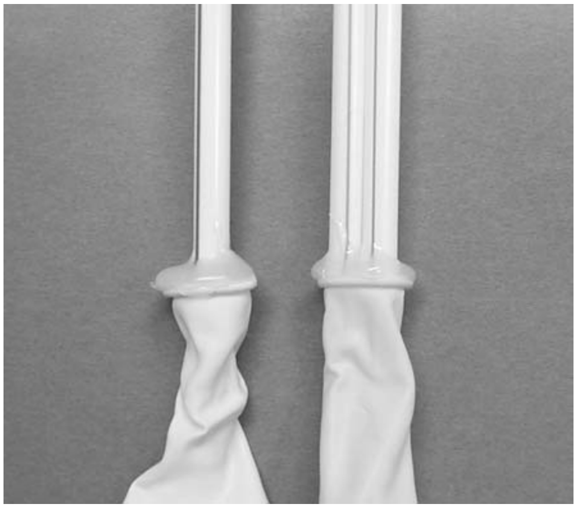
You will be given the materials listed at right to build a balloon car.

Materials

3-9	straws
2-6	elbow straws — small and medium diameters
3-5	balloons
2-4	styrofoam cups
1	strip of masking tape (1 meter in length)
1	low-temp hot glue gun with extra glue sticks

ing Instructions

C. Using a glue gun

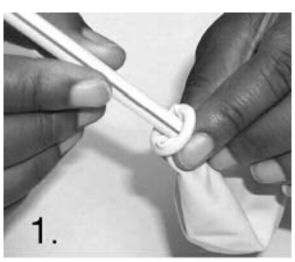


To make an effective balloon-straw propulsion system, you need to make an airtight seal between the straw and the balloon. (If you don't, what do you think will happen when you blow up the balloon?) You will be using a low-temperature hot-glue gun to do this. These guns heat up and melt round sticks of solid glue until the glue becomes liquid — at a temperature a bit less than boiling water (about 82°C or 180° F). You control how much glue comes out by squeezing the glue gun's trigger.

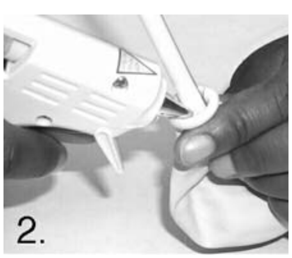
Safety — When you plug the glue gun into an electric outlet, be careful!! The tip of the glue gun gets hot — DON'T TOUCH IT AT ANY TIME. If you get the hot glue on your hand, wipe it off quickly to avoid any burns. When you are finished, unplug the gun, since it will remain hot until it's unplugged. Practice safety and good sense when using this tool!!

The glue gun uses electricity to heat itself and the glue. Plug in your glue gun in a safe receptacle, and use its built-in stand so that you can avoid laying the gun on its side. When the glue gun is empty or the glue stick is too short, feed a fresh glue stick through the hole in the back of the gun. When the tip of the glue gun is hot enough to melt the glue, press the trigger to push the glue stick towards the gun's heated nozzle. A liquid bead of clear glue will come out of the tip as you squeeze the trigger, which can then be applied to the items being joined.

D. Attaching the straw to the balloon

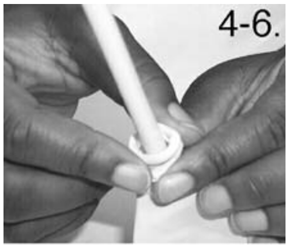


1. Insert a straw about 3 cm into the balloon, and then roll the end of the balloon back upon itself so that the straw is visible.

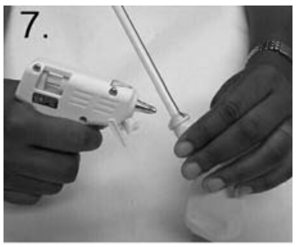


2. Put the tip of the glue gun into the balloon, and fill the space around the straw with glue, as far down the straw's length as you can inside the balloon.
3. Make sure there are no gaps in the glue around the straw.

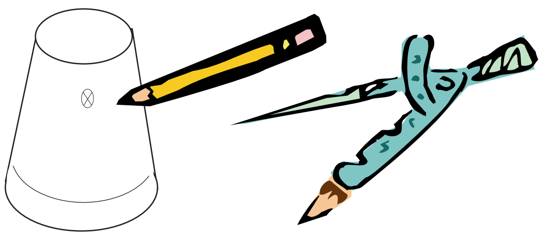
Instructions - Continued



4. Roll the balloon up the length of the straw a short distance, pushing and spreading the glue smoothly around the straw.
5. Add more glue into the balloon. When the space is filled with glue, roll the balloon further up the length of the straw.
6. Continue this process until the balloon is fully unrolled.



7. Top off your work with an extra "hill" of glue to make the best seal you can between the balloon and straw.
Gluing Hints: When you finish gluing, do not touch your balloons. ALLOW 20 MINUTES TO COOL. Having the glue form a little hill above the top of the balloon will make a better seal.



E. Cutting Holes into the Cup to Hold the Balloon

To make the two holes in the cup through which the balloon's straw will pass, use a pencil or compass and carefully poke holes through the cup, making sure the holes are lined up.

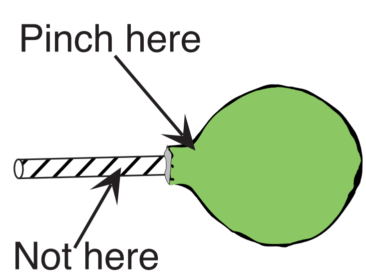
F. Attaching the Cup to the Coaster Car

To complete your basic balloon car, you need to attach the cup to the chassis. Do this with masking tape or some other adhesive. Hot glue is okay as well.

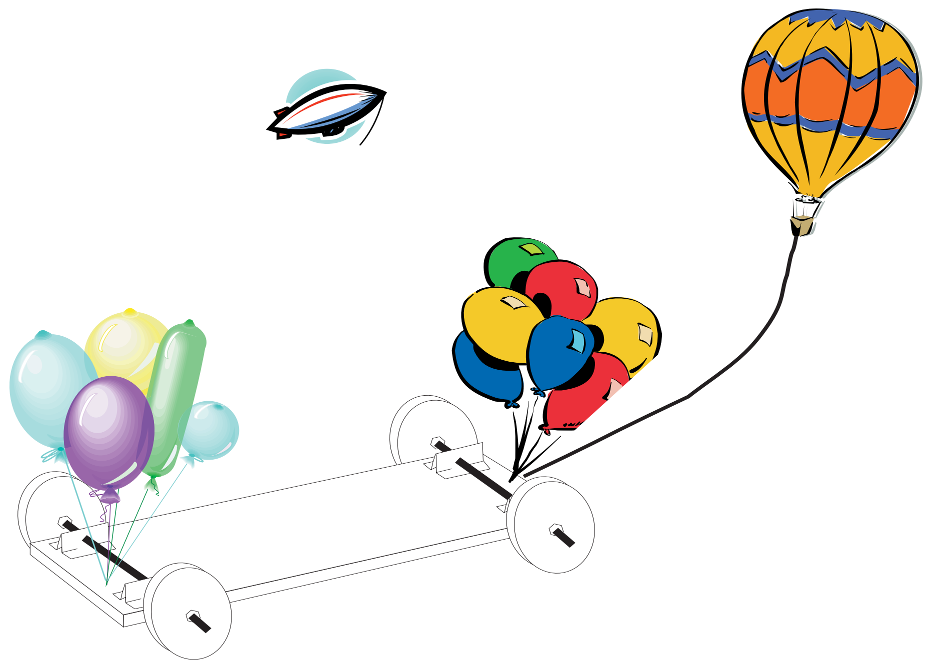
G. Inflating the Balloon and Controlling the Air Inside

1. When you inflate a balloon, moisture from your mouth gets on and inside the straw. To avoid catching germs from others, only one person should blow up a particular straw-and-balloon system. "Once you inflate it, you own it," is a good rule to remember.

2. After you inflate the balloon, you will need to pinch it shut so that the air does not escape until you want it to!! Avoid doing what comes naturally — pinching the straw at its open end and thus keeping the air in the balloon. By squeezing it at its end, you flatten the straw. Since the straw needs to be as nearly a perfect cylinder as possible, you must grab the balloon ahead of where the straw has been glued, so that you are pinching together the balloon, not the straw. By holding the inflated balloon in this way, you help the straw keep its original tube-like shape.



Messing About with Balloon Engines



Do the balloons attached to the coaster car shown above propel or make the car go forward? What is the difference between these balloons and the one you attached to your coaster car?

The first engine of your challenge car uses a blown-up balloon to make it move. But just having one or more blown-up balloons will not help you much towards your overall goal.

You know from building your first balloon car that the straw directs the flow of air out of the balloon. Your mission in class will be to "mess about" with different balloon-and-straw systems and to help you imagine how you can adjust the propulsion system to effect the car's motion and distance traveled. Keep notes of what you discover and learn from using your balloon car.

Your teacher may decide to have a gallery walk now, or maybe your class will have an open discussion about the observations and questions your formed during your messing about. The inportant thing is to begin identifying what factors effect the vehicle's behavior and how forces act on your vehicle.

Homework

As a designer, you can also "mess about" by changing the basic balloon system design given to you. Your team will have access to different materials to allow you to change your design. Examine these materials, and then on a note card or piece of paper, make two lists:

A. Design changes in the way balloons are used

B. Design changes in the way straws are used

• For each item on each of your lists, write predictions about what you think will result from these changes.

Forces

Recall the statement below.

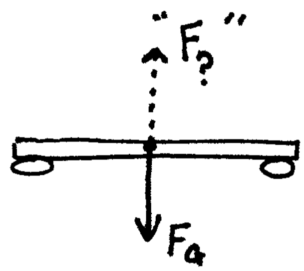
A force is a push or pull that comes from an interaction between two objects. The net force on an object causes its motion to change.

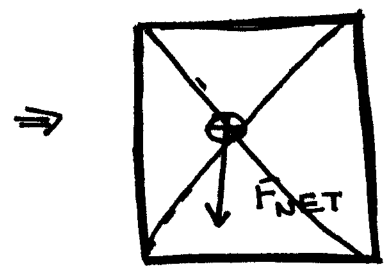
Up until now you have been looking at only one object at a time to analyze and draw the forces acting on it. However, you know that it takes two objects to create forces. You know that the earth (ground or floor) interacted with the coaster car to produce forces on the car. Also, the floor produced frictional forces on the wheels, a part of the car. The surrounding air also provided for more friction on the car.

All of these objects create force on the car, but does the car create forces on those objects? If we changed our focus from the car to the ground we could draw a different force diagram for the ground.

We know that a coaster car at rest experiences gravity through an interaction with the earth. This force pulls the car toward the floor (the earth). However, we know that this force must be balanced. Why? If the force was unbalanced, there would be a net force. If there is a net force, then there would be an acceleration.

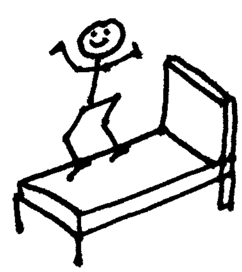
Ahh-ha, but there is no acceleration!
The car remains at rest.
So, something must be balancing the force of gravity.

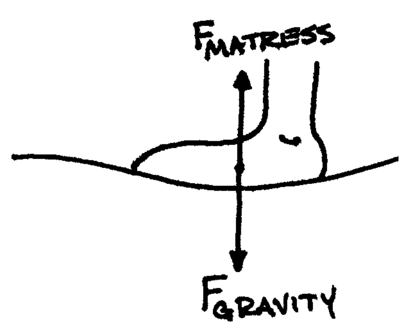




What's happening is that the ground is also pushing on the car!

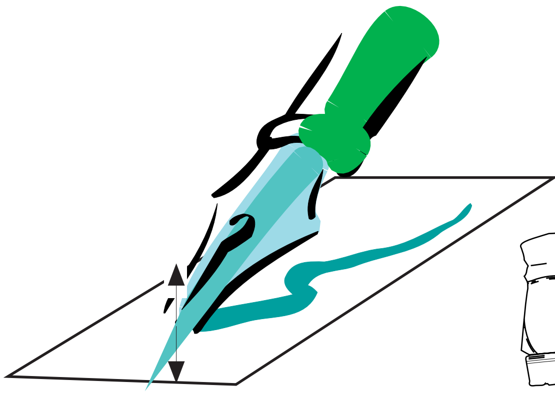
This might seem odd, but you've all experienced it. Think about jumping on a trampoline or on your bed. When you jump and push down on the surface, the force compresses the surface. At the same time, you experience a force from the surface. You can feel the surface pushing back. Also, what happens to you when the trampoline surface or mattress pushes back? Your motion changes…you begin to travel up off the surface. Remember, when a net force is exerted on an object, its motion changes. By the way, you are not to try this experiment at home…no jumping on the bed!!





In Pairs

What's interesting and probably hard to understand is that the force that the ground, the trampoline, and the bed each exert on you is equal to the force you exert on the surface. Each object will react differently to the force it experiences based on its mass (we'll discuss that later), but each does experience the same amount of force. Look at the examples below.

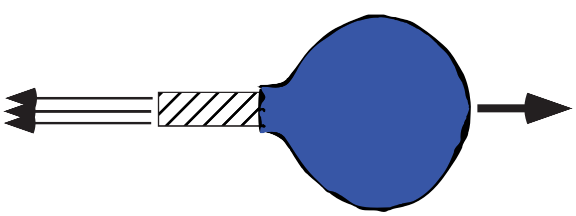


Pen pushes down on the paper, as the paper pushes back up on the pen (point will bend).

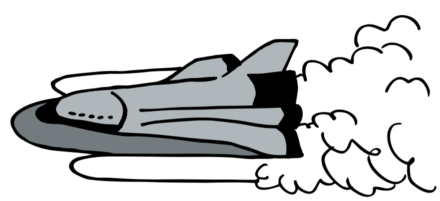
The ball kicks the shoe as hard as the shoe kicks the ball. (Imagine kicking a bowling ball.)

You should notice two special things about the force arrows in the above cases. First, each pair of arrows is the same length (what does that mean about the force?). Second, each pair points along the same line, but in opposite directions. Do you notice anything else?

Isaac Newton determined a remarkable sameness about the forces acting between two objects, no matter what they are or how big: The force of one object on another causes the second object to exert an equal and opposite force on the first. Neither is more important than the other. Still, people tend to focus on one force arrow, and often forget about the other. Which ones do you think people forget in the above examples?



The push of all the air molecules leaving the balloon is equal to their total push on the balloon.

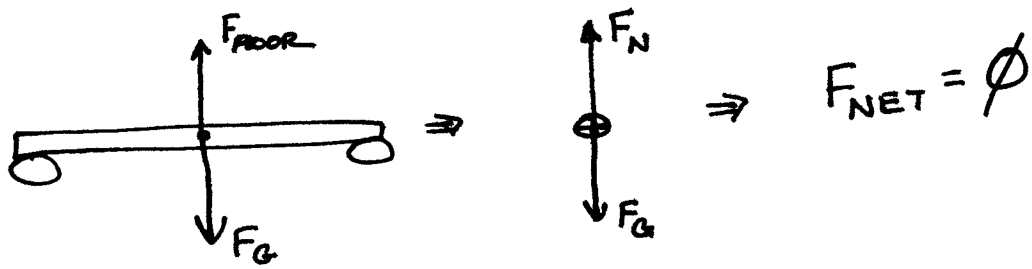


What pushes the Shuttle rocket forward?

The balloon-and-straw system in your balloon car is a great example of forces acting in pairs. As the balloon pushes the air that escapes from the straw, the exiting air propels the balloon, and the straw and car, forward with an equal force.

Normal Force

We have been talking about the force that surfaces push back with on objects. This force could be labeled F_{floor} , $F_{surface}$, $F_{trampoline}$, F_{bed} . However, to make things easier, we label the force with which surfaces push back on objects as Normal Force or F_n . So, our force diagram of the coaster car resting on the floor looks like this:



Try this!!

This activity might help you see how forces in pairs are equal in size.

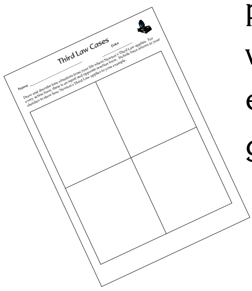
Bathroom scales are used to measure the weight of a person. We obtain this information by standing on the scale and viewing the numbers in the small window of the scale. The scale measures how hard you are pushing against the earth's surface. Do you see why you have to stand on it in order to get the correct weight? If you were to take a bathroom scale and hold it up to a wall and push on the scale, you could measure the force with which you are pushing on the wall.

Take two bathroom scales and place the feet (the bottoms) of the bathroom scales against one another. With your friend or classmate, push against each other keeping the two scales between you. Each of you should report what the scale reads as you push. Try these variations, and share the scale readings each time:

a. Each of you push at the same time.
b. Have one of you push and the other just resist the push.
c. Hold the two scales up to the door frame of an open doorway. Align the scales so that the bottom 2/3 of the scale (where you would stand) is against the wall and the top 1/3 (where you read the weight) is hanging out in the open doorway. You push against the wall and have your partner read the scale opposite of you. The scale facing the pusher shows how much force is generated by the pusher pushing on the wall. The other scale displays the force with which the wall is pushing back at the pusher. Read off their numbers. Are they the same?

Write a statement that compares the forces generated when two objects interact. (Hint: How do the forces compare in size and direction?)

in Pairs, cont'd.



Homework

For homework, find four examples from home, school, or some place near where you live, where you see Forces in Pairs at work. Write an explanation of each, and make a quick sketch of each on the "Forces in Pairs Cases" worksheet your teacher will give you.

Anatomy of

Forces Acting Inside a Balloon

To understand how the inflated balloon of your balloon car works, you need to know why the air inside wants to get out forcefully when you untie its opening, release the straw, or pop the balloon with a pin. Let's start with a question about a picture: What do you learn about how a balloon works from the photo below, made with a high-speed strobe light by Charlie Miller, associate of Dr. Harold Edgerton of MIT?

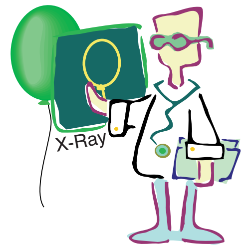
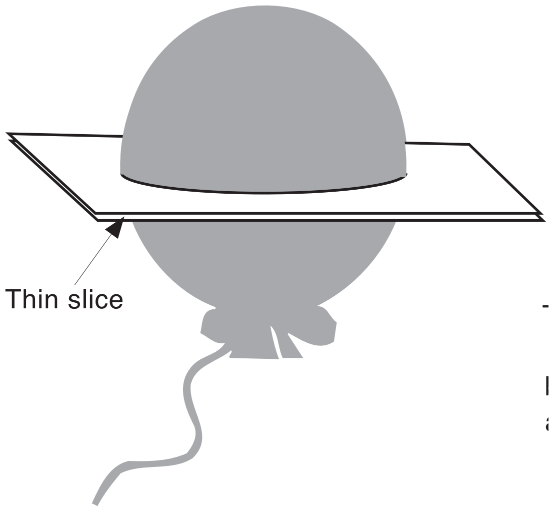
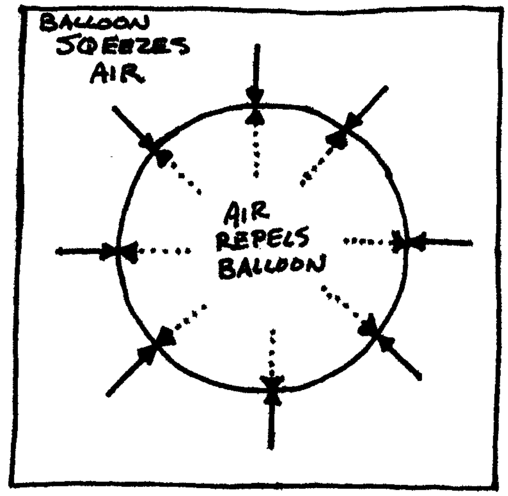


Photo used with permission of Charlie Miller

a Balloon

To understand how a balloon is like a rubber band, imagine that we can take a thin slice from the middle of the balloon. This is done so quickly that the balloon does not have time to burst. What would the slice look like?





Slice of balloon is like a streched rubber band, which tries to get smaller.

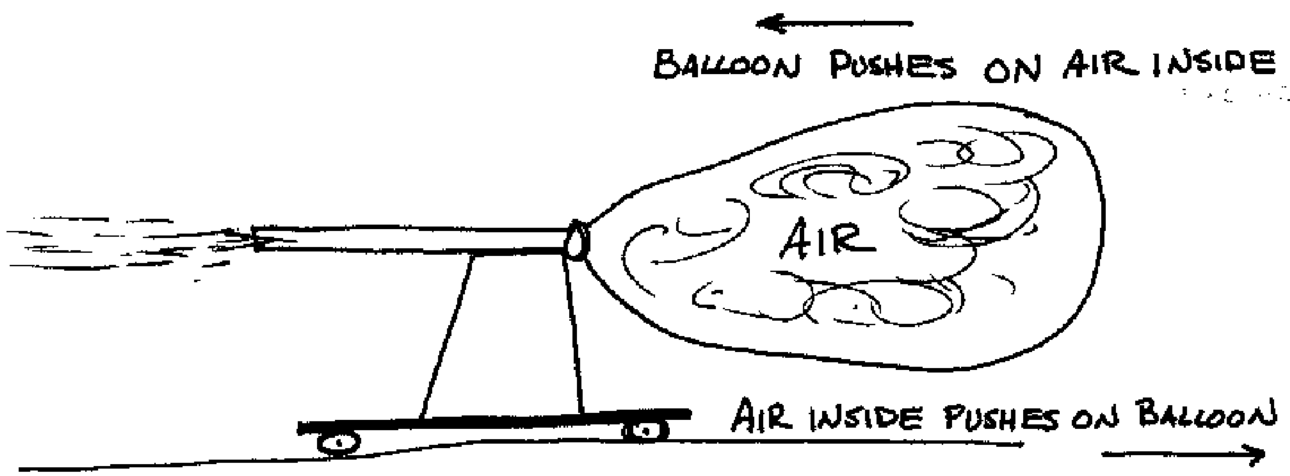
When you inflate a balloon, the elastic in the balloon causes it to want to shrink to its size before it was inflated — just like a stretched rubber band. If you could see the forces at work on the air molecules inside a balloon, they might look like the picture above. When the balloon is released, the air and the balloon (if not held onto) each accelerate in the direction they are pushed. The air goes one way, and the balloon goes the opposite way.

Force of

Now that you understand how the balloon deflates, we can discuss how the balloon powers your car.

When you attach the balloon engine to your car, the engine becomes part of the car, and the car has the ability to power itself. But, here is a tough question. What really is responsible for pushing the car forward? Discuss this question with your classmates and teacher, right now. Record some of the ideas below.

We know that for the car to move forward, there must be a force pushing it, and that force only exists if we inflate the balloon. When we inflate it, the air inside the balloon pushes on the balloon, and the balloon pushes on the air. Remember, forces occur in pairs, and the two forces are opposite in direction and equal in size. This means that the balloon is pushing on the air in one direction, and that the air inside the balloon is pushing on the balloon in the opposite direction.



AND…these forces are equal in size!!!!

Propulsion

Try to draw the force and net force diagrams for the balloon car (one object) and the air inside the balloon (consider the air mass as one object). Keep in mind that each object must have its own set of diagrams, Compare you diagrams with your group when you are finished and discuss the diagrams with your teacher and classmates.

	Forces on Air Inside	**Forces on Balloon Car**
Force Diagram		
Net Force Diagram		

Time for Experiments:

As you may have discovered while messing about with different balloon-straw systems, changing the number of balloons in your car, using narrower or wider straws, and so on, can greatly alter a car's performance. But just "messing about" doesn't give you enough information to do what every good designer must do. To make the best design choices, you need the most accurate evidence about the effects of your changes. Through experimenting and coming up with rules of thumb, you'll get better at predicting which combination of features will create the "best" balloon propulsion system for the challenge you face. You'll have to measure a car's performance fairly accurately and then test and measure the effects of different changes on different performance measures. As in *Apollo 13*, you will have to be careful about two things: being clear about what your are measuring, and making sure all your tests are Fair Tests.

What to Measure

1. Measuring Distance Traveled

Just as you did with your coaster car, you can investigate the effects of changes in the design of your car by measuring the *distance* it travels during a test run.

2. Acceleration Test

Remember, acceleration is a change in motion, and we measure motion as velocity or speed. You can measure differences between balloon engines by measuring how each changes the motion differently. All balloon cars start with a velocity of zero. If we measured the time it takes a balloon car (or in this case a balloon engine) to travel its first 1-2 meters, we could calculate an average velocity for the initial 1-2 meters of travel. Since we start at velocity equal to zero, this velocity could be used to calculate the acceleration. For example, if a balloon engine, Engine A, were attached, and the car traveled the meter in 0.5 seconds, the velocity (Distance/Time) would be:

$$\text{AVERAGE VELOCITY} = \text{DISTANCE} \div \text{TIME} = \frac{1 \text{ METER}}{0.5 \text{ SEC.}} = \boxed{2 \frac{\text{METERS}}{\text{SEC.}}}$$

If another balloon engine, Engine B, were attached and the car traveled the first meter in 1.0 seconds, then the velocity would be:

$$\text{AVERAGE VELOCITY} = \text{DISTANCE} \div \text{TIME} = \frac{1 \text{ METER}}{1 \text{ SEC.}} = \boxed{1 \frac{\text{METER}}{\text{SEC.}}}$$

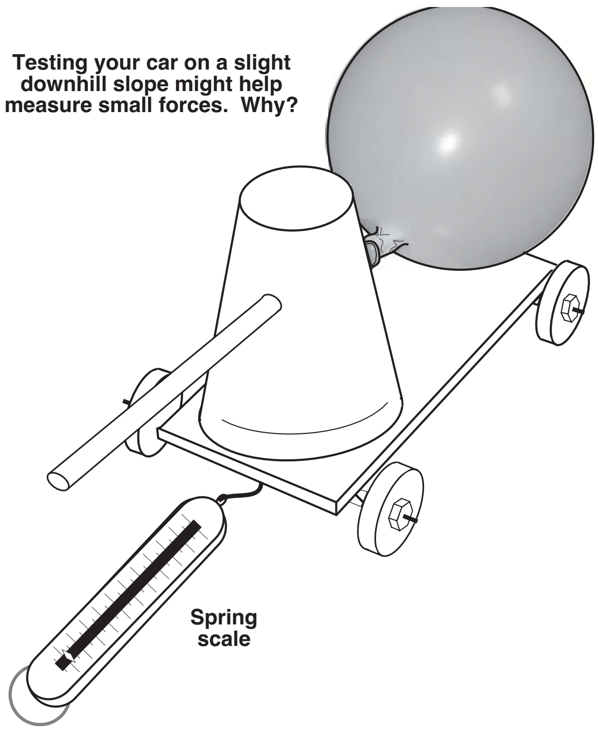
This, of course, means that Engine A reached the 1 meter mark faster than Engine B. So, which car experienced the greater change in its motion? This test can tell you a lot about the engines you are testing. How do you suppose that engine force and acceleration might be related? See if your tests help you discover this relationship.

3. Measuring Force of Propulsion (Optional)

Engineers want to know the f*orce of propulsion* ($F_{\text{propulsion}}$) that an engine produces. One way to

Measuring Your Car's Performance

measure this is to attach a spring scale to the back of the balloon car. When the car is ready to go, release it, and record the forces produced in the appropriate units. Try to come up with other methods for measuring forces. Your team might come up with a better idea than the one shown to the right.



Fair Tests

You should remember from *Apollo 13* the conditions for Fair Tests.

1. Only change one variable at a time.

2. Control other variables that might affect your results.

3. Be consistent with your measurement methods. Don't do it one way one time and another way the next.

4. Make sure you repeat the measurement enough times to be confident of your results.

Are your tests Fair Tests?

Extra Mile - Acceleration by the Numbers

You can use numbers to tell a story of acceleration or how much velocity changes over time. A car going 12 m/sec speeds up to 24 m/sec in 6 seconds. What is the car's acceleration?

Vstart (Vs) = the initial velocity of the body when time=0

Vfinal (Vf) = the velocity of body when the measured time period ends

$$\textbf{Acceleration (A)} = \frac{\textbf{Change in Velocity}}{\textbf{Change in Time}} = \frac{V_{final}(V_f) - V_{start}(V_s)}{\textbf{Time}} = \frac{(V_f) - (V_s)}{T}$$

$$A = \frac{V_{final}(V_F) - V_{start}(V_s)}{\text{time}} = \frac{24\text{ m/s} - 12\text{ m/s}}{6\text{ s}} = \frac{12\text{ m/s}}{6\text{ s}}$$

$$A = \frac{12\text{ m/s}}{6\text{ s}} = \frac{2\text{ meters/sec}}{\text{sec}} = 2\text{ meters /sec}^2$$

The car moves faster by 2 meters per second during every second it travels (2 m/sec^2).

Are Your Tests

Use these pages to check your experiment design and the procedures for running them.

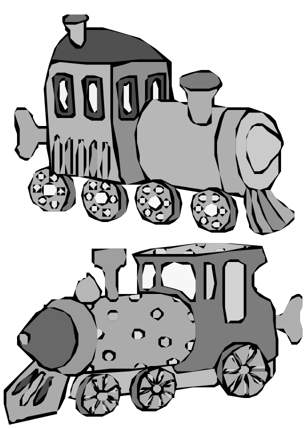
Fair-Test Experiments

When good scientists and engineers conduct experiments, they take special care to make sure their tests are fair. What does "fair" mean?

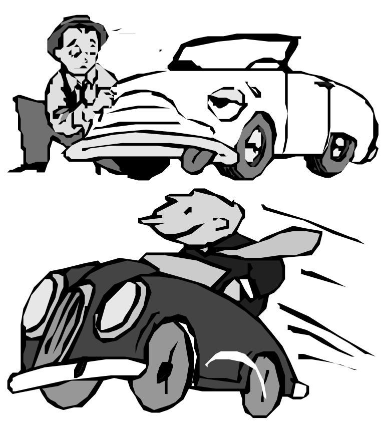
- They are careful about running the experiments in the same way every time.
- They don't base their results on a single or just a few tests.
- They don't give one item an advantage that the other does not have.

Scientists and engineers make sure their tests are "fair" so that their data provides a reliable base from which they can make good decisions. If one product outperforms another, but at an unfair advantage, can you really tell if the better results are because of its qualities, or because of the test.

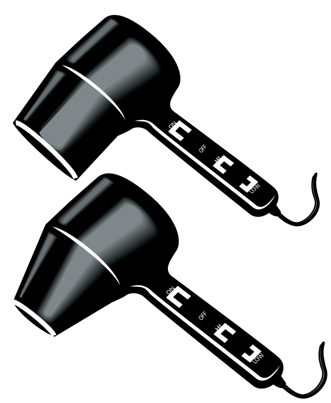
• If you tested two wind-up toys for how long they worked, would it be fair to wind one up only half-way?



• If you were comparing the acceleration of two brands of automobiles, would it be fair to compare a used car of one brand against a new one of another brand?



• If you were testing the drying efficiency of two hair dryers, would it be fair to compare one with a narrow-nozzle attachment to one with a much larger, round opening?



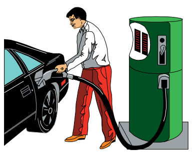
Really Fair?

Here are some issues to be careful of when doing any "fair-testing" of the balloon cars.

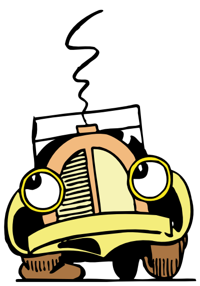
1. Inflating Your Balloon

When you blow up a balloon before a test, do you fill up the balloon the same amount each time you test your car? Would this make a difference?

Filling up the balloon with air is like winding up the spring of a wind-up toy, pulling back an arrow with a bow, or putting fuel in a car. The more energy you store, the more you get back in return.



Fair-Test Question: How could you make sure that for each test run that the balloon is filled up with the same amount? Discuss ideas for doing this with your team and then present in class ways to insure that you inflate your balloons the same amount.



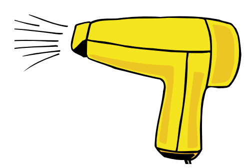
2. Age Of Your Balloon

Does a fresh balloon work better or worse than one that has been used a dozen times? Does a balloon's "age of use" make a difference in the car's performance? Machines and their mechanical parts get old, just like people and animals do. Old car engines leak oil, lose power, and eventually need to be rebuilt or replaced. Old bed springs have less bounce than new ones. Elastic bands in clothing and socks that are old cannot stretch as much and do not provide the same force as when they were new. Fair-Test Question: Design and conduct an experiment that tests whether a balloon's "age" affects your test results?

3. Straw's Opening

Sometimes the opening of a balloon-straw system gets flattened — does the air flow out in the same way when the straws' openings are different shapes? Does the straw's shape of its opening make a difference?

Similar Case: If you put a nozzle on your hair dryer, you get to pinpoint where the air goes. But does the same amount of air get through as a nozzle with a large opening?



Fair-Test Question: How could you test to find out if the shape of a straw's opening makes a difference in the balloon's push on the car? Design and conduct an experiment that tests whether the shape of the straw's opening makes a difference.

4. Other Issues

- Making sure that your tests are fair in part means having good controls in your experiments — making sure that test conditions are the same each time you run your experiment.
- Do your results always come out *exactly* the same every time? How many trials should you conduct to get reliable data about your prototype cars' performance?
- What are some other ways your vehicle tests could be more fair?

Balloon Engine Poster Session

Now that you have conducted experiments, it is time to share and gather information with the entire class. Different groups will have investigated the effects of different balloon engine variables. It is important that everyone learn about each in order to make sound design choices for their future balloon engines. You will have a Balloon Car Experiment Poster Session.

Be prepared to discuss your findings during the poster session. When listening to the presentations, it will be important to ask the questions you need answered to understand results, and to satisfy yourself that the results and conclusions others have drawn are valid. You may need to send some groups back to re-do their experiments. Be sure that you believe the results other groups report.

Your Poster

Include in your poster a Rule of Thumb about the design of a Balloon Car engine. Your poster should include an explanation of the Rule of Thumb that is based in the science concepts you have studied so far. Think about what the balloon engine is doing to the force and net force acting on the car.

Listening To Your Peers

Make sure that you can answer this set of questions after each presentation:

1. What was the group trying to find out?
2. How did they do it?
3. What did they learn?
4. What rules of thumb do their results suggest?

Explaining Rules of Thumb

Do your best, as a class, to explain the rules of thumb that have been proposed. Some rules of thumb will be easy to explain; some you can't explain yet. You will return to these Rules of Thumb later after you look more closely at the science of these balloon engines. You may want to amend, or change, your Rules of Thumb then to better reflect what you learn about force and motion.

Experimental Results:

More On Paired Forces
You have been exploring how forces occur in pairs when two objects interact. Remember our definition?

A force is a push or pull that comes from an interaction between two objects. The net force on an object causes its motion to change.

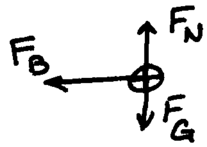
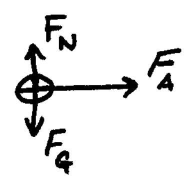
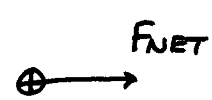
But you know something more about how forces are created when two objects interact. You know that each object experiences a force from the other object that is equal in size and opposite in direction. So, we can derive a new definition:

A force is a push or pull that comes from an interaction between two objects. The net force on an object causes its motion to change. Each object experiences a force from the other object. These two forces are equal in size and opposite in direction.

Let's consider the example of a head-on collision between two billiard balls (pool balls).

The balls roll toward each other. When they strike, they each experience a force from the other. This would also be the case if one was at rest and the other collided with it.

Look at the force diagram and net force diagram for each billiard ball below.

	Ball A	Ball B
Force Diagram		
Net Force Diagram		

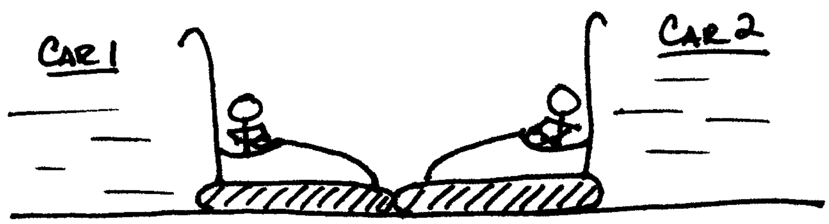
What's Really Happening

We also know that there is going to be an acceleration in the direction of the net force.

	Ball A	Ball B
Acceleration	←	→

Isn’t that what we see in real life? Each ball accelerates in the other direction, or at the very least goes from "moving" to "at rest".

Let’s consider the example of a head on collision between two bumper cars.



Draw the force diagram and net force diagram for each object below. Compare your diagrams with those of your classmates, and discuss them as a class.

	Car 1	Car 2
Force Diagram		
Net Force Diagram		
Acceleration		

Go on to the next two pages only after you draw your diagrams and discuss them as a class.

Experimental Results:

Car 1 experiences a force from Car 2, and Car 2 experiences a force from Car 1. It is important to remember that these forces play a role in determining the net force, but they are not the only forces involved. Car 1 and Car 2 experience equal forces, but what can you say is different about the two forces created? They are in opposite directions!

Now, you try!
Below, sketch an example where two objects interact and experience equal and opposite forces from one another. For each object, predict and explain what each object will do when they interact. Then, draw a force diagram and a net force diagram. Make sure your force arrows accurately depict the forces generated between the two objects.

Prediction for Object 1

Prediction for Object 2

(Sketch)

	Car 1	Car 2
Force Diagram		
Net Force Diagram		
Acceleration		

Did your force diagrams match your prediction? Share and discuss your examples as a class and verify each others diagrams.

What's Really Happening, cont.

In the bumper car example provided earlier, let's pretend that Car 1 is standing still, and that Car 2 is moving. Consider what will happen when the two cars interact. How will the motion of each car change? Draw the force diagrams for each car at the moment of impact. Discuss your answers with your classmates and teacher. (Hint: Should the diagrams look different than before? Why?)

	Car 1	**Car 2**
Force Diagram		
Net Force Diagram		
Acceleration		

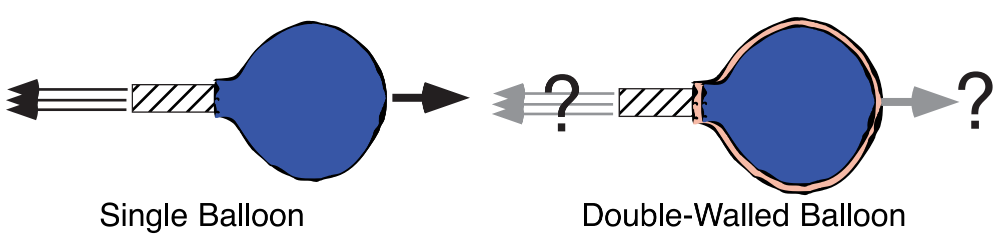
Net Force and

When you performed your experiments, changing the design of the balloon engines, you were altering the force of propulsion. From the earlier discussion of Forces in Pairs, you learned that the balloon pushes on the air in the balloon and that the air in the balloon pushes back on the balloon. Since the balloon is connected to the car, we can say that the car pushes on the air in the engine, and that the air in the engine pushes on the car. By changing the way the car (balloon) pushes on the air, we see changes in the way the air pushes on the car. We see a change in the force of propulsion.

You know that net forces create accelerations, changes in motion. The force of propulsion is a factor in determining the net force acting on a car. Write a statement that describes the relationship between the force of propulsion (Fp) and the acceleration the car experiences. (Hint: How do changes in the Fp change the Fnet?)

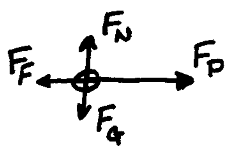
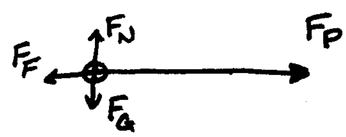
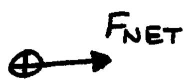
Referring to the notes you collected during your poster session, look at the balloon engines that greatly increased the performance of the car. Do you see a trend? What was happening with those balloon engines in terms of force? Discuss this with your class and then continue to read on.

Let's look at one engine change idea. Double ballooning, placing one balloon inside another, creates an increase in performance in most instances. You probably noticed that a double balloon is difficult to blow up. That's because there is double the elasticity compared to one balloon. The balloon pushes harder on the air inside, so it is harder to blow the air into the balloon. Once the double balloon is inflated the push on that air is increased.



Acceleration

Since forces occur in pairs, the air in the double balloon pushes harder on the car compared to the air in the single balloon. The result of this engine design is a higher net force that accelerates the car, changing its motion faster than a single balloon.

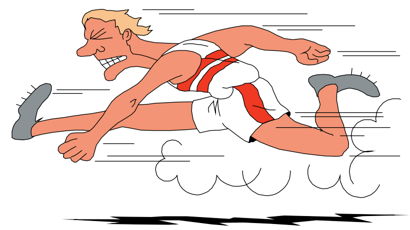
	Car w/ Single Balloon	**Car w/ Double Balloon**
Force Diagram		
Net Force Diagram		
Acceleration		

There is a link between net force and acceleration. Larger net forces create larger accelerations, and smaller net forces create smaller accelerations. This not only works for objects speeding up, but also for objects that are slowing down. Think about a car that brakes very hard...doesn't the car negatively accelerate very quickly when the brakes are pressed very hard? Look at your experiment and the others from the class. Which variable changes produced lower net forces and accelerations and higher net forces and accelerations? List them here.

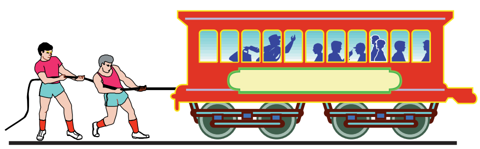
Net Force and

Look at the following examples where the size of the net force matches the size of the acceleration.

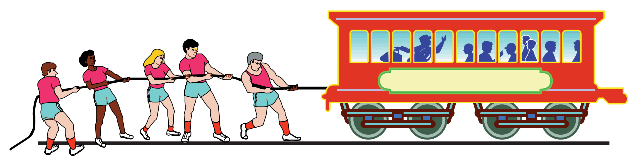
Average force, average acceleration



Extra force, extra acceleration



Small force, small acceleration



Added force, added acceleration

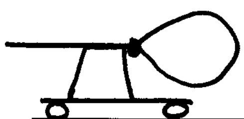
Homework
Find 3 examples where an object or person changes the net force acting on it.
a. Describe the situation where the net force changes.
b. Draw the force diagrams before and after the change.
c. Describe what happens to the acceleration after the force changes

Acceleration, cont'd.

<u>New Motion Storyboard</u>

Fill in the Motion Storyboard below for the balloon car shown. Assume that that in Section 1 the car is at rest with the balloon inflated but not yet released. In Sections 2 and 3, the balloon is deflating, and the car is moving across the floor. In Section 4, the balloon has completely deflated, but the car continues to coast across the floor. Finally, in Section 5, the car is stopped with the balloon completely deflated.

In the row marked Acceleration, draw an arrow to represent the direction of the acceleration. Remember, slowing down is negative acceleration and the arrow would point back toward the car. Also, the size of the acceleration arrow would represent the size of the acceleration…just like with force arrows. The length of the arrow shows how much it is slowing down or speeding up.



	1	2	3	4	5
Force Diagram	F_N F_G				
Net Force Diagram	$F_{NET} = \phi$				
Velocity	**Increasing** **Decreasing** **Stays the same**	**Increasing** **Decreasing** **Stays the same**	**Increasing** **Decreasing** **Stays the same**	**Increasing** **Decreasing** **Stays the same**	**Increasing** **Decreasing** **Stays the same**
Accel.	Acc. = ϕ (NO ARROW)				

<u>Return to your experiments, and create Motion Storyboards</u>

Review the experiments you performed. Using your data, create a Motion Storyboard that shows the force diagram, net force diagram, and velocity of your balloon car engines. Then, in the last row, draw an arrow that represents the acceleration of each car. Create a motion storyboard for each value of the variable you tested. For example, if a group tested how the number of engines affected the force on the car with 1, 2, and 3 engines, this group would have three Motion Storyboards. Make sure that the storyboards are correct relative to each other. If the force increases with a different design, the force diagrams should represent this occurrence. Afterwards, hold a Gallery Walk to share and compare the motion storyboards from your experiments. Check to make sure the storyboards match the results of the experiments, especially if more than one group tested a particular variable. Return to your rules of thumb, and, as a class, try to explain each using what you just learned.

The Balloon Car Challenge

Finally, the moment is here. You are about to begin designing and building your best balloon car. Your balloon car will potentially be run through 3 tests. You will need to maximize propulsion and lower friction to succeed in all of these challenges. First, you will run your balloon car to see how far and straight the car can travel across a flat surface. Second, your group will compete in a Tug-of-War match with your vehicle. Finally, we will see how much of a load your car will transport. This is called the Stall Load Activity. Details for this test are described later.
Good luck in all three challenges!!

The events described on the next few pages should take a few days, so do not feel that you have to accomplish all of them today. Here's the basic plan:
1) Return to the Whiteboard
2) Plan a "Best Balloon Car" Design
3) Pin-Up Session for your Planned Design
4) Construct and test your "Best Balloon Car", explain its behavior, Gallery Walk (and Rules of Thumb), Redesign, Iterate
5) Distance Challenge, Tug-of-War Challenge, and Stall Load Challenge
6) Revisit & Revise Rules of Thumb

Return to the Whiteboard

Returning to your class whiteboard, review some of the Learning Issues you have tackled and any new ones that have risen. Review the experiments, poster session, gallery walks, and rules of thumb to better update your whiteboard.

Then, identify some new questions you have. Now that you understand that several design changes can be made to increase propulsion force, how do you want to combine them? Which have priority? What lessons from coaster car can you incorporate into this car? Which do you still want to try?

Update your whiteboard to get ready for the next step…designing your best balloon car.

Design and Build Your Best Car

Plan Your Best Balloon Car

It is time to plan for your final balloon car. Make a very simple sketch for homework, or in class (up to your teacher). Describe some features of your idea for a final balloon car, and justify each one. Then, as a group, discuss and evaluate the ideas everyone has brought to the table. As a group, decide upon a design plan, and create a Pin-Up of your group's plan.

Remember, you should base your design plan on the facts that you have learned from your experiments and the experiments of others. You will need to justify your design decisions with evidence from experiments and gallery walks, and what you've learned about forces and motion.

Make a poster with a drawing or sketch of your best balloon car. Your poster should have details about the design choices you have made, justifications for those choices that are based in the science you have been learning, and you should cite some Rules of Thumb that your class has created. Then conduct a Pin-Up Session in your class. Your teacher will set the guidelines for that session, and you will want to take some notes. Use the guidelines from the launcher book about how to conduct a quality, useful Pin-Up session.

The Last Design Phase

Once you have conducted your Pin-Up Session, you will begin building your best car. Each time your build and test a car, fill out a "Testing My Design" sheet. Of course, you will want to share your design in a gallery walk. Then, use the feedback from your tests and your gallery walks to plan your next best design. During each iteration, create a Motion Storyboard for your design. Each one should have force diagrams, net force diagrams, velocity, and acceleration. Make sure that the Motion Storyboards are accurate relative to each other.

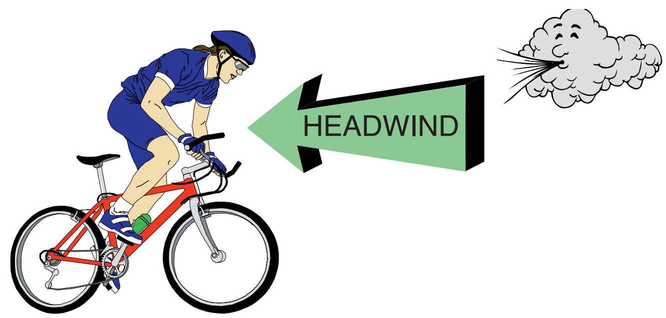
You will not have unlimited time to complete this process. Your teacher will determine how long you have to design your best car and how many iterations and gallery walks you'll have time for. Your teacher will also tell you which of the three challenges you will compete in. At the end of this module, you will have a shot at traversing the test track. This test track offers hills and a rough terrain, so be ready!

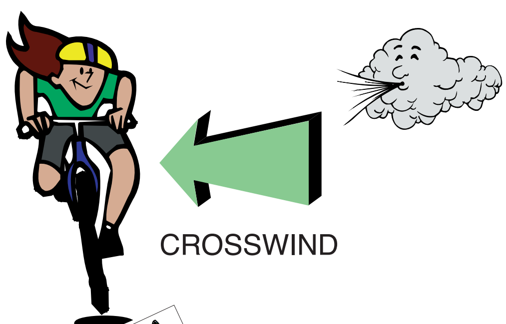
Combining

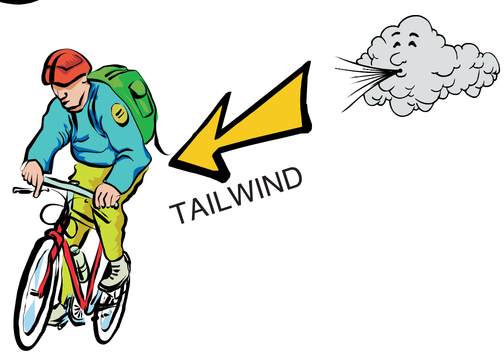
One approach to designing your propulsion system that you may already have been considering is combining two or more balloon systems to run on the same car. But is two or more better than one? To answer this question, think back on some of your own experiences while looking at the cases below.

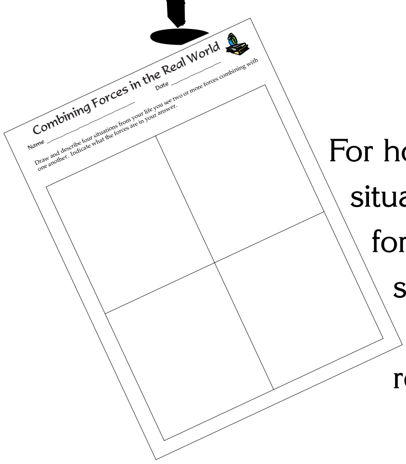
A. Would two engines on a boat provide more speed than one?

B. Does the wind in each of the three cases below combine with the biker's pedaling force to make her or him go faster? slower? the same speed?









Homework

For homework, try to come up with four other events and situations where forces got combined. What were the forces involved, and what was the situation? Use sketches to show these situations, and use arrows to indicate the direction and strength of the force, and the results or outcome of combining forces.

Forces


Extra Mile

Experiments with Combining Forces

Review of Forces

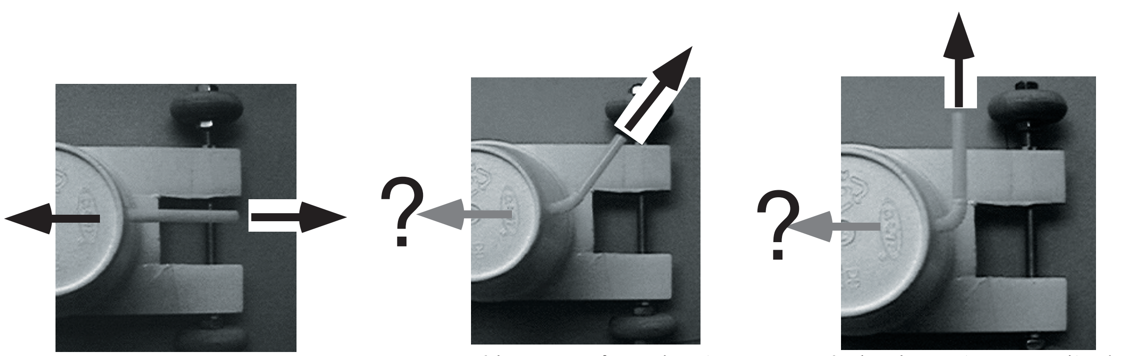
Forces have a size or **magnitude** — forces can be strong or weak. They also have a **direction** — forces can be directed backwards or forwards, up or down, left or right, etc. (See Vocabulary pages)

You are going to have a chance to do some "messing about" and experimenting with your balloon-straw systems to see the effects when different forces acting in different directions combine. You already know some things on this topic. Think about a tug of war, the mover trying to get the refrigerator out of the kitchen, and the examples from Coster Car.

Guidelines and Goals of Your Experiments

You will examine forces alone and combined with each other. Here are some guidelines for you to do this:

- You can incorporate two or more balloon-and-straw systems on the same car.
- You can use bent-elbow straws to change the direction of the balloon's force. (Is there another way to change the direction of the force on your balloon car using a straight straw?)



Propulsion from straw provides equal and opposite force on car

45° has same force, but in a different direction

At 90°, the thrust is perpendicular to the line of travel

By the end of your experimenting, you should understand how the following kinds of forces combine:

a. forces pointing in the same direction
b. forces pointing in opposite directions
c. forces that are perpendicular to each other

- My Experiment

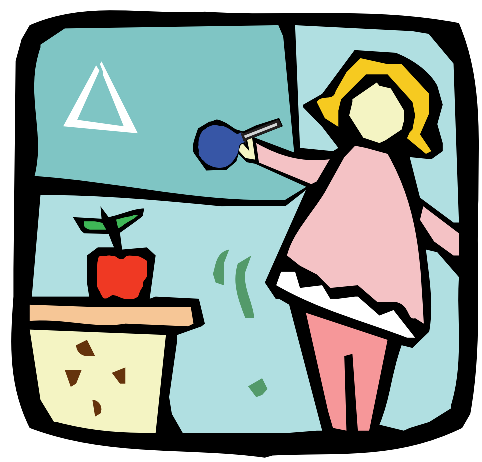
Your task here is to design and run experiments to learn these things. Even though learning is the key issue here, don't forget accuracy during testing and other features of designing a good experiment.

Balloon Car Presentation:

Introduction

You have built and rebuilt and designed and redesigned your balloon cars to maximize the distances they can travel. This process is similar to what good industrial design companies do — get to know the product and its various uses to help them better focus on the design task. Now is the time to see whose car goes farthest on a flat test track.

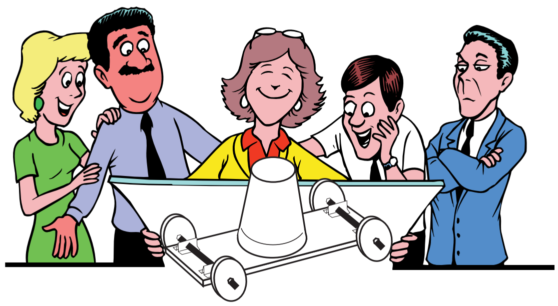
Test Run and Presentation

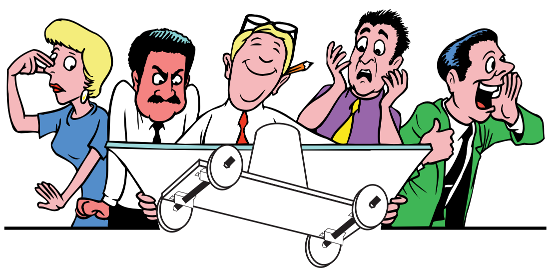


You will give a brief presentation about your car, show its performance, and then answer questions from your classmates and teacher.

1. In your presentation, show evidence both of your design and science thinking. This means showing ideas that you considered, including some that you built and discarded, and the results of experiments you have conducted. Be sure to explain what you observed in your early designs and what made you decide on the changes you made in your cars.
2. Run your car for the entire class.
3. After you demonstrate your car, comment on what you noticed, and say something about how you would improve your car if you had more time.

Distance Challenge





Observing the Presentations

As you observe others' presentations, you will both be learning from and assessing the work of the other teams. Use the "Gallery Walk Observations" pages from the Design Diary for taking notes, based on what you hear and see during the car talks and demonstrations. Write your notes with two goals in mind:

(1) for the other teams to use as feedback, and

(2) for your own use in designing a better car for the final challenge.

Include the topics below in your notes:

Checklist for Assessing a Presentation

It's helpful to know how you are going to be evaluated for a presentation -- here is a checklist of three important areas your work, and others that you watch, should address for the presentation for this and the final sections of *Vehicles in Motion*.

Design Ideas — How good did the design ideas seem and why? Was the history of the design idea clearly shown?

Science Ideas — Did the team give good reasons for their design decisions? What science ideas did they use well in their talk?

Presentation — How clearly did the team present their ideas via graphics, data charts, and other test results?

A Challenge of Balloon Car

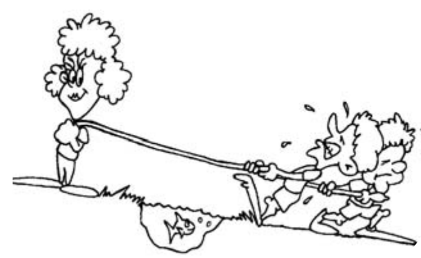
Entertainment on the South Pole

The few species of animals and plants that live in the Antarctic have to survive in some of the harshest conditions on the planet. Some of the coldest temperatures and months-long periods of darkness during winter. You would see endless stretches of ice, barren rock, even desert!

Life for humans in Antarctica has additional problems. Equipment breaks and fails much more easily than elsewhere. Trash disposal is always a problem. Communication with the rest of the world is quite difficult. Also, since few people stay in Antarctica, friends are few, and live entertainment is scarce.

The Antarctic group for whom you are designing a car wants, even needs, to have some fun!! To entertain themselves, they are planning to have a tug-of-war -- but they don't want to use people in the competition because of the risks involved. Instead, they want to use the balloon car models you have been designing for them.

What are some creative, fun, and fair ways of doing tug-of-war with your cars?



As a class, you need to come up with rules for this competition and decide how it should take place. How many cars on each side? On what sort of "playing field" will the tug take place? What conditions are important? What would make a tug-of-war unfair? How will you know who the is winner, and by how much? Can there be a tie? How will you connect your cars together?

As you might guess, this is another design task, one that at least requires planning if not testing and designing. Popular games like baseball, basketball, and football did not get invented in a single moment -- the rules of each of these sports changed over time as people had better ideas for what would make for a more interesting, and fairer, game. Can you think of recent rule changes in these sports?

Once you have designed and decided on the rules, you are ready to play. But before you do, think about this. As you designed your game, did you notice how you did it? What was similar and different about designing rules versus designing devices and products?

Combining Forces

Tug-of-War

The Competition

For the final tug-of-war competition, you may be cooperating with a number of teams. As you play, notice what kinds of designs work best when connected together. How do the cars interact with one another? How are forces combined?

After the match, each group will give a short report to the class on what you learned about creating the best Balloon-Car Tug-of-War system. Report on tests you ran and what worked best for the competition. Be sure to tell (1) what you are proud of in your design, and (2) what you would improve on to make it a better car for a next tug of war.

Homework

1. Imagine placing a balloon car on a ramp with its balloon facing uphill and its straw pointing downhill. Draw a sketch of the car, with a system balloon around this car. Indicate what forces affect its motion when the car with a filled balloon is released.

2. Now imagine the same car pointing in the opposite direction, with the balloon pointing downhill and the straw pointing back up the hill. Make a drawing of the car, a system balloon, and the forces at work on it when the car is released. What will be the difference in performance between the car in the first and second situation?

An Extra Mile Experiment

Extra Mile

Just about everyone knows that a coaster car will go farther and faster going down a steep hill compared to a hill that has a more gentle slope. But what will happen if you add more mass to the car? Will that result in your car behaving differently when it goes down the hill?

Take out a piece of paper or an index card, and write out a prediction:

> A heavier coaster car will travel (faster / slower / the same) as a lighter coaster car, when both go down the same ramp.

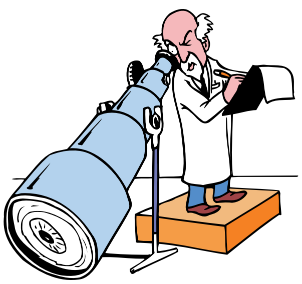
After you write out your prediction, write a sentence to explain why you think your prediction is correct. Then try it out, and see if your prediction was correct. Be prepared to report to the class your prediction and the results you observed.

Adding Load

Carrying Heavy Things in the Frozen Antarctic

In the Antarctic, there sometime is a need for vehicles to carry heavy loads over the frigid, icy terrains. In this activity, you will investigate how payload affect the your vehicle's behavior. A payload is the total weight of the cargo carried by a vehicle. The cargo does not include the weight of the vehicle or the propulsion system. What kinds of balloon car behavior could you measure as you do experiments with different payloads on your balloon car? Remember, you have already reported the distance traveled in earlier vehicle tests. What else might you want to measure? How could you display these data?

Testing Your Engines With Different Loads



One way to test how mass affects the behavior of the vehicle is to slowly increase the car's mass and and observe its performance for each payload. Do this by adding a small mass to the car, inflating the balloon and releasing it. Recording its distance traveled, speed, and anything else you decide to measure, and put your results in a "My Experiment" Design Diary page. Repeat the test as many times as you think you need in order to get reliable data. Then add more mass to the car, and repeat the testing.

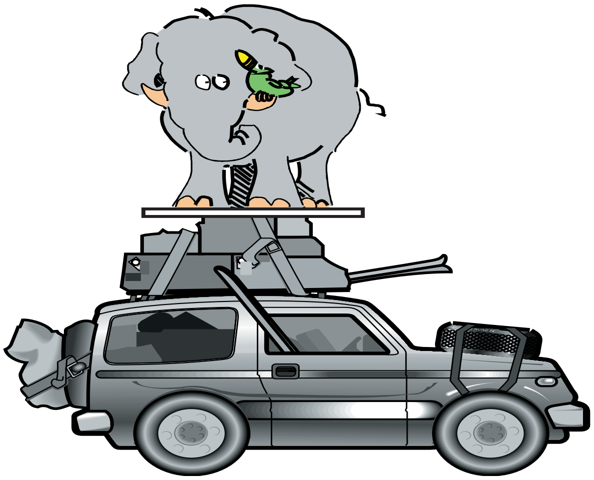
You might want to continue adding mass until the vehicle does not move. Reduce it by a little, until the car barely moves. The lowest payload where the car does not move is called the **stall load**.

Cases of Stall Loads

In 1997, a number of climbers attempted to reach the top of the hightest mountain in the world, Mount Everest. Some of Everest is located in the country of Nepal, which lies between India and China -- the rest is in China. The climbers got caught in a blinding snowstorm, with a windchill of below -80° C. (lower than -100° F.). One climber needed to be evacuated or he would die. The government of Nepal sent a medical helicopter on a dangerous mission — to fly up higher than the vehicle was designed to go to rescue the climber.

When the helicopter arrived in the high mountains, it loaded its passenger on board. The helicopter had less thrust to lift up because the air is so much thinner in the high altitudes. The pilot ran its engines at full power. The craft could barely lift off, but it did, and the man's life was saved. The helicopter had nearly reached its **stall load**.

to Your Car



An Uninvited Pachyderm

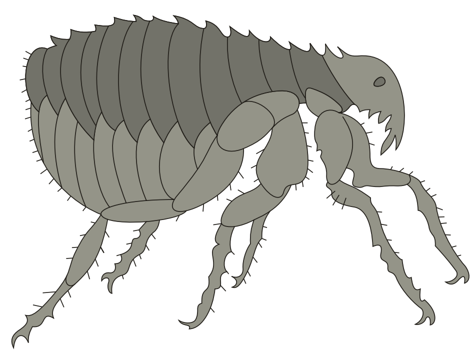
A family plans to drive through the Rocky Mountains with a full vehicle. When an unexpected guest joins them, the load on the axles and friction on the bearings increases. The car will not move. It has <u>gone beyond</u> its **stall load**, and it cannot move.

A Porter with a Problem

A porter at a hotel is trying to carry a backpack of a world traveller up to her 4th floor room. The problem is that the hotel has no elevators, and the hiker put all of her clothes, cooking gear, even her computer, in the backpack.
Even before the porter takes his first step, he says, "I can't walk — this is too much to carry."
He has <u>gone beyond</u> his **stall load**.

Fantastic Flea

Here is a true story of how little forces can make big things move. A scientist attached one end of a string to the back of a trained flea and the other end to a dry-ice puck with a weight on it. The flea is so small it is hard to see. The load, which is thousands of times heavier than the flea, rides on a cushion of gas. Amazingly, the flea jumps and pulls forward and moves the large canister on the puck, very, very slowly.



Homework

1. Run some tests to find out the stall loads of the current cars in your class. Why do different balloon-and-straw systems have different stall loads?

2. What is the key difference between the flea story above and your balloon car with a heavy load?

3. Extra Mile Question: Make a sketch or drawing, and write an explanation of why a heavy load causes a model car to stall.

Investigating Stall

You have been looking at the behavior of your car as you increased its mass. What did you see? What happened to the acceleration of your car? As a group, come up with a Rule of Thumb that describes how the acceleration changed as the mass got larger. Be sure to include in your rule any variable that you found you had to control.

Rule of Thumb: How Acceleration Depends on Mass

Does your Rule of Thumb agree with what other groups discovered?

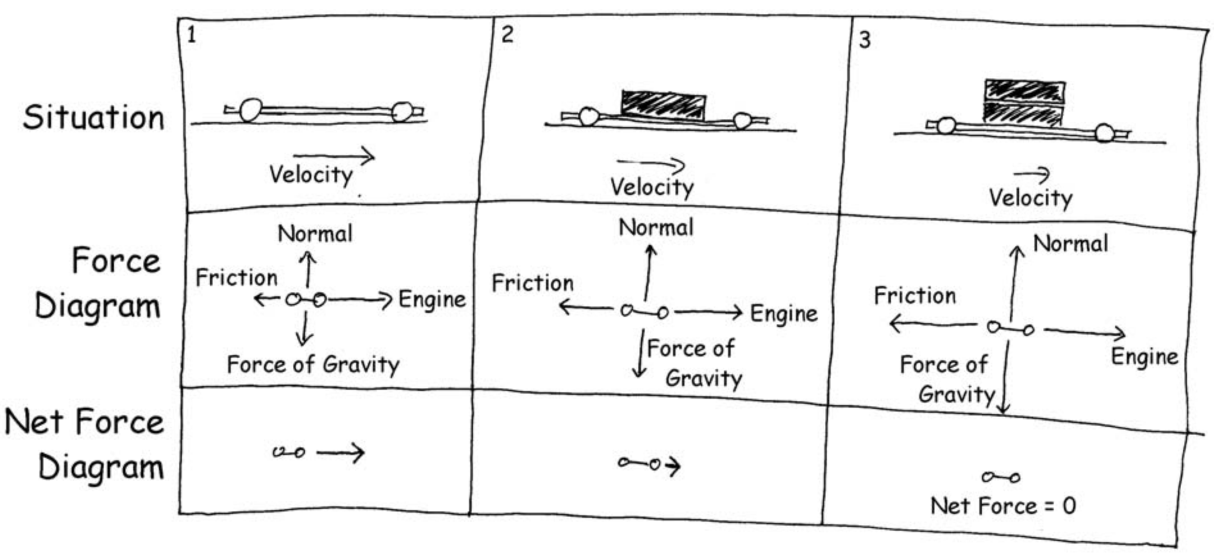
Your Rule of Thumb helps you to understand why the acceleration changed. But it does not help at all in understanding why the acceleration went away when you reached the stall load. To understand that, you have to know a little more about friction.

Friction and Stall Load
Try this simple experiment:

1. Slide your hand lightly across your desk, and feel the friction force.
2. Now press your hand hard against the desk while sliding. Feel the friction force again.

Did you find that the friction increased as you pressed harder? Your car feels the same thing. As you add mass to your car, the axle is pressed harder against the inside of the straw. The wheels are pressed harder against the ground. And, just as with your hand, the harder these things are pressed together, the larger the friction becomes between them.

A sequence of force diagrams might look like this:



Load Science

As more mass is added to the car, several forces change:
◊ The force of gravity gets larger
◊ The normal force gets larger (the ground has to hold up more mass)
◊ The friction gets larger (the car is pressed harder against the ground)

But one important force does not change:
The engine force stays the same

The force of gravity and the normal force always balance. In the first two cases, the force of friction is smaller than the engine force, so the net force is in the direction of the engine. The net force gets smaller, but it is still there, so the car still accelerates.

In case 3, the force of friction and the engine force balance. Since all the forces are in balance, the net force is zero. There can be no acceleration, so the car never gets moving. It has reached its stall load.

Reflection Questions

1. If the friction always stayed the same, no matter how much mass was added, would your car still have a stall load? Explain your answer using force and net force diagrams.

2. How could you use gravity to increase or decrease the stall load? Draw force diagrams that show each of these two situations. Have you had a similar experience?

3. Can you think of any other way to change the stall load? Explain your answer using force diagrams.

4. Is the flea story an example of stall load, or is it an example of your Rule of Thumb? Explain your answer. Come up with another example that illustrates your rule.

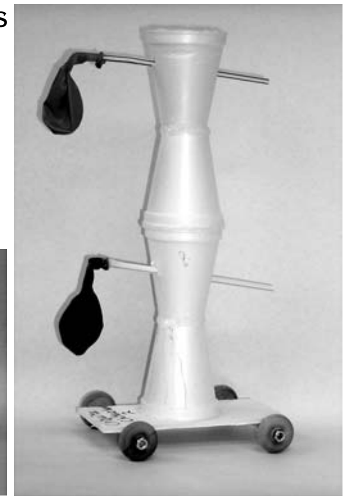
5. Extra Mile Why doesn't the car move backwards when you have added more mass than the stall load?

Class Statement

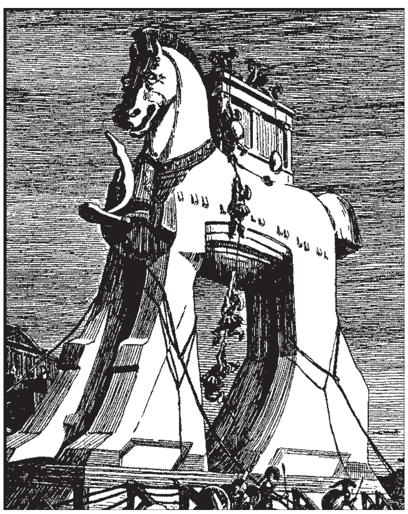
As a class, write a clear statement about force. Be sure to include information about how they are formed and how forces work in pairs. Discuss the relationship force has to motion and acceleration, and discuss the effect mass has on force and acceleration. Debate your statement as a class, and try to come to consensus. You will revisit your statement later.

Review & Summary

1. Use force diagrams and your Rules of Thumb to explain what happens to a balloon car's performance before and after you increase its load so that you double the car's total mass. Extra Credit: What happens to the coaster car's motion when you double its mass?

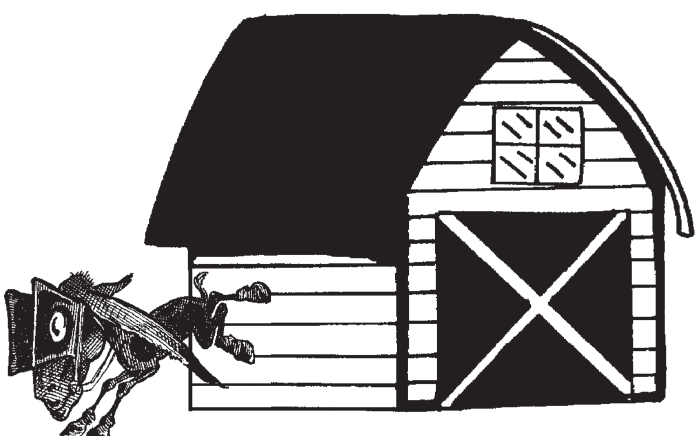


2. Use force diagrams and your Rules of Thumb to explain what happens to a car's performance as it runs when you use two balloon-and-straw systems versus one, when the masses of two vehicles are the same.



3. Explain how a rocket moves and how the Trojans moved the famous wooden horse inside their city (that led to its destruction) using what you know about forces. Explain your answer using force arrow and net force diagrams.

4. Explain using words and drawings the forces involved in a mule kicking a barn and a frog jumping off a log.



Section 2 Balloon Cars

<u>Diagnosing car problems</u>

5. Your friend has a balloon car that speeds up very quickly and then slows down very quickly. Predict what you think are key features of the balloon car's design, and its major flaw, based on this description of the car's performance? What might you do to improve this performance?

<u>Designing Experiments for Testing Cars</u>

6. Describe three things you need to be careful to control when doing experiments and gathering data on a newly designed balloon car.

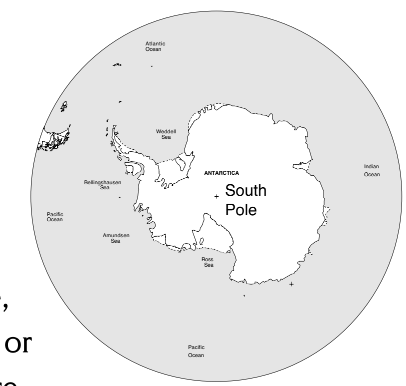
7. Give a short definition, and draw a simple sketch to explain and illustrate the following:
Speed versus Velocity —

Weight versus Mass —

Stall Load —

8. Describe two possible strengths of using balloon car-type propulsion for use in the Antarctic Challenge. Give at least one reason for each of your answers.

9. Describe two weaknesses of using balloon car-type propulsion for the Antarctic Challenge, and give reasons for your answers.



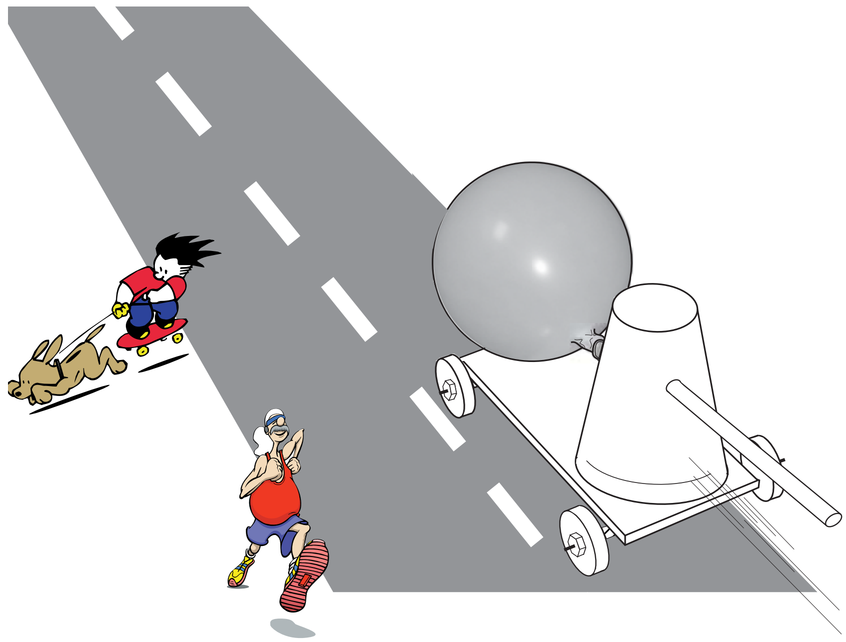
10. Write a one-paragraph description of what you team has done in improving the design of your car. Focus on the two or three big decisions you have made, and tell what reasons you had (or discovered) to support these decisions.

11. Look over the LBD™ Cycle chart. Which steps have you not done, or not done for a long time? Give a plan for when you might do each, or an explanation why they are not the right steps to take in the near future.

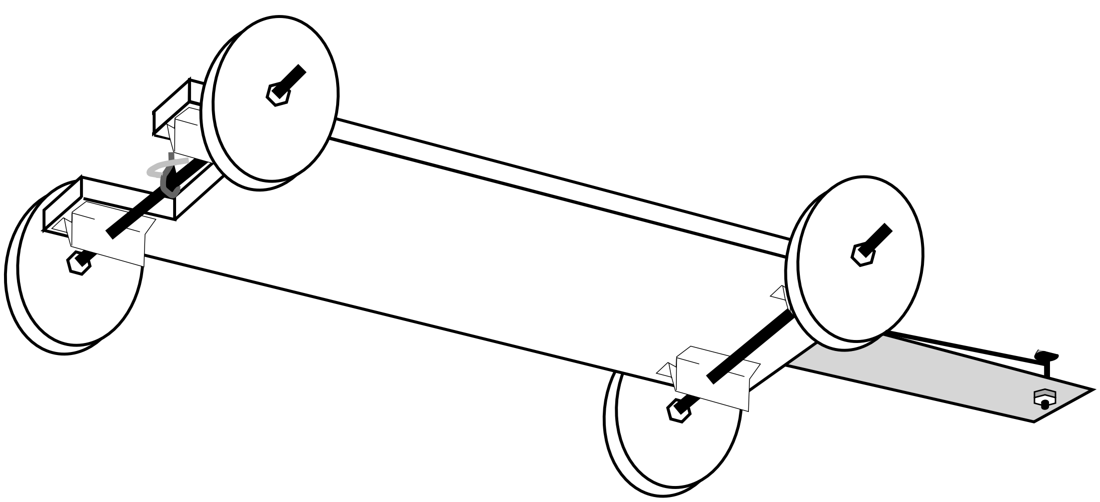
12. Test your car on the flat test track <u>twice</u> and use the better test to represent your car's current performance status. <u>Then</u>, predict how you think this car will run on a track with a 5-cm and a 10-cm hill. Test your balloon car twice on the hilly track, and report on what you saw, and tell why you think your car performed the way it did, and why it behaved the same or differently than you predicted.

13. Write up a new set of Product Specifications that you think your car should meet, now that you have seen how well your car works on hills. Focus on, "What more do I need to learn about propulsion systems to make the best car for a hilly track?"

Vehicles in Motion
Section 3



Rubber-Band Cars

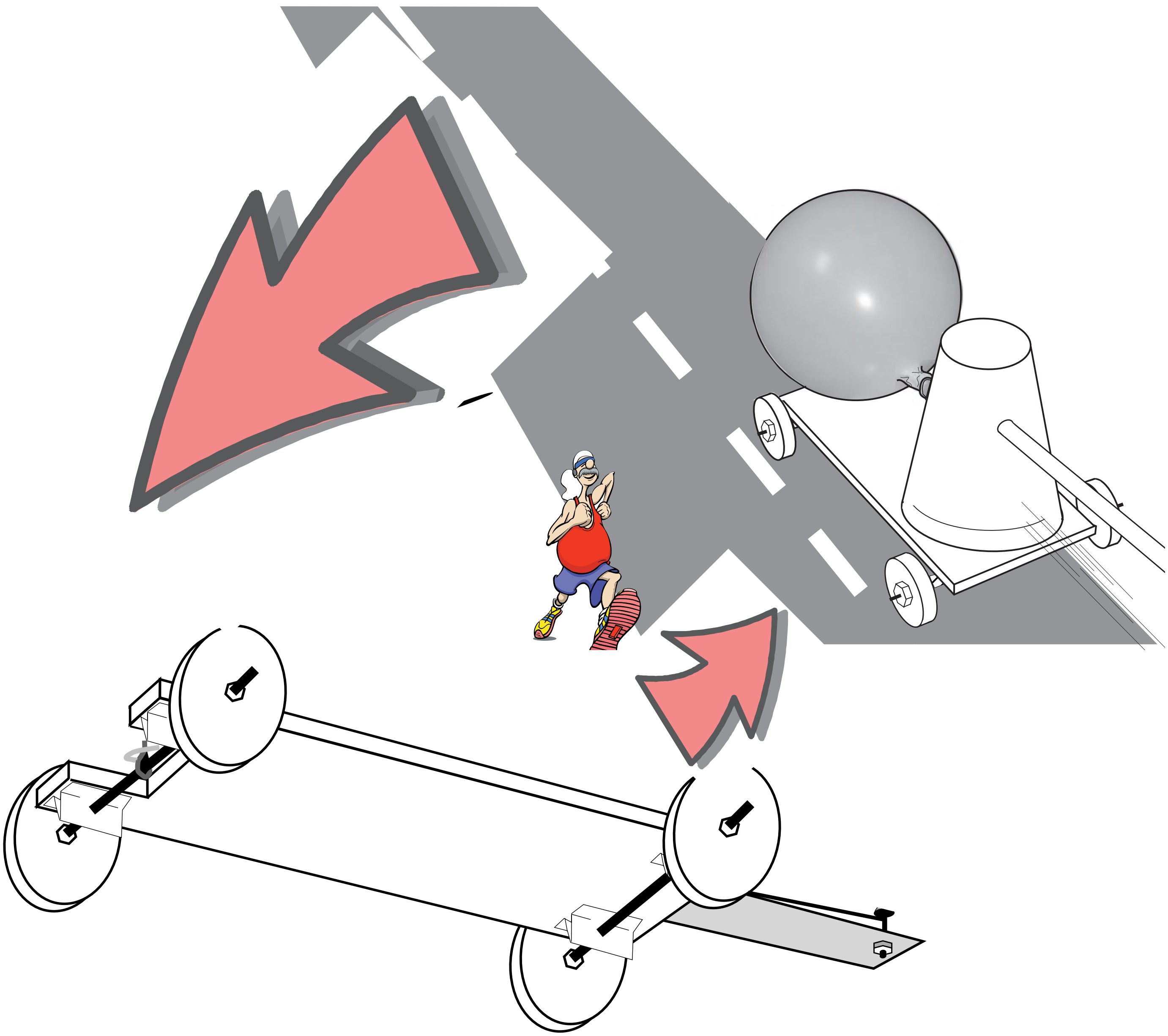


Section 3 Table of Contents

Rubber Band Car Challenge

The Challenge

In section 3 of Vehicles in Motion, you will be given plans for building a new propulsion system -- one using rubber bands. You will compare this new engine to the balloon engine, and find out how well each one suits the challenge. You will experiment with them, and then you'll design the best rubber band powered car based on all the systems you've seen thus far.

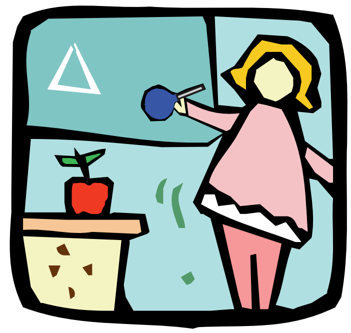


Rubber Band Car Objectives

Product for the Rubber Band Car Challenge

In the Rubber Band Car-Run Challenge, you will test your best car design on a test track, with the aim of getting your car to travel the furthest distance possible, under its own power.

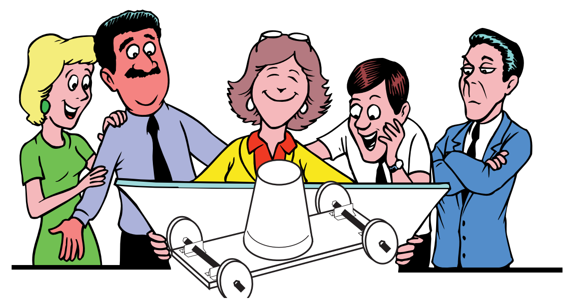
Project Presentation



Near the end of Section 3, you will give a brief presentation about your car, show its performance, and then answer questions from your classmates and teacher. Your presentation should include the following:

1. Evidence of your design process, tests of car performance including ideas that got discarded, and science thinking. Your tests should include a graph that approximates your car's performance in a test run.
2. Run your newest car design for the entire class on a test track.
3. After you demonstrate your car, comment on what you noticed, and say something about how you would improve your car if you had more time.

Observing the Presentations



As you observe others' presentations, you will be both learning from and assessing the work of the other teams. Use the "Gallery Walk Notes" and "Pin-Up Notes" to record feedback on your own car's design, and ideas from other teams' designs.

Assessment and Objectives

Your Rubber Band Car Challenge presentation will be reviewed by your classmates and teacher, and will be given a score. You will also do homework and take a quiz on the science and technology concepts presented in this and previous sections. These ideas include:

- Science skills: Using graphs to tell stories and interpreting what they say about car performance
- Technology skills: Evaluating technological products (balloon and rubber band cars); understanding the LBD™ Cycle
- Science concepts: Newton's Laws of Motion; acceleration and velocity; science ideas to support design decisions

Section 3: Addressing the

Your main goal in Section 3 is to examine what you have been learning about forces and motion in order to come up with a new engine design to better control the way force is provided to your car. You will look at what science formally has developed to describe forces and their affect on motion by exploring Newton's Laws. Then, you will investigate how graphing the force and velocity of your car's motion can influence design changes that might lead to success on the test track. You will iteratively build and test a Rubber Band Car, continuing to focus on how Newton's Laws are in action. Finally, you will build and test your best Rubber Band Car. You'll work on the Rubber Band Car Challenge for about 8-12 days. Here is the sequence of activities you will be following for Section 3:

Procedure

1. A Look at Two of Newton's Laws: Review the statements you and your classmates have been formulating over the past several weeks about the nature of forces and motion. You will then look at Newton's First and Second Laws of Motion. You will try to see how your ideas of forces and motion match up with Sir Issac Newton's ideas.

2. Graphing Force and Motion: To better understand the relationship between net force, acceleration, velocity, and distance with your cars, you will look at how graphing these aspects versus time (the time it takes your car to complete a run). Your motion storyboards will help you create the graphs that tell a story about how your car travels, similar to how the storyboards tell a story.. These graphs and a short experiemnts will show you that a new engine is necessary.. Return to the whiteboard to discuss new learning issues, and create new ideas to try out in the future.

3. Building the Rubberband Car, Messing About, and More Whiteboarding: You will be given basic instructions to build a Rubber Band Car. Then you will Mess About to get a feel for this new engine, and conduct a Gallery Walk to review and discuss your observations with the class. Return to the whiteboard to update its contents, now focusing on the Rubber Band Car. Begin to formulate ideas and variables for running experiments.

4. Learning Newton's Third Law: As you did before, you will be exploring Newton's Third, and final, Law of Motion to get a better understanding of how this engine and car work, and how it is differrent and similar to the other cars you have built. You will do some more graphing. After this, you will then plan the experiments you would like to conduct.

Rubber Band Car Challenge

5. Running Experiments, Reporting to the Class in a Poster Session, and Evaluating Your Experiments -- You will return to the whiteboard and identify the design features you will focus on in some experiments. Choose one variable in the car's design and run an experiment to find out the affect of it on a rubber band car. Use "My Experiment" Design Diary pages to help you design your experiment, collect data, and reflect on what you find. Remember that answering a "how" question will tell you more than simply answering a yes/no question. Design a way to display your data and conclusions in a Poster Session. You'll review the work of your classmates and discuss possible Rules of Thumb for a balloon car. During this time it is important to pay close attention to the experimental tactics of your group and your classmates. Make sure that tests are fair and verify that everyone's procedures are sound. During your poster session you should provide graphs detailing the force and motion of your car.

6. Another Round of Experiments, if necessary: It's possible that the results of your first experiment weren't good enough to derive a rule of thumb. Perhaps you didn't control some variable well enough. Perhaps your measurements weren't accurate. Or maybe you didn't run enough trials. If your peers weren't satisfied with your results, go back and improve your experiment, and run it again. Design a way to display your data and conclusions in a Poster Session.

7. Whiteboarding and a Final Design: Record all of the useful information from the experiments you conducted on the whiteboard. You may start to notice that there are tradeoffs that will have to be considered before you can begin making decisions about the final design. Then, you will plan your final design with your group, and conduct a Pin-Up session to share your design idea. Then, build and test your final design, remembering to use Test and Design Design Diary sheets along the way. As with your other designs, you will probably make changes to your original plan. Make sure you fill out a new Test and Design sheet everytime you make a design change. Share your final design in a Gallery Walk, and run it across the test track for the class to see.

Reviewing Your Ideas

You have been writing statements to describe the relationships between force, motion, net force, acceleration, and velocity throughout this Vehicle in Motion unit. Below, rewrite those statements (looking back in the book if needed) to recall what you have said while exploring force and motion.

Definition of Force

Statement of the relationship between force and net force.

Statement of the relationship between net force and changes in motion.

# of Force and Motion

Statement of the relationship between net force and acceleration.

Statement of how the size and direction of net force affects the size and direction of acceleration if mass is constant.

Statement of how mass affects the size of acceleration if force is constant.

Newton's First

A Thought Experiment in Design

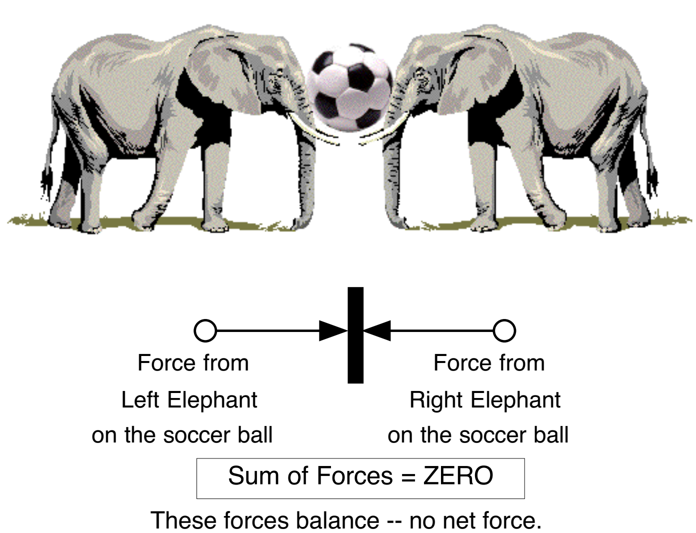
In the car tests you have run thus far, most of the time, you have been seeing a vehicle that was either speeding up or slowing down. Very little time was spent going at the same speed.
How could you get your car to go at a steady speed, without change? What kind of car would it be? On what kind of track, in what conditions would it have to run to go at a constant speed?
At the end of this activity, you will be asked to do what Albert Einstein, the most famous physicist of the 20th century, called a "thought experiment". Rather than designing and building something and then taking it to a track to test it, you'll be asked to think up a solution and then imagine running it on a track that you construct in your own mind.
The following are some science ideas to help you with this task, and to understand better how your coaster car works.

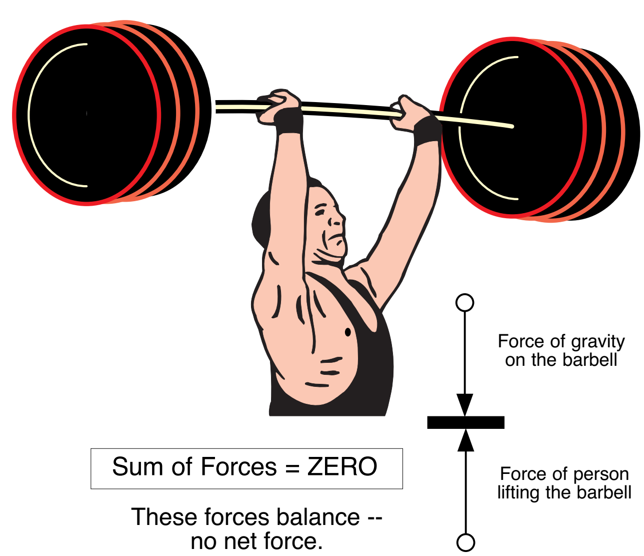
Newton's First Law of Motion

Sir Isaac Newton's three laws of motion describe how forces affect the way things move when unbalanced or "net forces" act on them. He came up with those laws more than 300 years ago, and they still work well today.

When no unbalanced or net force acts on them, objects at rest will stay at rest, and objects in motion will continue in the same motion.

Notice that the First Law of Motion deals with both "forces" and "motion". The First Law deals with situations when the forces acting on an object from all directions cancel each other out -- that is, when there are no unbalanced or "net" forces. What follows are three cases where all of the forces acting on a system cancel out to zero.





Law of Motion

If the head-to-head pushing force from each elephant is equal (each pushing in the opposite direction), the resulting "net force" on the soccer ball is zero. The weight lifter is pushing up with the exact same force that gravity is pulling down on the barbell. A tug-of-war match with equally strong teams is another example of zero net forces. The forces on the rope from the team on the left are equal to the forces from the team at the right, so that the "net force" on the rope is zero. Since the rope was not moving at the start of the tug-of-war, it remains stationary so long as the teams are equal.

A Law of Motion with Two Parts

The First Law of Motion has two parts — one is easy to believe, the other is harder to believe. However, when this part of the law has been studied and tested, it has always been found to be true. First, the easy part of the First Law of Motion:

First Law of Motion, Part 1:

When the net force acting on something is zero, things at rest (not moving) stay at rest.

For the moment, the man reading the newspaper is a living example of the first part of the First Law of Motion. The downward force of gravity on the man is canceled by the upward push of the chair holding him up. So, the net force is zero. For the next few seconds at least, the man is at rest and will stay at rest.

If the train comes as scheduled, however, things will change. There will be a new force from the train, and the First Law will no longer apply, because the net force acting on the reader will no longer be zero.

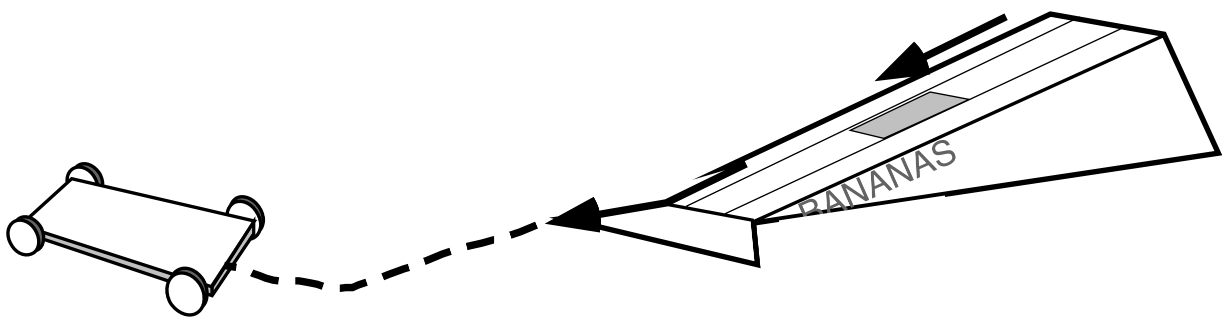
Newton's First

The second part of the First Law of Motion is the harder part to understand. People misunderstood this aspect of motion for thousands and thousands of years — until scientists like Galileo and Newton came along.

First Law of Motion, Part 2:

When the net force acting on something is zero, things in motion will stay in the same motion.

The First Law says that if something is in motion, and no net force acts on it, it will stay in motion without change and it will *never* stop. This is so hard to believe because we rarely have direct experience on the planet Earth of objects that will move without changing forever. Your cars don't stay in motion. Why not?



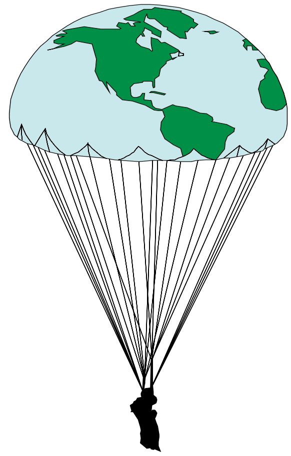
Before the 1500's, philosophers, kings, even scientists used to think that everything that moves finally stops moving. Everything eventually comes to rest was the old understanding of motion. For centuries, people argued that if you roll a ball down a level hallway, it will stop moving, eventually. If you start a top spinning, at first it will turn very fast, but then it will spin slower and slower and finally stop. The second part of the First Law says something quite different — if forces cancel out to zero <u>and</u> something is moving, it is going to keep moving <u>forever</u>.

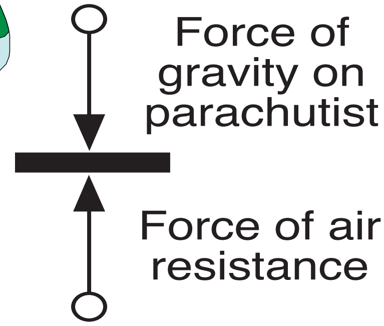
Think back. Why does your moving coaster car come to a stop? Since your car has no way to propel itself, the forces of friction cause it to slow down and eventually stop. If you could get rid of all the friction, then once it got moving, your car would move forward forever. However, you can't get rid of friction completely. You can reduce it with some lubrication like oil. Would such a "greased" car go further in a trial run?

Law of Motion

What are some examples of this second part of the First Law?

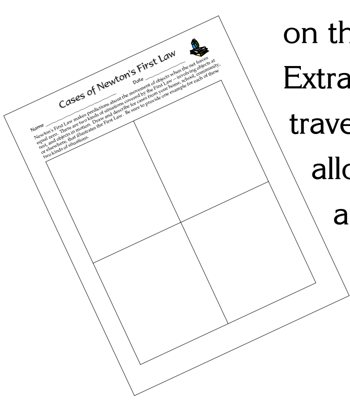
Parachute free-fall is one. After the initial jolt of the parachute opening, the parachutist travels at a constant speed until landing. Two main forces are at work here — gravity and air resistance. Gravity wants to speed up the parachutist, while resistance wants to slow her down. Once these forces are in balance, the person travels downward at an unchanging (or terminal) speed.



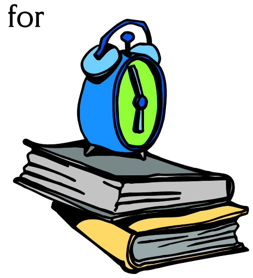


Review the statements you recorded on page 136 and 137 and determine which statements match Newton's First Law described on these pages. Then, rewrite Newton's First Law using words that you used in your statements.

Homework



Come up with four examples of Newton's First Law of Motion for homework. Sketch and describe with words these examples on the "Newton's First Law" activity sheet.



Extra Mile Question: How could you make a coaster car travel at a constant speed without touching it? You are not allowed to add anything to the car. You may want to think about changing what is outside the car system. In other words, design a testing environment where a coaster car can travel without speeding up or slowing down.

Newton's Second

Now you're ready to learn about a law of science that describes how things move.

Newton's First Law of Motion deals with situations where an object or system experiences balance of forces, in other words, has a zero net force. When this happens, things that are not moving stay not moving; things in motion stay in motion and move in the same direction.

Newton's Second Law deals with changes in motion that result from a net force acting on a mass. With Newton's Second Law, you can predict where things will be and how they will move. This can be helpful when you need to make decisions about your car's design.

The Second Law of Motion

A net force on a system causes objects to accelerate.
The more net force on an system, the more it accelerates.
But the more massive the system, the less the acceleration.

To predict the motion of an object, you need to have information about two things:

a. How **massive** is the object?
b. How much **net force** is there and in what direction?

You can use numbers with the Second Law formula to figure out how much objects speed up and slow down (called acceleration) when a net force acts on an object or system.

$$\text{Net Force} = \text{Mass} \times \text{Acceleration}$$

$$\text{Acceleration} = \frac{\text{Net Force}}{\text{Mass}}$$

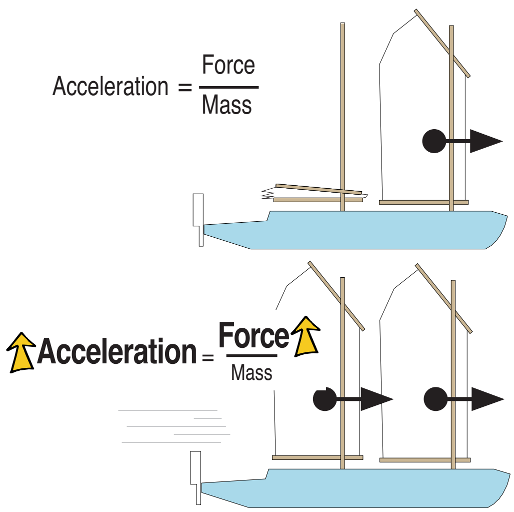
$$\text{Mass} = \frac{\text{Net Force}}{\text{Acceleration}}$$

Law of Motion

Easy-To-Remember Cases of the Second Law of Motion

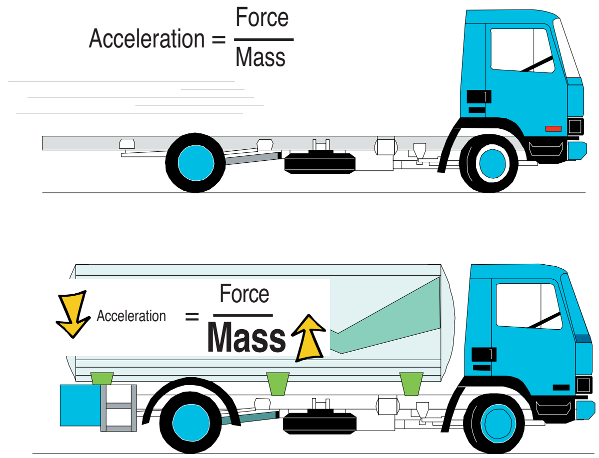
A simple way to know what the Second Law says is to commit to your memory two easy cases involving doubling (multiply by 2) and halving (divide by 2) one of the factors that affects motion.

1. Double the *force* and you **double** how fast you *speed up*.



With twice the sail area and force, the bottom boat will speed up twice as fast.

2. Double the *load* and you *speed up half as fast*.



With double the mass, the bottom truck will speed up half as fast.

Newton's Second

$$\text{Acceleration} = \frac{V_{final} - V_{start}}{\text{Time}} \qquad \text{Force} = \text{Mass} \times \text{Acceleration}$$

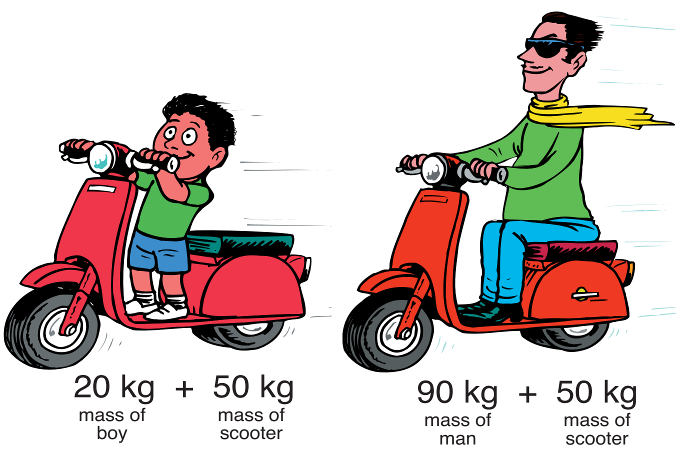
Second Law by the Numbers

1. A car going 12 m/sec speeds up to 24 m/sec in 6 seconds. What is the car's acceleration?

2. If the mass of the car is 1000 kg, what was the size of the force acting on the car to slow it down? Units of force in terms of kg., m., and sec. are expressed in Newtons (N.).

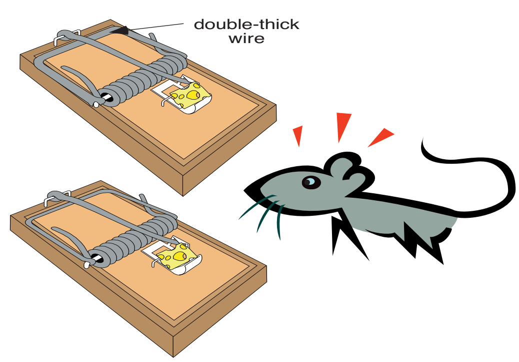
3. What if the mass doubles to 2000 kg.?

4. If the force slowing the car down was 16, 000 N., what would the new acceleration be? Assume the original mass of 1000 kg.



5. The man on the scooter can increase his speed a half meter-per-second for every second he runs his scooter at full throttle. How fast can the little boy increase his speed, going full throttle, with a similar scooter? How fast will each be going after 3 seconds, if they start from rest or a dead stop?

6. Two mousetrap designs are being tested. One has a heavier wire (top) with twice the mass of the other — both use the same strength spring.
Use the 2nd Law to tell which device will allow the mouse more time to escape before being caught after the mouse touches the cheese and trips the trap?



Law of Motion (continued)

Homework

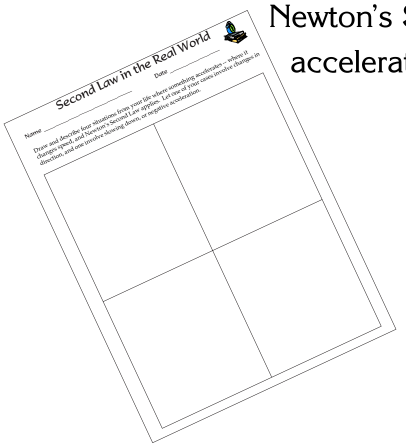
1. What do you think would happen if you double both the force and the mass of the spring?

2. Is it possible to have a mass so large that it does not move at all when you apply a force? Explain your answer.

3. Use the Second Law to describe how changes in your balloon car's design have made it perform differently. Be sure to state clearly the changes in the design, in performance, and the links to this law of motion.

4. Find and describe a scene from a television show or movie that contains a scene with motion that breaks either the First or Second Laws of Motion, and so could never really happen.

5. Complete the "Second Law in the Real World" worksheet. Sketch examples of where you see Newton's Second Law at work. Include a description with each sketch of acceleration and the Second Law.



Review the statements you recorded on page 136 and 137 and determine which statements match Newton's Second Law described on these pages. Then, rewrite Newton's Second Law using words that you used in your statements.

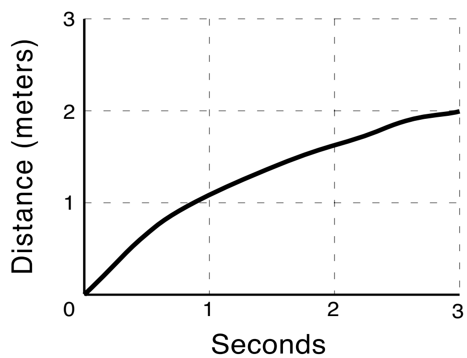
Using Graphs To

Telling a Story with Graphs

Usually the data you collect from experiments goes in your Design Diary -- on the "My Experiments" and "Testing My Design" pages. You can display this information in a number of ways -- including words, tables, graphs. Each of these "pictures" of data can help you tell a story of what you carefully observed to those who read it. In this activity, you will tell stories based on information in graphs that describe your car's performance.

Harvesting Numbers from Graphs

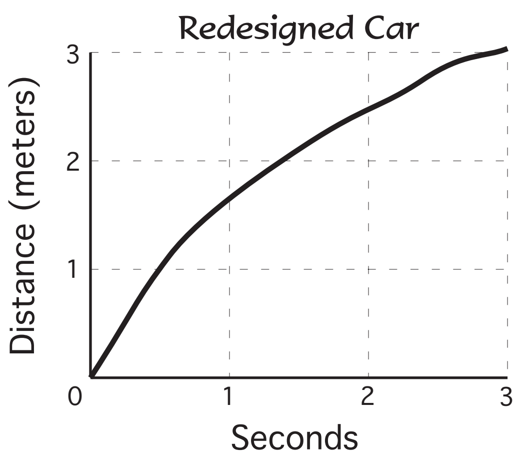
Graphs are a special kind of picture -- one can be worth thousands of words, or at least numbers. The graph below contains information about how a toy car traveled over a certain period of time. With it, you can tell how far it had traveled at any moment during that time. Working with a partner or by yourself, see how many pairs of time-distance figures you can gather from this graph and place on your own copy of the data table shown to the right of the graph.



Time	Distance
0.5	
1.0	
1.5	
2.0	
2.5	
3.0	

Look at the graph above, and try to tell a story of how the car moved. How far did it go? When was it moving the fastest? Did it go at a steady speed? Can you figure out its average speed?

The Same Car Redesigned -- Below is a graph above of the same car after it was redesigned. Fill in the table and compare its performance with the earlier version of the car. What effect did the new design have? What changes might have been done to the car to make it perform in this way? Did the changes help?

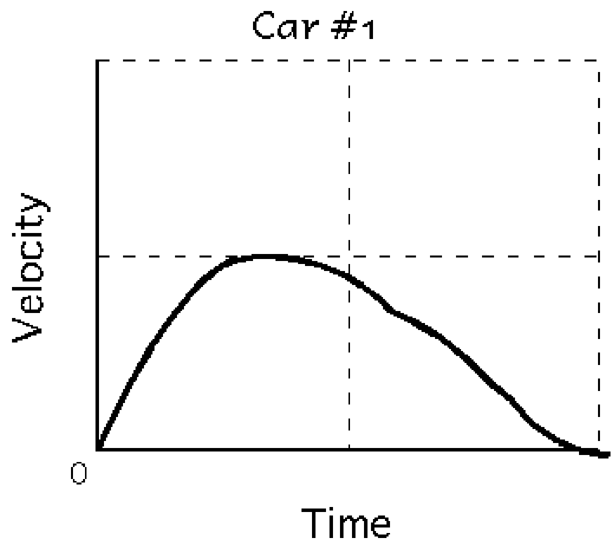


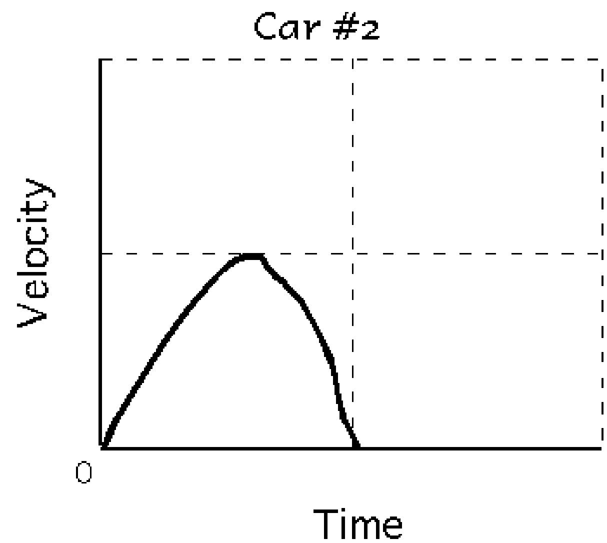
Time	Distance
0.5	
1.0	
1.5	
2.0	
2.5	
3.0	

Tell Stories

Figuring Out What a Car Is Like from Its Graph

You can use graphs for other things besides harvesting loads of numbers. Notice first that the two graphs below have different labels than those on the previous page. Next, look at the shape of the graphs below for the two different model cars. What story does each shape tell of how cars 1 and 2 performed?





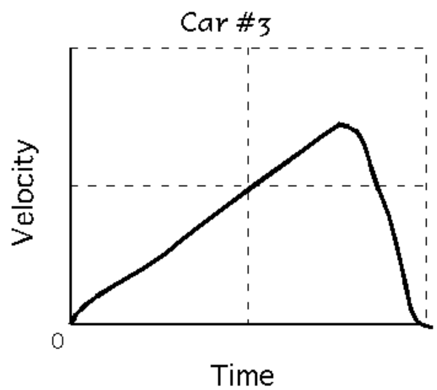
Now read a sample story below that attempts to interpret what happened during the tests for cars 1 and 2. See how the story fits the pictures of observed data shown.

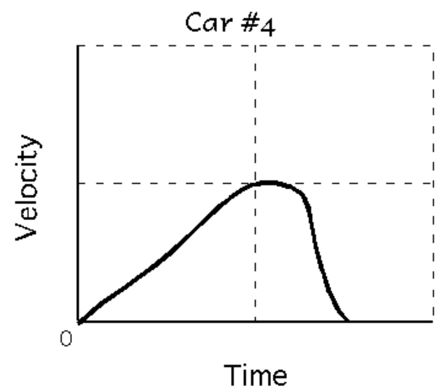
1. First of all, the initial rise in the graph does not mean the car went up a hill. It says that each car speeded up at the same rate, and reached the same maximum speed at about the same time -- in a bit more than half a second.
2. Car 1 kept going at the maximum speed a bit longer than Car 2, which started to slow down almost immediately.
3. *Educated Guess: Car 1 must have less friction in its bearings because it kept on traveling a whole second more than Car 2.*
4. Car 1 speeded up at a faster rate than when it slowed down and came to a stop. Car 2 stopped faster than it started.
5. *Educated Guess: The two cars might have the same propulsion system on board, since their initial start-up was equally fast.*
6. *Conclusion Based on Math: Since Car 1 coasted for a longer period of time, it must have traveled further than Car 2. More time in motion means more distance traveled.*

Using Graphs To

Seeing the Big Picture with Graphs

Looking at the shape of a graph after gathering data numbers and putting them on a table lets you then pay more attention to a story's "big picture" after you know some of the details. Putting aside the specific numbers for a moment, what can you tell is different about cars 3 and 4 just by looking at the shape and size of their graphs?





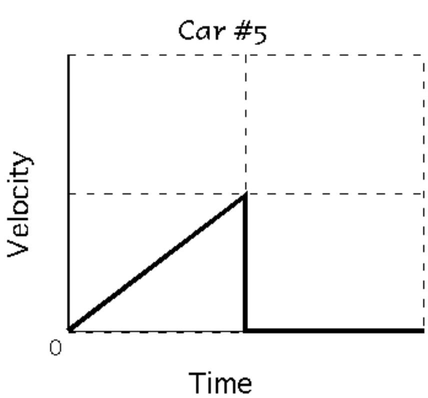
Here are some other questions to answer:

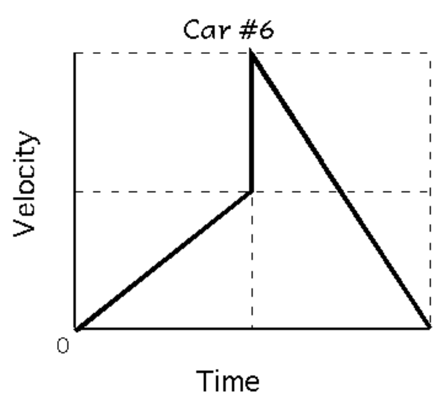
- Are these cars more or less similar than the previous pair? How?
- What story can you tell about how each ran during its test?
- What are some of the important events in each test run?
- Do you think the cars share similar problems? What are some key differences?
- Which went further? How can you tell?
- What might you try to do to improve if your job was to redesign these cars?

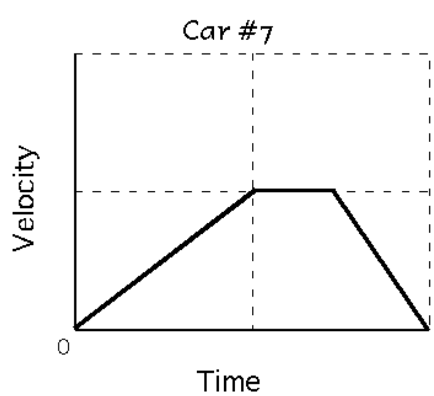
Now, turn back to the previous page and look at all that could be said about a pair of graphs by comparing them. Do the same thing with cars 3 and 4 as was done with the first pair -- when was maximum speed achieved by each, how long did each sustain this speed, and so on?

Finding the Impossible Story

Sometimes, you can tell when the story a graph tells doesn't make sense. Look over the graphs for cars 5-7 below. They all perform the same for the first second of a test run, and then each performs differently after that. Describe what happens to each car from second 1 to 2. Which graph tells a story that is impossible and could not happen for a model car?





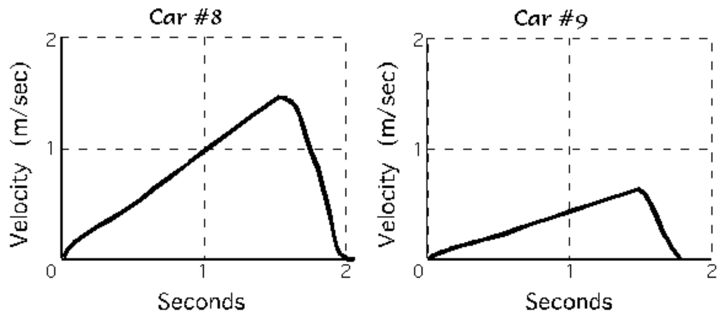


What other things can you say about these cars? What might their design have been like?

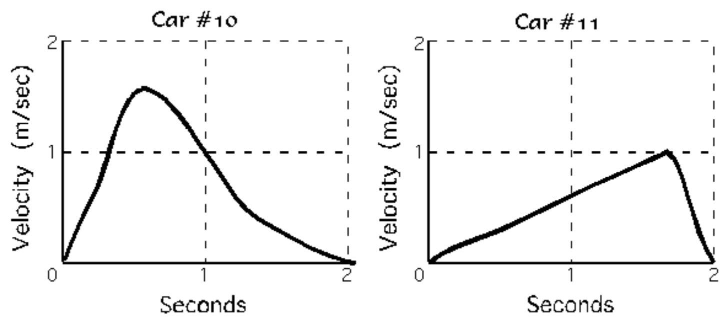
Tell Stories (continued)

Matching the Graph to the Story

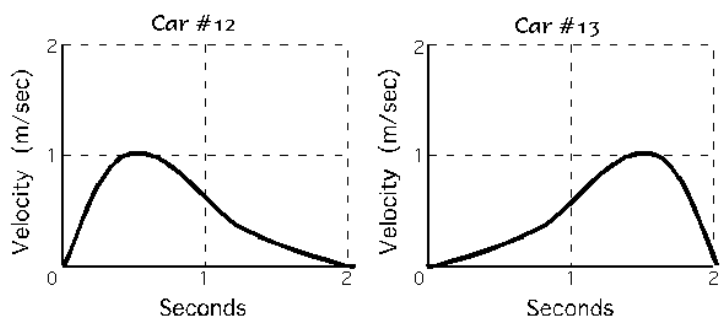
Just by looking at the shape of a pair of graphs, you can probably match a story or answer questions about the cars' motion. Try this with the following pairs of graphs, and be ready to explain your answers.



8-9. Assume identical cars. Which has the heavier load?



10-11. Which car experienced the largest average net force?



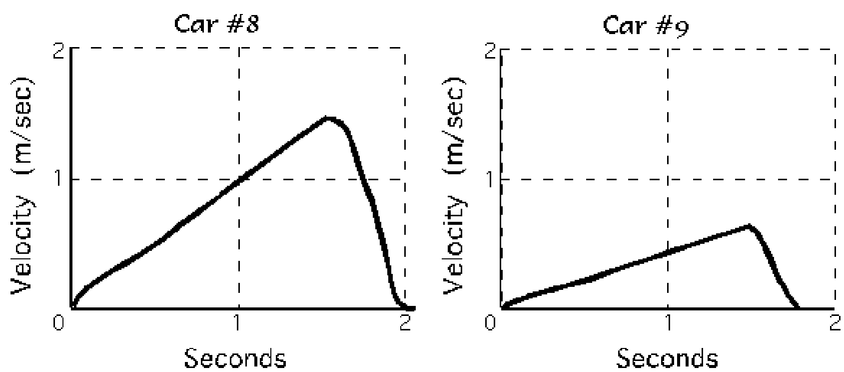
12-13. Which car has better bearings?

Using a Graph to Tell Your Own Car's Story

Unless your class has special measuring equipment, it is difficult to create a velocity-time graph for the cars you built. During class or for homework, take your current car design on a test run, and estimate its performance on a velocity-time graph. Instead of measuring or calculating the car's actual speed for each moment -- try to make a simpler graph. With a nearby clock or stopwatch in hand, observe two things during your car's test runs: (1) at what time does your car reach its maximum speed, and (2) when does it stop moving. Create a rough velocity-time graph showing this information. Then try to make a distance-time graph. Compare the graph you make with to those of other teams. What information could you add to make your graph tell a more complete story?

Newton's Laws and Graphs

You can use Newton's Laws to improve the stories told by your graphs and find out more about your cars. Let's look at car #8 and car #9 from the "Using Graphs to Tell Stories" page. Here are the velocity graphs from that section:



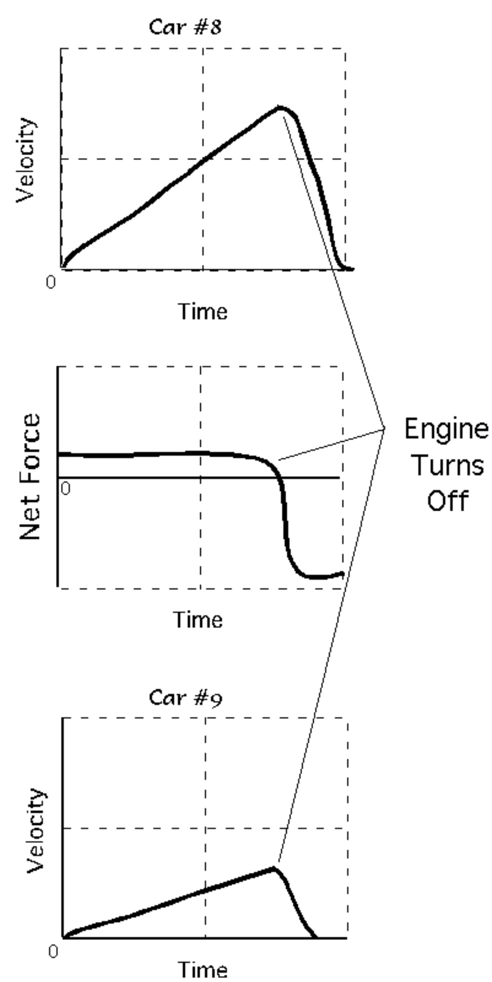
8-9. Assume identical cars. Which has the heavier load?

The cars are identical. The only difference is the load they carry. That means that the force produced by the engine is the same for both, and the force of friction in the bearings is the same for both.That means a graph of the net force will be the same for both.

The net force is positive for a while. During that time, the cars speed up and the velocity graphs climb. Then, the net force becomes negative, when the engine turns off and only friction is left. At that point the cars start slowing down, and the velocity graphs fall.

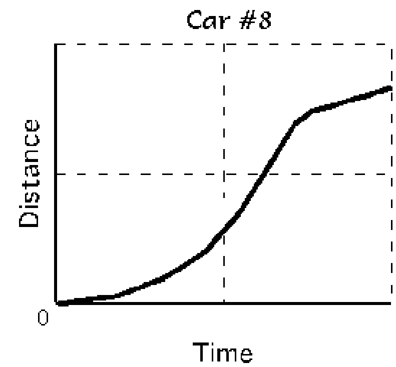
But car #8 reaches a bigger velocity than car #9. How can that be if they both have the same force? Newton's Second Law tells you. If car #9 is carrying a larger load, then its mass is larger. According to Newton, then, its acceleration must be smaller. Both cars are speeding up, but because of its load car #9 is speeding up more slowly so it doesn't reach as high a velocity as car #8.

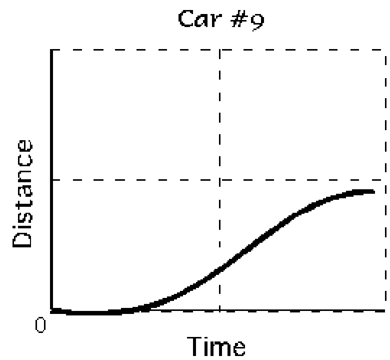
$$\textbf{acceleration} = \frac{\textbf{Net Force}}{\textbf{mass}}$$



Newton's Laws and Graphs

You can probably guess which car will travel further, but can you show it on a graph? Here are distance vs. time graphs for cars 8 and 9.

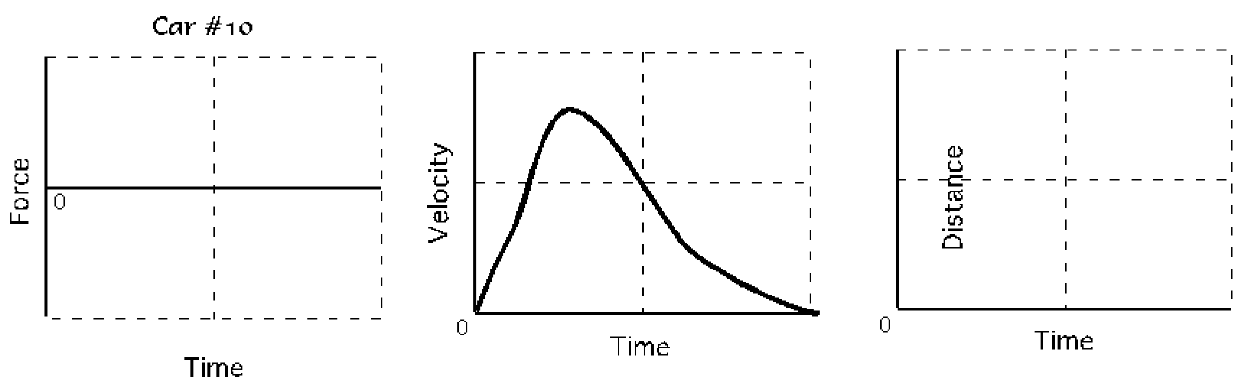


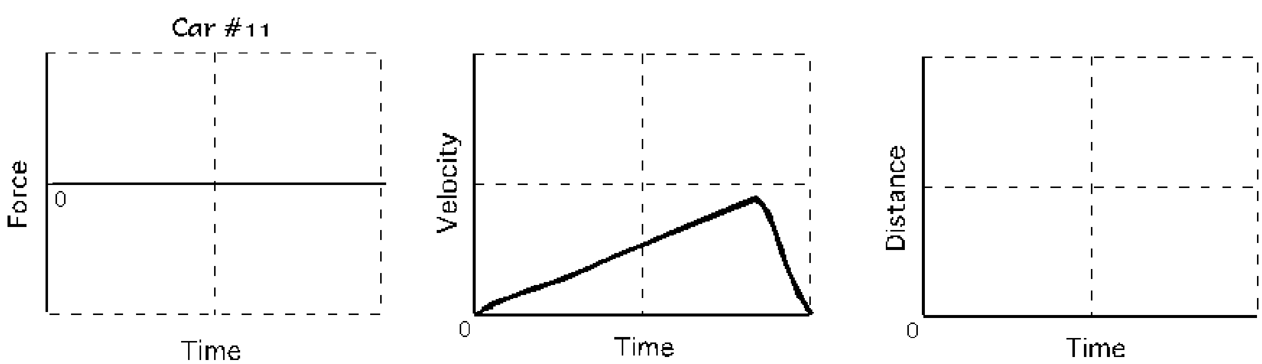


Can you see where the engines turn off in these graphs? Compare with the velocity graphs. Can you explain why the distance graphs keep going up even after the engines turn off? How can you tell from the distance graphs that car 8 reached a bigger velocity?

You Try It

Car #10 and car #11 are *not* identical. They will have different force graphs. Draw possible force vs. time and distance vs. time graphs for each one. Use Newton's Laws and your graphs to help you tell the stories of these two cars.





Are Balloons

IYou now have a lot of experience with balloon engines. You have found ways to get the largest force out of them, and ways to put them together with cars to get the best performance from the overall system.

But will that system be the best for solving the challenge? Or are there other engines that might work better? What would the best engine be like?

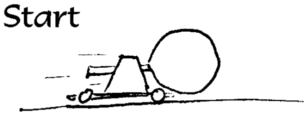
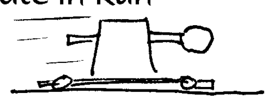
How Balloons Produce a Force

On page 98, you learned how balloons produce a propulsion force. But if that force does not happen at the right time, it might not be useful for the challenge.

Try blowing up a balloon, and pay attention to how hard you have to blow as the balloon inflates. Do you have to blow hardest at the beginning, in the middle, or toward the end?

Balloons do the same thing backwards, as they push the air out. Just as you have to blow air in the hardest at the beginning, when the balloon is small, the balloon will blow air out the hardest at the end, when the balloon is small again, just before it runs out of air.

Use the motion storyboard below to summarize the velocity, force and acceleration for a balloon car test. You can refer to the storyboards you made before, but don't just copy them -- you may need to change what you thought.

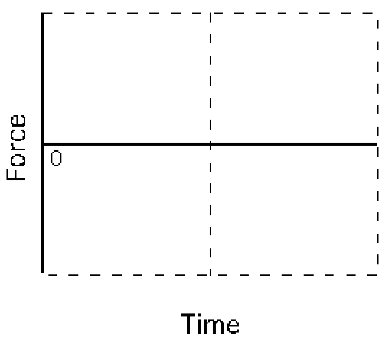
Start	Early in Run	Late in Run	Beginning to Coast
			
Velocity is (circle one): smallest in between largest getting smaller	Velocity is (circle one): smallest in between largest getting smaller	Velocity is (circle one): smallest in between largest getting smaller	Velocity is (circle one): smallest in between largest getting smaller
Balloon Force is (circle one): smallest in between largest there is no force	Balloon Force is (circle one): smallest in between largest there is no force	Balloon Force is (circle one): smallest in between largest there is no force	Balloon Force is (circle one): smallest in between largest there is no force
Acceleration is (circle one): smallest in between largest changed direction	Acceleration is (circle one): smallest in between largest changed direction	Acceleration is (circle one): smallest in between largest changed direction	Acceleration is (circle one): smallest in between largest changed direction

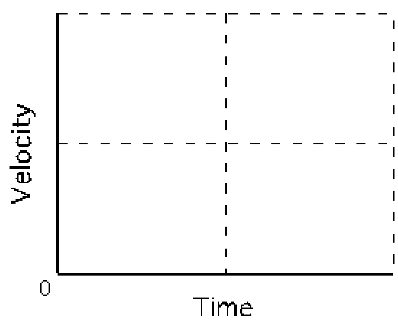
the "Right" Engines?

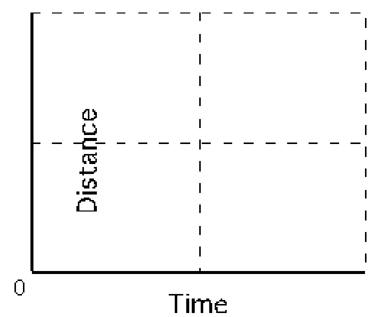
As you've seen, Newton's Laws and Graphs can help you to better understand a car's performance. Refer back to the section "Graphs and Newton's Laws" for examples, and use your motion storyboard for the balloon car run under "How Balloons Produce a Force."

Draw Force vs. time, velocity vs. time, and distance vs. time graphs that tell the story of your balloon car. Compare you graphs with another group whose car performed differently. Make sure that you understand how to draw your graphs so that you can see the difference.

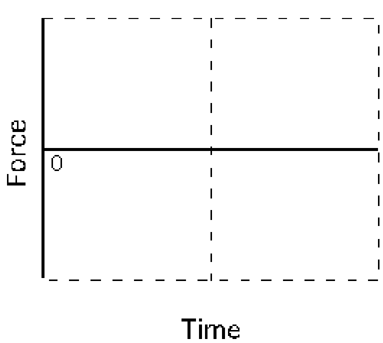
Graphs for Our Car

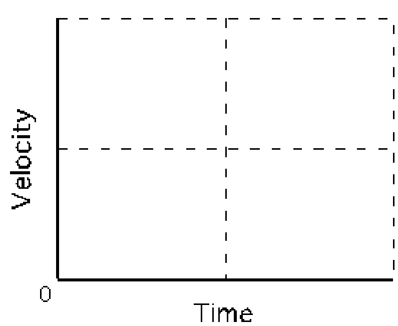


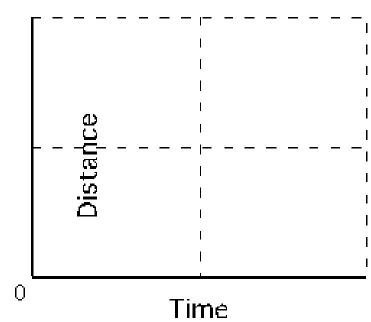




Graphs for Another Group's Car







How Newton's Laws Explain the Difference

Reflection Questions

1. Draw a motion storyboard and a set of Force vs. time, velocity vs. time and acceleration vs. time graphs that tell the story of a balloon car whose balloon engine produces twice as much force as yours, but which has the same friction in the bearings. Use Newton's Laws to explain the differences between these graphs and the graphs for your car.

2. Draw a motion storyboard and a set of Force vs. time, velocity vs. time and acceleration vs. time graphs that tell the story of a balloon car whose mass is twice the mass of your car, but which is otherwise identical. Use Newton's Laws to explain the differences between these graphs and the graphs for your car.

the "Right" Engines? (continued)

Balloons and Hills

To succeed in the challenge, your car will have to go over a hill. How good are balloon engines at pushing a car over a hill?

Your teacher will set up three test tracks to try your cars on. One will have a hill at the beginning, another will have a hill in the middle, and the third one will have a hill at the end, like this:

Car will (Circle one): go over easily barely go over not go over at all	Explain using force, velocity and acceleration

Car will (Circle one): go over easily barely go over not go over at all	Explain using force, velocity and acceleration

Car will (Circle one): go over easily barely go over not go over at all	Explain using force, velocity and acceleration

Based on what you know about balloon cars, record your predictions. For each case, do you think your car will make it over the hill? Be sure to justify your claims!

After you have predicted what you think will happen, try your car and see how well it performs. Then record your observations in the table on the next page.

Are Balloons

Observations

Observations

Observations

Compare results with the rest of the class to see which hill is easiest to get over and which one is hardest.

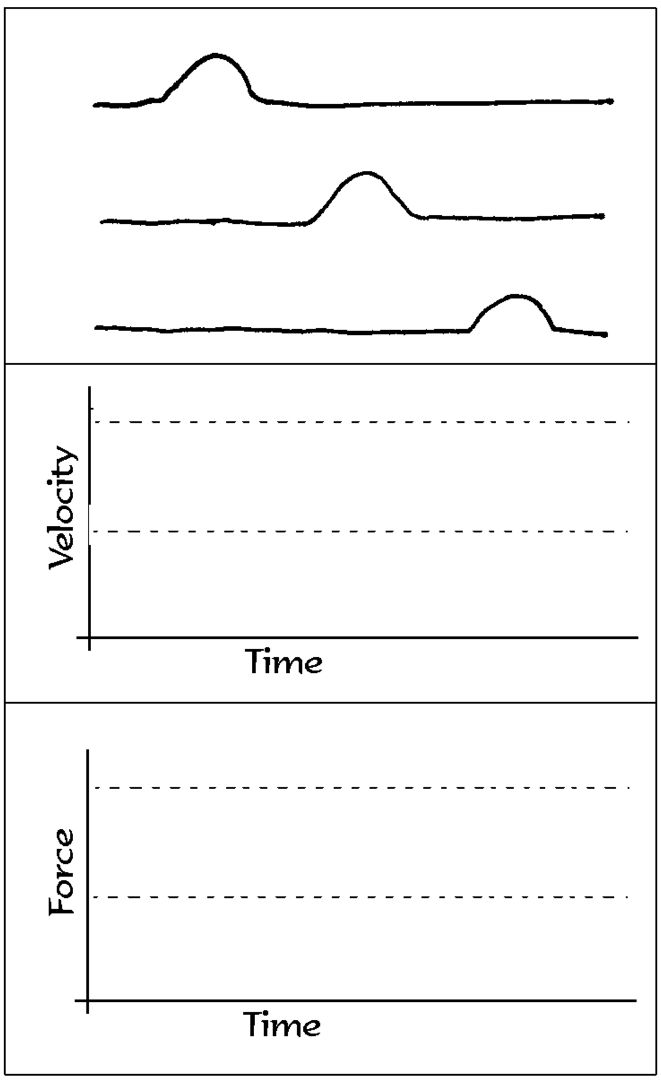
the "Right" Engines? (continued)

Understanding What Happened

To see why your cars behaved as they did, and to see what the best engine for the challenge would be like, it is useful to compare pictures of the engine's performance with pictures of the test tracks.

On the pictures below, draw graphs showing how the velocity and balloon force changed over time. You don't have to plot exact points. Just draw a line that shows how they changed, going up if they get bigger or down if they get smaller. Use your motion storyboard on the previous page to help.

Don't try to plot numbers. Just make relative shapes like the ones you saw in "Graphs and Stories."



“Best Engine” Rules of Thumb

What seems to have been most important in getting the cars over the hills? Was it easiest when the force was large or when the velocity was large? Complete these rules of thumb that summarize the roles of velocity and force in getting your car over a hill.

Velocity Rule of Thumb The car goes over the hill most easily when the velocity is

Explanation

Force Rule of Thumb The car goes over the hill most easily when the force is

Explanation

What does “Right Engine” Mean?

The test track for the challenge has hills at the beginning. What would the best engine be like for a car that would succeed at the challenge? Complete this Rule of Thumb for engine design using force, acceleration and velocity..

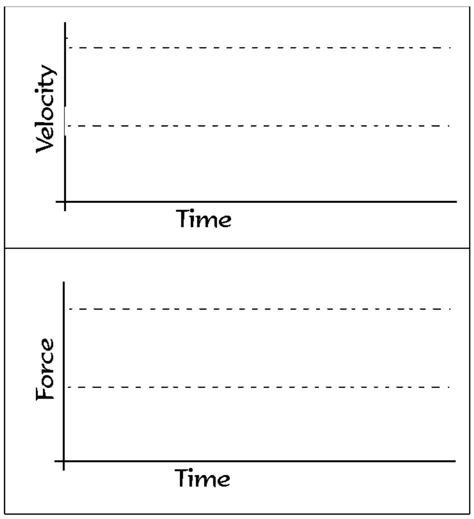
"Best Engine" Rule of Thumb The best engine would be

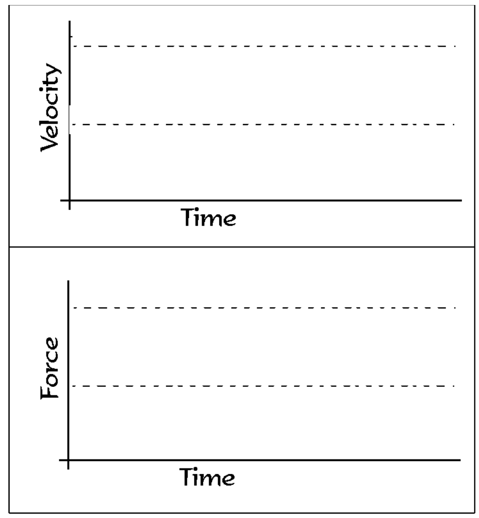
Explanation

For your test track, does the balloon engine match your “Best Engine” Rule of Thumb?

Reflection Questions

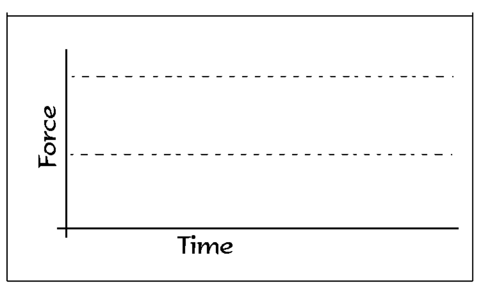
1. Cars from different groups probably performed differently on the hills. Take two other cars, and draw force and velocity graphs that show why they were different from yours.





2. Does the meaning of “Right Engine” depend on the test track? Would your “Best Engine” rule of thumb apply to all possible test tracks? Explain.

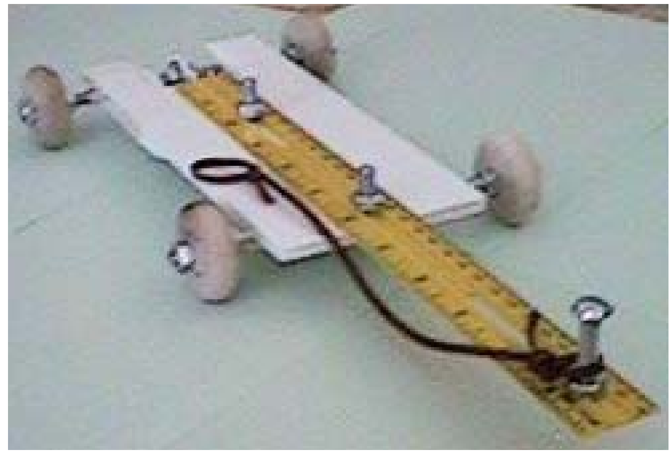
3. Draw a force graph for a “bad engine.” Explain why the engine would be bad for your test track.



Rubber-Band Car —

A. Outline of the Rubber-Band Car Building Instructions

The next four pages of instruction describe how to construct a rubber-band propulsion system. The steps are divided into seven parts:

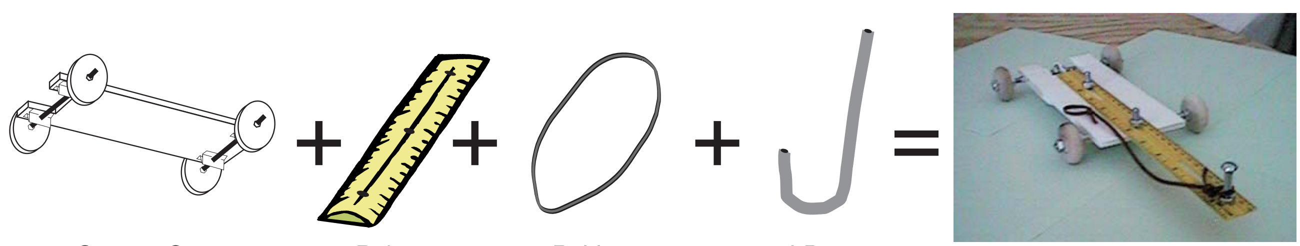


A. Introduction to Building a Rubber-Band Car
B. Materials and Tools You Will Need
C. Cutting and Trimming the Chassis
D. Attaching the Ruler to the Chassis
E.1 Making and Attaching the J-Post to the Axle *OR*
E.2 An Easier Alternative to the J-Post -- Building an X-Post
F. How to Operate Your Rubber Band Car

A. Introduction to Building a Rubber-Band Car

Like the balloon car, the rubber-band car uses the power stored in stretched elastic material to make the car move. Instead of sending pressurized air out the back of the car, as with the balloon car, this new model uses a stretched rubber band attached directly to the rear axle to make the axle turn around. By winding the rubber band around and around the axle, as the rubber band stretches, it stores mechanical energy. When released, the wheels turn and moves the car. The rubber-band car described below has four basic sub-systems:

a. Coaster car
b. Ruler (for extending rubber band), with mounting machine screws and nuts
c. Rubber band
d. J-Post (attached to the rear axle with two regular nuts)



The rubber-band car is easy to build and operate. Your finished car (see top figure) will have a ruler attached firmly to its chassis using nuts and screws. A post will be attached to the front of the ruler to hold one end of the rubber band. The other end of the rubber band gets attached to a J-shaped hook on the rear axle. By turning the wheels backwards, you stretch the rubber band and "wind up" the car. The energy stored in the band is what propels the car when you release it.

Building Instructions

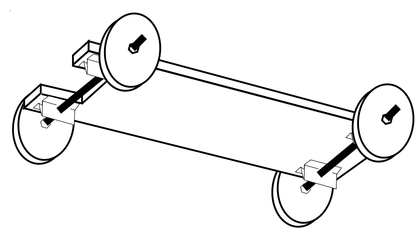
B. Materials and Tools You Will Need

You will need the following materials to build your falling-weight car.

Materials and Tools List

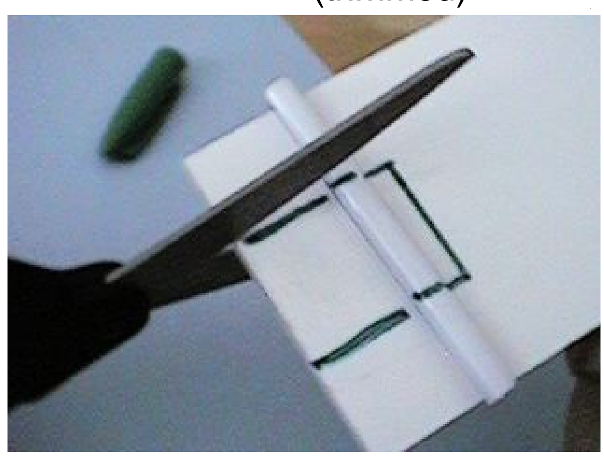
1	Ruler (with holes along center)
3	Machine screws (1/8" or 3/16")
3	Nuts (1/8" or 3/16")
1	Coaster Car
1-2	Large rubber bands
2	Nuts (1/4") for middle of axle
1	5-cm piece of plastic-coated wire
1	Pair adjustable pliers
1	Pair needle-nose pliers
1	Scissors

C. Cutting and Trimming the Chassis



Coaster Car
(trimmed)

Before putting the car together, you have to cut out a section of foamcore material from the rear of the chassis. This will make room for a "J-hook" that you will lock with two regular nuts to the middle of the rear axle.



C-1. Measure and mark up the area that is going to be cut out from the center of your car's back end, shown in the illustration to the right.

C-2. Use large scissors to make the first two cuts into the body of your car.

C-3. Get your teacher to make the final cut with a utility knife across the car's body, since scissors will not do as neat a job.

NOTE: You may find that with added use, your car's chassis will become bent or weaken. Get with your design team and think of ways to strength it. One suggestion includes gluing a second layer of foamcore or cardboard to the chassis. A second involves taping or hotgluing strips of wood, e.g., popsicle sticks, along the length of the chassis for added strength.

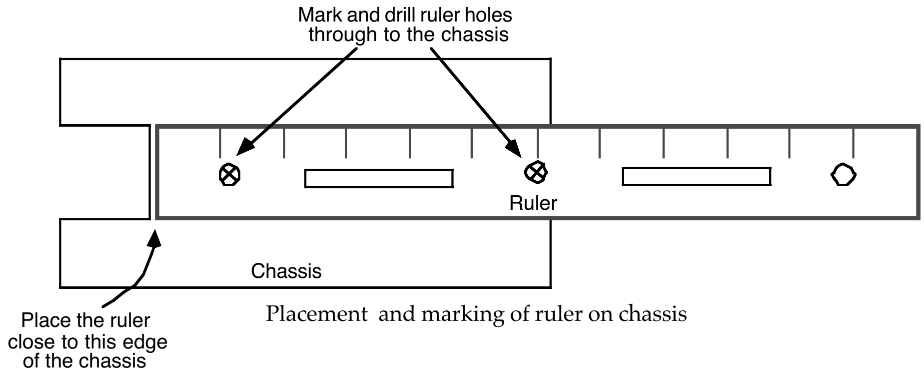
Rubber-Band Car —

D. Attaching the Ruler to the Chassis and Marking the Chassis

D-1. Center your ruler along the length of the car as shown below. The ruler should be placed close to the opening you cut out of the rear of the chassis. Using the ruler holes as guides, mark the chassis where you will need to punch holes to attach the ruler with screws.

D-2. Remove the ruler, and use a paper or metal punch, or even drill, to make these holes marked.

D-3. Place the ruler over the car body and push machine screws up from below, through the ruler and body. Tighten matching 1/8" nuts onto the screws, to help keep the ruler in place. Add a post to the front end of the ruler by putting a machine screw through the forward-most hole on the ruler. Tighten the two opposing nuts to hold the screw in place.



Placement and marking of ruler on chassis

E.1 Making and Attaching the J-Post to the Axle

You need to attach one end of the rubber band to the front end of the ruler, and the other to the J-Post. However, this second end cannot be tied or glued to the J-Post, as the rubber band needs to be released after it gets unwound.

One way to do this is to attach a J-Post onto the rear axle. The rubber band is looped around the post and then wound around the axle. You can make a J-Post by bending a piece of coated wire into the shape of a "J" with large needle-nosed pliers and then cutting it to the correct size. The post should extend out a bit less than 1 cm (about a third of an inch long).

E.1-1. Grab the end of the wire firmly with the pliers.

E.1-2. Bend the wire with the pliers until the bottom forms a "J".

E.1-3. Use the cutting jaws of the pliers to trim the excess wire from the top of the "J" -- the post should extend a bit less than 1 cm (1/3" inch) from the tightened nuts.

Building Instructions (continued)

The J-Post must stay firmly fixed to the center of the rear axle so that it will not slip or rotate when the stretched rubber band pulls against it. To do this, follow these steps:

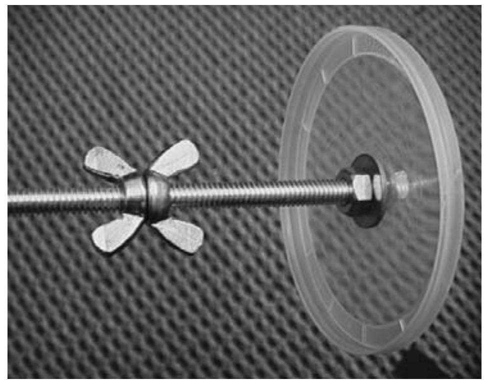
E.1-4. Place the J-Post in the center of the rear axle as shown on the previous page.

E.1-5. Spin two regular nuts in opposite directions towards the wire from either end of the axle, until they rest up against the J-Post.

E.1-6. Use pliers to tighten the nuts firmly against the wire.

E.2 An Easier Alternative to the J-Post: building an X-Post

Making a J-Post requires you to use wire cutters and pliers, while the X-Post, describe below requires no tools, and only two wing nuts. The picture below tells almost the entire story. Follow the instructions below to make your own.



E.2-1. Take a rear axle with one wheel attached to it, and remove all other materials from the axle.

E.2-2. Orient one wing nut so that its wings point towards the wheel and spin it from the other side to the middle of the axle.

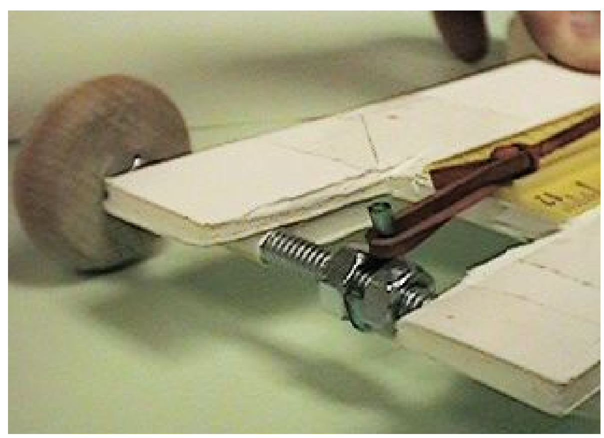
E.2-3. Place a second wing nut on the side of the axle without a wheel. This time point the wings in the opposite direction.

E.2-4. Spin the wing nut towards the middle until it touches the first nut. Tighten the two against one another so that the nuts hold tight to the axle.

E.2-5. Take the wing nuts off, and then reassemble as part of the rear axle of your car.

F. How to Operate Your Rubber-Band Car

You are now ready to wind up your rubber-band car and take it out for a test spin.



F-1. Place one end of a long rubber band around the front post and the other around the J-Post or X-Post.

F-2. Turn the wheels of the car backwards so that the rubber band winds around the axle. As the rubber band begins to stretch, watch to make sure it winds around without binding. Be careful not to wind it too far!!

F-3. When the rubber band is tight, put the wheels of your car firmly to the ground. You are now ready to release your car and send it off to the races.

Messing About with Rubber Band Cars

Now that you have constructed cars with your new rubber band engines, you need to become familiar with how they behave. It is time for Messing About, just as you did with the coaster and balloon cars.

While you are messing about, you should observe the behavior of the cars, but also be sure to pay attention to all the variables that you think might affect their performance. What works well? What does not work very well? In what ways could you change your car that might make it work better?

Whiteboarding

After messing about, you will whiteboard as a class. As usual, you will summarize all your observations and design ideas. *As much as possible, you should express your ideas in terms of Newton's Laws.* Which variables seem to affect the acceleration of your cars? How does that affect the distance travelled? Is time important? What forces are important, and what roles do those forces play in the performance of your cars? Is friction good, bad, or both? How well do you think a rubber band engine fits your "Best Engine" rules of thumb?

Soon, you will be designing experiments to explore the design possibilities for rubber band cars. This means that in addition to thinking about which variables are important, you should also be thinking about ways to change the design of the car to test those variables. What changes do you think might make the car perform better or worse?

Newton's Third Law:

With Newton's First and Second Laws, you can make predictions about how an object moves. If you know its mass and the forces acting on it, you can tell at any moment:

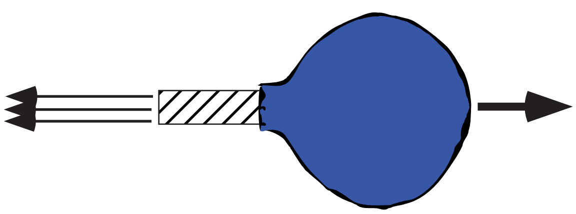
- where it will be,
- how fast it is going, and
- how its motion is changing.

These laws have been vital to the engineering of toys, cars, planes, and missiles. They also are critical in computer simulation program — games use Newton's first two laws of motion to model the behavior of speed cars or biplanes and make them seem real on the screen.

Newton's Third Law does something else. It tells a story about how pairs of things interact. It says that every force is the result of two objects interacting with each other.

Newton's Third Law

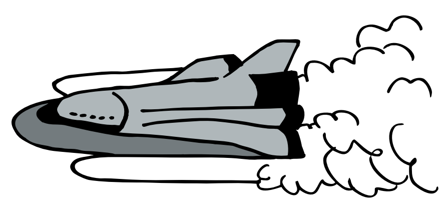
When two objects interact, each experiences a force.
These forces are equal in size and opposite in direction.



The push on **all** the air molecules leaving the balloon is equal to their total push on the balloon.

The balloon-and-straw system in your balloon car is a great example of Newton's Third Law. As the balloon pushes the air that escapes from the straw, the exiting air propels the balloon, and the straw and car, forward with an equal force.

With your classmates and teacher discuss how Newton's Third Law explains the propulsion of the Space Shuttle. Share your ideas and see how they match up with other examples of Newton's Third Law that your class has cited.

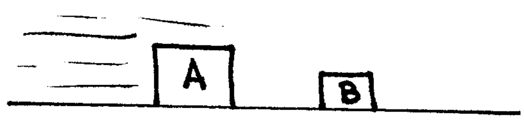


Forces in Pairs

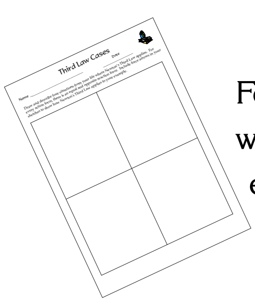
<u>Extra Mile Question</u>

When you were attempting to sole problems using F = M x A (Newton's Second Law) you can use Newton's Third Law to help you alsop. Let's look at two blocks of different masses colliding: Block A has a mass of 100 kg and is accelerating at 2 m/s^2 when Block A hits Block B. Block B has a mass is 5 kg., what force will A exert on B? What will be the resulting acceleration of B? Assume that there is no friction between the surface and the blocks.

Remember, Third Law can help you determine what force each block experiences, and Second law can help you determine the Force, Mass, and Acceleration of an object.



Review the statements you recorded on page 136 and 137 and determine which statements match Newton's Third Law described on these pages. Then, rewrite Newton's Third Law using words that you used in your statements.



Homework

For homework, find four examples from home, school, or the place where you live, where you see Newton's Third Law at work. Write an explanation of each, and make a quick sketch of each on the "Third Law Cases" worksheet your teacher will give you.

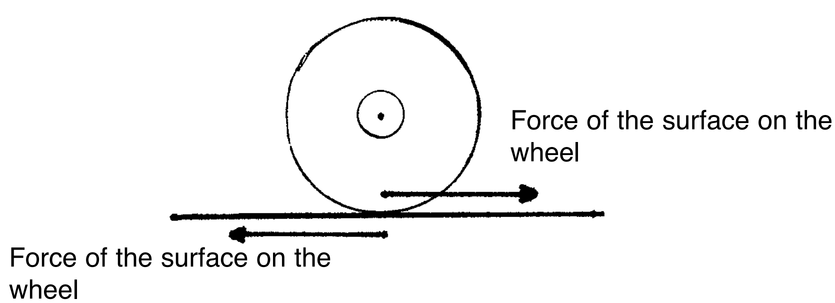
Rubberband Car Engine:

You may have noticed one significant between the way the Rubberband Car operates and the way the Balloon Car operates. The rubberband motor actually drives (or spins) the axle. The Balloon and Coaster Cars experience a push, but in a very different way. You may have also noticed that the rubberband engine causes the wheels to spin out with some wheels, and the result is that the engine provides propulsion force to the car, but the car does not utilize that force.

The Rubberband Car is different, however, Newton's Laws determine and govern the motion of the Rubberband Car as much as they do the Balloon and Coaster Cars. So, how does the Rubberband Car work?

Remember, Newton's Third Law says that when two objects interact, they each create a force on each other that is equal in size and opposite in direction. For the Balloon Car, the car and the air inside the balloon interact to create a force on the car (and a force on the air), and with the Coaster Car, the car interacts with the earth. The earth pulls down on the car, and the car pushes down on the earth. So, what object interacts with the Rubberband Car to create the pair of force? Discuss this question with your classmates and teacher.

The car once again interacts with the earth, but differently than the way the Coaster Car does. When the rubberband rotates the axle, it rotates the wheels too. If there is enough friction between the surface and the wheels, the wheels will push against the surface. As Newton's Third Law details, the surface pushes on the wheel with an equal and opposite force.

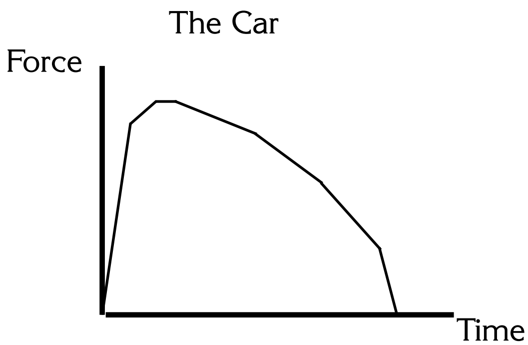


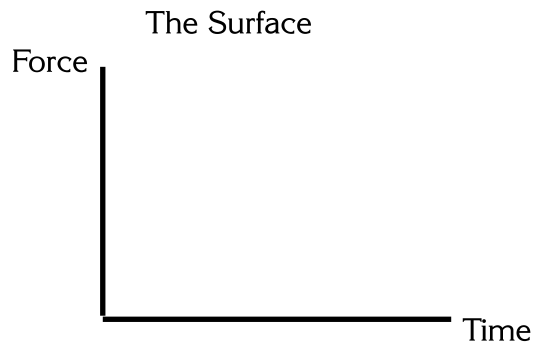
The direction of the forces are parallel to the surface. This is illustrated by what you have seen in movies and in real life when a vehicle on a dirt road accelerates quickly. You see the dirt accelerate from the bottom of the tire parallel to the ground, and the car accelerates in the opposite direction.

An interesting question…what does Newton's Second Law predict about the way the dirt and car will accelerate, how do their accelerations compare? What causes the differences in their accelerations? What evidence do you have to support this prediction?

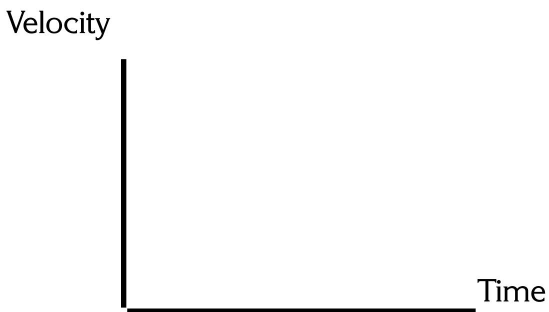
How does this thing work?

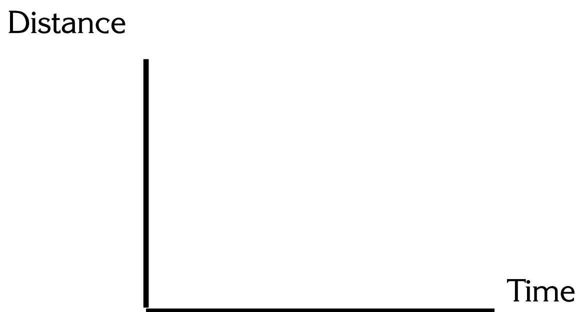
Let's look at the Force vs. Time graphs for each object. The graph for the car is already filled in. See if you can fill in the graph for the surface (floor). Hint: think about what Newton's Third Law says about forces in pairs for objects that interact.





Obviously the surface has some friction to hold it in place with the glue holding the floor down. Therefore, you do not see the surface accelerate. But, the Rubberband Car does if there is enough friction between it and the surface. Graph the Velocity vs. Time and Distance vs. Time graphs for the car. Use the force graph above to guide your answer. Discuss our answers with your classmates and teacher.





<u>Homework</u>

Good vs. Bad Friction

Up until now you have been trying to rid your car of excess rolling friction. This decreased the net force moving your car forward. However, now you need some friction…some sliding friction. If you car wheels do not have enough of this sliding friction, they will just spin out. You need some good friction, some traction!

However, what is the downside to choosing wheels with too much traction? Think about rolling friction, especially when you have to coast beyond the test track. Explain and discuss answer in terms of Newton's First and Second Laws with your classmates and teacher.

Experiments with Rubber Band Cars

Fair Tests

Now that you have collected all your ideas about how to improve the rubber band cars, each group will take one idea and design an experiment to test it. Use the "My Experiment" Design Diary pages to help, and *remember to always make Fair Tests*.

Collect Performance Graphs

After your experiments, you will be presenting your results to the class. As part of your prersentation, you will have to include three graphs: Force vs. time, velocity vs. time, and distance vs. time. You will not have to include numbers on the graphs, but you will have to show changes in behavior. For instance, if in one test your car moves more slowly than in another, your velocity graph should show that difference. It is probably best to sketch the graphs along with each test. You can decide later which ones to present to the class.

Poster Session

After you have finished all your experiments, you will present your conclusions to the rest of the class so that everyone can decide the best way to improve their cars. In your poster, you should include the following:

1. The variable you were testing
2. Your experimental procedure
3. Your results and conclusions
4. Chosen graphs that support your conclusions
5. Proposed Rules of Thumb based on your results. As much as possible, your Rules of Thumb should be stated in terms of forces, accelerations, and Newton's laws.

If the class decides that more information is needed before redesigning your rubber band cars, you may choose to do another set of experiments and another poster session.

Whiteboarding

You have collected a lot of information about the Rubber Band cars. You should now have a clearer idea of how the different parts of the car work together to determine how it performs.

You should return to the whiteboards now, and update them with your new information. Remember that your challenge has two parts: getting over a hill, and then going as far as possible beyond the hill. Be sure to keep this in mind when updating the whiteboards. Some ideas you have may be better suited for the hill, and others for the the travel afterwards. You might have to make some tradeoffs!

Design the Best Rubber Band Car

Once you are satisfied that you have a good understanding of rubber band cars, it is time to design and build the one that you think will perform best in the challenge. As usual, you will show your design during a Pinup Session, then build and test it, and finally show your results in a Gallery Walk.

Pinup Session

When you present your designs, you must of course include all your design decisions. What kind of wheels will you use? How will you design and operate your engine? Are there any other parts of the car you need to redesign?

In addition, you should explain how each decision applies to the challenge. Does it help you get over the hill, travel a long distance, or both? Finally, you should explain how Newton's Laws justify each of your decisions. You may use one, two or all three laws for each decision. It is up to you.

Design and Test

You probably won't get it right on the first try. As with Messing About and in your Experiments, you will learn more about the best ways to design and build your cars as you use them. Be sure to use the Design and Test pages in the Design Diary to help you keep track of your decisions. As always, use the language of Newton's Laws.

Gallery Walk

Once you are satisfied that you have the best rubber band car you can make, you will demonstrate its performance in a gallery walk. As part of the gallery walk, use your original pinup along with your car to help you explain how and why your design ideas have changed. Then show it off!

Who is this Newton guy anyway?

Isaac Newton was one of the greatest physicists the world has ever known. He was born in the tiny village of Woolsthorpe, England, on Christmas Day 1642. His family had a farm there. When Isaac was young, he not only helped on the farm, but he made working models of large farm machines, such as waterwheels and a mill for grinding wheat into flour. As an adult, he made other models that were the marvel of the world. One was of our solar system and included the sun and planets going around it.

Isaac attended Grantham Grammar School and entered Trinity College, Cambridge, when he was 18. He received his degree four years later in 1664. There are no reliable records to tell what sort of student he was. He stayed on in Cambridge, though, and in a few years, he became the Lucasian Professor of Mathematics (today Stephen Hawking holds that professorship). Before this, however, something remarkable happened: Cambridge University closed down for two years, 1665–67, because of an outbreak of a dangerous disease, the bubonic plague. It had been raging 100 miles away in London, and when it arrived in Cambridge, Newton went home to Woolsthorpe. During those two years, Newton formulated his laws of motion, law of gravitation, an entire branch of mathematics called the calculus, and demonstrated that white light is made up of all colors. He did all this before the age of 25!

You may have heard the story that Newton got the idea of gravity when an apple fell on his head. This probably did not happen. Instead, Newton was inspired to connect things that fall to Earth with things that orbit the Earth. He asked, "Is the same force that pulls the apple to the ground also making the orbiting moon fall towards the Earth?" Other scientists before Newton asked this question and had studied both falling objects and lunar (and planetary) orbits. One of these scientists was Galileo, who died the year Newton was born. Others before Newton had learned that falling objects accelerate (go faster and faster) as they fall and that planetary orbital paths are in the shape of ellipses, not circles, as was first thought. Newton, however, explained <u>why</u> this happened using this theory of gravity.

In later life, Newton was asked how he had been able to discover his laws. He replied that he had thought about questions unceasingly until he had the answers. He also said he had lots of help from earlier great scientists like Galileo:

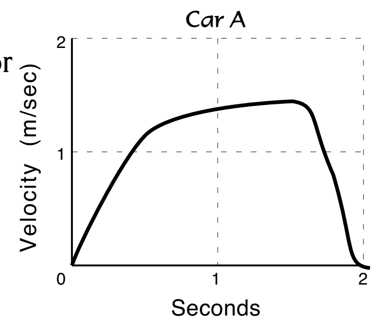
"If I have seen further than others, it is because I have stood on the shoulders of giants."

Review and Summary
Section 3 Rubber Band Cars

1. Describe one strength and one weakness in the original design for the rubber-band car. Use Newton's Laws Second Law of Motion to describe why they perform differently.

2. If cost were no object, and you could use any materials you wanted, what is one improvement you could make on the rubber-band car that you think would dramatically improve the performance of each?

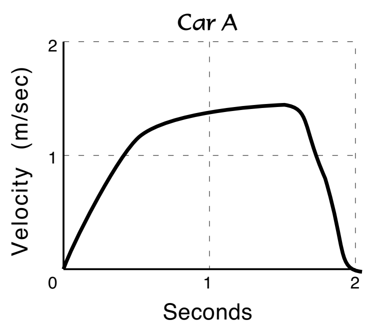
3. Create a data chart based on the information from the following velocity-time graph to the right for a test car.

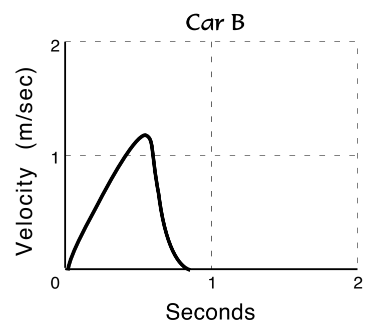


Time	Velocity
0.5	
1.0	
1.5	
2.0	

4. Look at the performance charts below and to the right for the same car -- one graph showing a test run after it was first built, and the other a bit later. Answer the following questions after you have studied the case A and B carefully:

a. What is the maximum speed of each?
b. Which car went farther? Give two different arguments why you think so.
c. What is similar in the two cars' runs?
d. Which is probably the earlier test car? Why
e. What is an improvement that probably was done to the later car? What evidence supports this?
f. Estimate or calculate how far each car traveled.
g. What is one problem that both of the cars probably share? How would you improve this design flaw?





5. Pick what you think is the best design your team has created and tested thus far. Collect data on its performance, if you haven't already done so. Then choose any other team's car that interests you, and get data on its performance. Examine the differences between the designs, and compare the velocity-time graphs for each. Write a 3-paragraph report comparing the two designs. Make suggestions for future directions the redesign of each might take.