Vehicles in Motion Teacher Materials
version 5.0

Introduction

Unit goals for students

In *Vehicles in Motion*, students will …………… Along the way, they will:

1. Develop and understand scientific process skills, which include design, construction, use and interpretation.
2. Raise and develop strategies to investigate appropriate questions, problem solving, collaboration, and design.
3. Use vehicle construction (?) as a means of testing predictions and as a means to design.
4. Abstract scientific rules of thumb.
5. Identify forces, Newton's Laws, velocity, gravity, inertia, acceleration, and their relationships to one another through ……
6. Understand the use of force arrows
7. Identify ways to ……………….

Overview of the Unit

Vehicles in Motion is a design-based physical science unit that studies forces and motion. The unit poses a challenge set in Antarctica where students become part of a research/design team to develop a model for a vehicle to explore the continent. This scene gives students a real-world context in which to place their design and science learning, and is referred to at different points in the curriculum. The Grand Challenge for *Vehicles is Motion* is to devise the best self-propelled vehicle that will travel along a track and crest one or two hills, and then continue to move for the longest distance. Like most design tasks, this activity is clearly important for Antarctic expeditions, since limited resources make getting the most benefit from available materials and energy stores a premium.

Vehicles in Motion is divided into a sequence of three smaller challenges. The first design challenge has students design the model car that can coast as far as possible; the second involves a car with a balloon propulsion system traveling the longest distance on a single “filling”. In the third challenge, students explore two additional methods of car propulsion (rubber bands and falling weights) and then design and test the best possible car to complete the Grand Challenge.

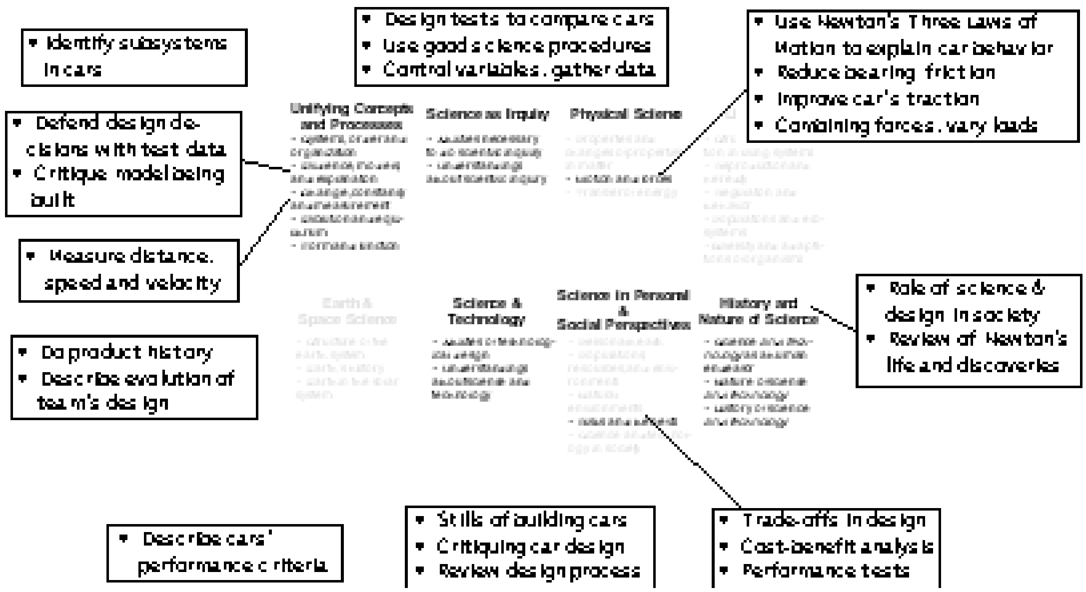
Science Standards

Throughout development of *Vehicles in Motion,* we’ve kept in mind the National Science Education Standards. Their emphasis on understanding technology as a critical application of science ideas is central to Learning by Design™, as is the use of design as a companion skill in inquiry. Authors of the NSES felt so strongly about this linkage between the “designed world” and students that they made a rough analogy:

> “This standard helps establish design as the
> technological parallel to inquiry in science.”

According to this standard, students should be able to solve simple design problems, analyze technological products and systems, and assess quality. Both these technological standards and more standard science-oriented standards are covered in this unit.

NSES Standards for Grades 5-8
and Links to LbD's *Vehicles in Motion*



Getting Ready for the Vehicles in Motion Unit

Here are some things you need to do before starting the *Vehicles in Motion* unit:

•Collect toy cars (see the separate handout for students). They will need them during the second day of the unit. Page 21 of this book gives more detail about the kinds of cars you'll want to collect.

•Build a test track, perhaps more than one. Set it up right away and leave it up to make it available throughout the challenge. See instructions below. These will be needed for day 2 as well.

•We suggest strongly that you build the cars yourself before the class does it. This gives you much more understanding of the design difficulties the students will go through.

- Build ramps. See the instructions at the end of this piece of writing. These will be needed to begin the coaster-car section.
- You will need to cut chassis for each group before they get started on the coaster cars.
- Also, you may want to hot glue the balloons to the straws for balloon cars.

Building a Test Track

To build a test track (perhaps more than one), please do the following:

Collect remnants of carpet. Carpet stores are a good source of runs of even, low-pile carpet, and are usually willing to give samples.

A single track should be about 4 meters long by 30-40 cm wide (13 ft x 12-15 in).

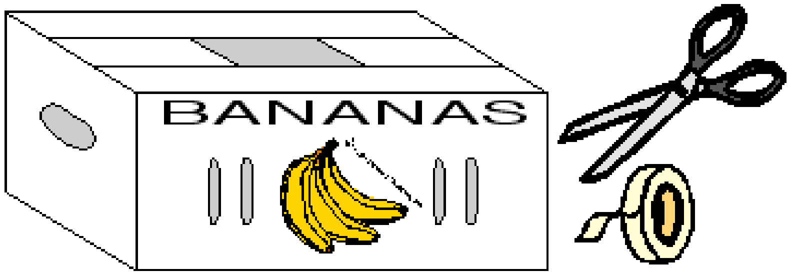
You may want each group to have the same kind or to try many different grades of carpet (industrial, indoor-outdoor) to help in learning about the resistance to motion of different terrain, or you may have a single test track.

- Install in a 10-cm hill in the track by placing a soft-drink can, books, or block of wood under the carpet about half the distance from the ends.
- You may want to install both a 5-cm and 10-cm hill.
- The carpet may have to be taped down at each end.

Building a Coaster-Car Test Ramp

For the coaster-car challenge, students are given instructions for building a low-tech, propulsion-less vehicle. Their goal is to improve upon the original, baseline design, and to demonstrate their improvements by conducting fair-comparison tests of different versions of their cars. Since the cars don't move on their own, they must somehow give the car a "standardized push". Otherwise, if they use more subjective methods, the resulting total distance traveled will not help them make well-supported design decisions. A simple way to do that is to provide students with a ramp, so that different versions of cars can be released from the same part of the ramp and the distance traveled accurately measured.

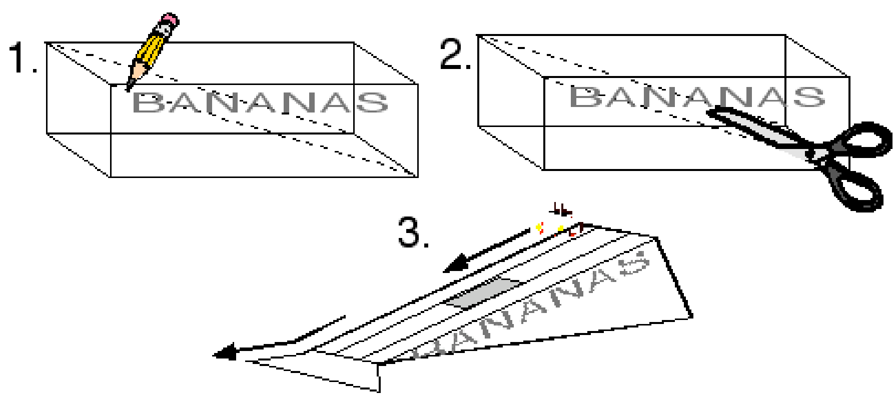
You will need to build ramps from banana boxes for students to test their coaster cars. The following are easy-to-build instructions for making a ramp for testing the coaster car. The "main ingredient" needed for the ramps are empty banana boxes, in good condition, quantities of which are available from any grocery store or supermarket, and can be had free for the asking. If you can’t get banana boxes, boxes that hold copy paper will do.



Materials
3-4 Banana boxes, top and bottom
1 Heavy-duty scissors, or utility knife
1 Roll of masking, duct or scotch tape
1 Manila folder

You will be able to make two ramps from the lid and the base of the banana box. The instructions are the same for both. The cars will run on the top of the lid, which will be sloped downward because the sides were cut along diagonal lines.

Here are the steps for constructing a coaster-car ramp:



(1) Draw a diagonal line on the long sides of the box top.

(2) With a pair of heavy duty scissors, utility knife or saber saw, cut along these lines on both of the box's sides. Tape the sides together as needed.

(3) Leave the side flaps attached to the ramp, to provide the car with a smoother transition to the floor. Cover the hole with a manila folder.

General Comments about this Unit

Using the Learning by Design Cycle as a Map – In the launcher unit, Apollo 13, you and your students completed several Learning by Design™ cycles. Still, you and your students need to grow in your use of whiteboards and gallery walks, get more comfortable and at ease with "messing about" activities, and become more proficient with designing experiments and testing the design ideas that you build and run.

Now it is time for students to understand what LBD is about. We have removed much of the scaffolding from now on. We will give pointers but will not always be explicit about activities. Please do spend time with students on what Learning by Design™ is, probably the day after you test.

You may want to refer your students to the LBD Design Cycle. You should refer to it often! You might think of using the LBD Cycle illustration as a map for all your students' work during a unit. Work that involves more open-ended investigations and design tend to result in some students feeling that whatever learning does get done is too scattered.

Using approaches that get students to reflect and review upon their learning helps. Doing things like reviewing the Objectives of this Unit , using the "Questions and Research Topics" and "Lessons Learned" pages from the Design Diary pages, and having students explicitly say where they are in the LBD cycle at different points in the unit should do three things:

a. help orient students as to what recently happened, what's happening, and what may happen soon

b. support students in seeing their own progress, and

c. encourage students' self-reflection of their actions and learning, which is an important learning goal.

Using Design Diaries

We want you to use Design Diaries as a map to help students keep their bearings while getting to understand the Grand Challenge. In particular, the Diary pages help students to keep records and manage their designing and learning for the different challenges.

Design Diary pages are included as reproducible handouts in this teacher book. They also can be found in the Apollo 13 Student Handbook's Appendix. Students will do some Design Diary work individually at home, and this work will be presented to and used by their groups in the development of their designs; they should also use diary pages to keep a single group record to track the design's progress.

Referring Back to Apollo 13

To review other aspects of LBD, students might also want to refer back to pages in Section 3 of the *Apollo 13* book, especially those on design, decision making, collaborative learning, and gallery walks. Please encourage the students to do that.

Encouraging Reflecting and Summarizing

Several times during students' work on each challenge, look back at the page called Objectives of the Unit, and then compare this to the Lessons Learned pages they collect in their Design Diaries. Use the former as a checklist to remind you and your students of the major learning goals of this unit.

There are many information pages in *Vehicles in Motion* Forces of Friction; Bearing Fact Sheet; and Who Is This Guy Newton Anyway?. There is no need to use the information (or even the activity) pages in the order given. If your class wants to investigate effects of load on their car's performance before effects of propulsion, for example, feel free to let the students make that decision. If an information page seems to be in the wrong place (e.g., the students are not ready for it), skip it, go on, and go back when the right time comes.

Your roles as teacher

1. Stand back and let students work and discover how to make and test things. But do help them keep on track, work together, make decisions and talk science.
2. Empower students with "can do" attitudes regarding building things. Watch what is happening on a gender basis. Give all students opportunities to experience all aspects of design.
3. Give students time to succeed and fail at conducting experiments – focus on controlling variables, carefully repeating conditions and good experimental techniques.
4. Facilitate fabrication of cars.
5. Use whiteboarding to manage sequencing and connections. Refer often to the ideas and learning issues recorded. Use them to gain perspective on how much has been learned. You'll probably want to use several sets of whiteboards – one for the coaster car, and one for the balloon car.
6. Help students link car behavior to mechanisms and science concepts.
7. Facilitate choosing of propulsion systems.
8. Facilitate students recording each experiment and test they conduct and building a case for their design decisions.
9. Support student discussions of what a good experiment is. Key question: "Was that a fair test?"
10. Support students in reporting interim results.
11. Use student teams as experts to inform the entire class about key facets of their challenge.
12. Ask good follow-up questions to teams on their design process and product.
13. Listen for student misunderstandings.
14. Check to make sure students are working collaboratively and developing skills in this area.

15. Make sure the groups are considering the basic and optional criteria that each design must meet.
16. Take some time with the whole class for discussion of cases in the real world.
17. Help facilitate Gallery Walks.
18. Revisit Decision Making often.
19. Watch your time.

Vehicles in Motion – Antarctic Challenge

Overview

A study of motion and forces is the key theme of Vehicles in Motion -- and all related issues that can lead to the science-informed design of a vehicle for use in the Antarctic. An overall listing of objectives for the unit can be broken down into the concepts related to the physics of motion, otherwise called kinematics, and the skills from four domains related to doing LBD in your classroom: science, design, collaboration and communication, and decision making.

The aim of the first days of the *Vehicle in Motion* Unit is to give students a clear sense of where they are going with the next weeks of their time -- to design, test, and build a series of vehicles for the Grand Challenge. Once they understand the problem, students will then build and test coaster cars, which will be used later in the construction and testing of cars with different propulsion systems.

The opening pages of Vehicles in Motion set the stage for the main design task: creating and building a model of a car that will be used in Antarctica. Students form teams that will make recommendations for a car design for the harsh climate of the South Pole region. The users of this car will be scientists who are doing research there, and who have many constraints in resources available. The main performance goal for the car is to travel long distances of varied, hilly terrain.

The Antarctic Challenge not only tells of the design challenges students will be facing over the next six to eight weeks, but also alludes to the fact that science, in particular the science of motion, will be studied. It also mentions that students will be working collaboratively and in groups.

PLEASE NOTE: Certain aspects, constraints and conditions of the Antarctic environment are not emphasized in students doing Vehicles in Motion's overall design challenge. In particular, the model cars that students will build and test need not be able to work effectively in snow and low-temperature conditions. In fact, the four car models that students will build and improve upon do not utilize the power and propulsion systems that would work best in the South Pole - high cost and degree of complexity led gas engines or electric-powered motors cars not to be included in this unit. In fact, terrain is modeled with two small bumps on the carpeted test track. Distance traveled beyond the hills is the only significant performance outcome upon which the cars will be measured and compared.

Teaching Strategies and Research Notes

The first pages of Vehicles in Motion are basically in-class reading. Asking students what they know about Antarctica before doing the reading, and the conditions that might be found there, may help augment the brief description of the region.

There may be terms under Objectives of this Unit that students will understand by the end of the unit, but not before. Reassure them of this, saying that they will be revisiting this page to note their progress.

The link between good design and good science is not a given in materials like Learning by Design, but it is a central goal, nonetheless. Design can be done, sometimes quite effectively, through craft knowledge and trial-and-error build-and-test methods alone. The aim of the LBD curricula is to use the excitement generated by doing design work as a starting point for learning about big ideas in science. Much mention of this will be made throughout the unit. (Similar curriculum to Learning by Design includes: Technology, Science, Mathematics Connection Activities [LaPorte and Sanders, 1995]; Design Science [TERC's Jack Lochhead, PI], Nuffield's Design and Technology series [Barlex, 1995]; Society of Automotive Engineers' World in Motion II [Boynton, 1997]; Illinois State's Integrated Mathematics, Science and Technology [Loepp, 1998]; CCNY's

City Technology Curriculum Guides [Benenson], Northwestern's Materials World Modules [Chang, 1998]; and Harvard-Smithsonian's DESIGNS: Doable Engineering Science Investigations Geared for Non-Science Students [Philip Sadler, PI].)

Making students aware of the key objectives of what they must do has been part of good instructional principles for years.

Planning for the Activity & Materials Needed

Make sure to review the challenge before class. If this is your first time teaching with this unit, you will have gaps in your understanding of where all of these concepts fit into the three parts of Vehicles in Motion.

No one can be expected to see the full ramifications of a unit without going through it at least once. The experience of the Learning by Design team is that familiarity with a unit comes after a few seasons with it -- you can't rush this process, just as you can't rush the maturation of students' ideas.

You might want to find a video with scenes from Antarctica to show students for a few minutes. Documentaries are the most likely source of scenes from the continent of the South Pole. The use of videos to give concreteness to the design challenge is used in the United Kingdom for the National Standard's testing of students on their design skills [Kimbell et al, 1991].

VEHICLES IN MOTION 5.1
DAY-BY-DAY LESSON OUTLINES
Introduction and Coaster Car Challenge
(Total of 12 to 16 days)

INTRODUCTION

1 to 2 days

Student Pages: 8 – 15

Goals
1. Introduce the Unit, the Antarctica Challenge, and the Grand Challenge
2. Messing About with toy cars followed by Whiteboarding to gain familiarity with forces and motion and to help students identify what they know and what they need to learn more about
3. Discussion of Problem Specifications, Constraints/Criteria, and what needs to be learned to successfully complete the Grand Challenge

Materials: vehicles, ramp, test track
You will need vehicles and toys that are propelled in a variety of ways, possibly including:
- springs
- rubber bands
- balloons
- gravity
- multi/single gears
- electricity (solar or battery)
- on-vehicle/off-vehicle propulsion system
- flywheels (pull-back cars or strings that are yanked)

These vehicles may be brought by the teacher or the students and should be labeled with their owner's names. Have ramps and the test track available as well. The test track is a strip of low pile carpet 1 foot wide and 10-12 feet long, and this usually can be purchased for less than $10 at any home improvement store. Place a 5 cm. and 10 cm. hill in the test track by placing books underneath it. This will be your test track for the entire challenge.

Overview of Activities:
1. The class reviews the Antarctica Challenge. Have students restate the challenge aloud to verify understanding of it. Identify possible constraints and criteria and potential difficulties in achieving the challenge.
3. "Messing About" - Have students work in their groups, playing with a variety of vehicles to identify their behaviors in terms of travel AND examining each to describe its propulsion mechanisms, figure out how the device works, and identify key parts of the propulsion system, how it stores and releases energy. Use the Messing About Design Diary page. Make sure each group has some access to the test track.
4. Whiteboarding – Groups share what they observed about each car -- its behavior and how it might work. Focus discussion in two areas: (a) what have we observed? (b) what do we need to learn more about to progress with the Grand Challenge? Questions should fall into several categories: (i) how can we make things move? (ii) how can we keep things moving? (iii) how can we make them go faster or farther? (iv) how can we make them stop? It is important, before going on to the Coaster Car Challenge, that the class generate questions in Category II – How can we keep things moving?

Homework Possibilities
- Page 13, “What Have We Learned?”
- Complete a Problem Understanding Design Diary page to frame the Antarctic and/or Grand Challenge.
- Complete a Problem Specification Page for the Grand Challenge

COASTER-CAR CHALLENGE
10 to 12 days

Goals: Address Questions generated earlier about keeping things going; science content focuses on identifying forces, combining forces, and recognizing the effects of forces; motion storyboards are used as an analysis tool for representing the forces in an event

Days 1 and 2 **Date:**

Student Pages: 18-27

Goals
1. Introduce the Coaster Car Challenge and the questions it will help answer
2. Discuss Criteria/Constraints for the Coaster Car Challenge
3. Construct and mess about with first versions of coaster cars
4. Begin to identify design features that could be altered to improve performance.
5. Refine designs and reconstruct cars and measure their performance.

Materials:
Coaster Car Vehicle Kit:
1 - 10 x 30 cm piece of foamcore (for the car chassis)
2 - 17 cm pieces of 1/4” coarse threaded shaft material (for the axles)
4 - wooden wheels
4 - regular nuts for 1/4” threaded shaft
4 - wing nuts for 1/4” threaded shaft
1 - meter-long strip of masking tape for construction of the vehicles
Glue Ramps Challenge tracks
Bearing Materials:
2 - large-diametered straws (about 7 mm, outer diameter, for car bearings)

Teams will also need access to the following *tools*:
- pliers to tightening the regular and wing nuts against the wheel so that it rotates without slipping as the axle rotates.
- a pair of scissors to cut the straws to their proper length
- stopwatch to measure time of travel
- measuring tape or meter stick to note distance traveled

Ramps
Messing About pages
Testing my Design pages

Overview of Activities

- The class reviews the Coaster Car Challenge on pp. 18-21 and discusses criteria/constraints. Make sure students know that while engaging in the Coaster Car Challenge, they will be focusing on the questions generated yesterday about keeping things going.
- Students construct their coaster cars following the directions on pp. 22-25.
- Students will Mess About with the basic version of the Coaster Car. The purpose is for students to understand how the car works and how it travels, and to formulate some early observations, limitations, and capabilities of the design. This should take no more than 15-20 minutes. Use the Messing About Design Diary page.
- Whiteboarding. Reconvene the class to share early observations. Around a new whiteboard, students identify aspects of the design that might affect performance. Before sending students back to redesign their cars, review Testing my Design Design Diary sheets. Make clear that after refining their cars, they will be formulating a procedure for measuring their car's performance and carrying out the procedure and recording their data.
- Back in small groups, students refine their cars based on discussions and collect data about their car's performance. Students should record their procedures and results on Testing My Design sheets.

Days 3 and 4 (might take only one day with advanced students) Date:

Student Pages: 28-36

Materials: Same as previous days

Goals: Compare how cars perform, with two issues in mind: fair testing and introducing the notion of forces.

1. Complete the task of obtaining data on the performance of the coaster car.
2. Discuss fair testing (optional if it doesn't come up)
3. Formulate a definition of "Forces".
4. Learn how to use arrows to draw forces.
5. Understand that friction is a force.

Overview of Activities

1. If they didn't finish yesterday, students will complete the initial round of measuring performance of their coaster cars, pp. 26 – 27. Their purpose, remember, was to measure how well their initial design works and to practice formulating and carrying out a good, fair procedure.
2. Students present their car's performance to each other, either in a Gallery Walk or a more simple way. Two issues may come up here:

- Some cars go farther and/or straighter than others. Why?
- Some cars that reportedly go farther and/or straighter than others don't really seem to have so much advantage – i.e., groups may not all have measured performance the same way.

3. The second issue might or might not come up. If it does, and if the class does not yet understand the notion of fair testing well enough, then his is a good time to spend some time on it. The big issue here is that unless they measured their cars' performance the same way

(and they probably didn't on this round), it isn't possible to compare the performance of different cars. Have kids show the ways they measured; have kids notice which comparisons are unfair; have kids come up with a fair procedure that they will use from now on.

4. If necessary, have them re-measure their cars' performance using the common procedure. We're actually hoping that this doesn't need to happen for 8th graders, that instead it will be easy to imagine which cars went farther than others and that you can move easily into the more pressing discussion about the forces involved in making the cars move as far as they did (issue (a) above).
5. Move into the discussion of (a) above. Ask students to tell you why they think the different cars performed differently. They will probably tell you about the ways the wheels are attached and whether the wheels hit the chassis and things like that. After they have a chance to do that, tell them that all of those things influence the "forces" that are acting on the cars. Ask them to share their ideas about what forces are.
6. Read pages 28 and 29 together. Discuss what forces are and how to measure force.
7. Move forward to pages 30 and 31, and help students how force arrows can be used to describe the direction and magnitude (size) of forces. Review some examples of these pages. Following this, have students read a "good enough" definition of what a force is to give them a springboard if their definitions are not complete or too misconceived, pp. 31. Give students the opportunity to try drawing force arrows for situations familiar from the Launcher unit and previous pages (pp. 32 – 33).
8. Student s learn how friction is a force by reviewing some scenarios and drawing force arrows to describe the friction. Then, students create their own examples of friction and draw force arrows for these situations, pp. 35-36.
9. Finally, ask students to make their first attempt to draw force arrows on a diagram of the coaster car traveling down the ramp and across the floor, pp. 34-36.

<u>Homework Possibilities</u>
1. Page 36, Questions
2. Friction in the Real World worksheet – very important

Day 5 (for advanced classes, may be combined with Day 6) Date:

<u>Student Pages</u>: 37-43

<u>Goals</u>: Put new understandings of forces to work
1. Finish and Review pp. 27-36, Discuss friction homework
2. Using initial results, revise the list of variables effecting the performance of Coaster Cars
3. Begin learning to debug designs and about the role of bearings.

<u>Overview of Activities</u>
1. Discuss friction homework,
2. Whiteboarding: As a class, apply what's been learned to explaining their cars' difficulties. Revise the set of variables affecting performance of Coaster Cars (on the whiteboard from a few days ago).
3. Read pages in the book about debugging their cars, pp. 38-39, and what bearings do, pp. 40-41.

4. Students work in small groups to explain what's wrong with their cars.

Homework Possibilities
1. Questions on pp. 41 and 43.
2. Bearings: Lost and Found Worksheet, pp. 41 (optional)

Day 6 **Date:**

Student Pages: 44-59

Goals
- Begin to understand that forces originate from the interactions between objects.
- Learn how the definition of the system will determine how forces can be discussed.
- Learn how multiple forces acting on one system combine to produce a net force.
- Learn how to draw force diagrams and net force diagrams.
- Return to Coaster Cars for redesign.

Overview of Day 6 Activities
1. Students analyze the weightlifter to see that the forces the man and barbell experience are the result of the interaction between the two objects. They look at several other examples to see that interactions create forces. Then, students read about "defining the system" so that they can analyze situations and describe forces more easily and accurately, pp. 44-47.
2. Students learn that systems or objects experience many forces at once, pp. 48-49. They read about and practice drawing force arrows that accurately represent the size and direction of forces acting on one system of object using something similar to a math number line, pp. 50-52. Then, they learn how to analyze this Force Diagram to create a Net Force Diagram. They practice this with several examples and situations, pp. 53-54.
3. Students learn that motion depends upon the balancing of forces on an object. They try to formulate their own statements that describe this within the context of a ball, and then more generally, pp. 55-56. Finally, students learn how to draw force and net force diagrams without the number line approach and practice creating these diagrams some more, pp. 57-59.

Homework Possibility
- Systems in a System Worksheet
- Assign any force arrow activities from the text that were not covered completely in class.

Days 7 and 8 **Date:**

Student Pages: 60-61

Goals: Apply what's just been learned in the context of the Coaster Car Challenge.
1. Review force arrow drawings in the context of learning about gravity propelling coaster cars.
2. Make one change in their coaster cars, measure performance, and compare to old performance.
3. Conduct a Poster Session based on old and new coaster car tests.

4. Develop Rules of Thumb for coaster-car design

Overview of Activities
1. Class should review homework and the ideas learned from previous day about force diagrams and net force.
2. Follow this with a mini-lecture on how gravity works to power the coaster car – pp. 60 - 61. Try to help students see that gravity is a kind of force and goes by the same rules as other forces. Use your discretion regarding the time spent on this activity and discussion. What must be clear is that the students should understand that steeper ramps provide more force in the direction car is going (downhill). Remember, the force of gravity is the same because the car is the same mass each time, but the direction of this force acts relative to the car makes all the difference.
3. Using a combination of what they've been learning about forces, about debugging their cars, and about the car's systems, each group should choose one change they could make in their car to make it perform better. (1) Using the agreed-upon measuring procedure, they should re-measure the performance of their car if they have not done so already, using Testing my Design pages for recording data. (2) They should make the one change they think might make a big difference. (3) They should measure the performance of their revised car , again recording data on Testing my Design pages. They should make sure, as well, to write down on those pages the change they made and why they made that change. (4) They should draw the forces for their cars (both old and revised).
4. Follow this with a Poster Session where students present the change they made, why they made it, and the difference it made in forces and performance. Each group should recommend a Rule of Thumb during their presentation.
5. Proposed Rules of Thumb should be publicly recorded, and, guided by the teacher, the class should try to use the science they've been learning to explain why the rule of thumb works.

Days 9 **Date:**

Student Pages: 62- 71

Goals
1. Analyze how net force affects the car.
2. Learn how objects in motion can have zero net force
3. Learn how to measure motion, velocity and average velocity.

Overview of Day 9 Activities
1. Students will look at Motion Storyboards for the first time. These tools are used to analyze the motion of a car. They are detailed on pp. 62-63, and students will analyze a sample Motion Storyboard. On page 63, students are asked to create Motion Storyboards from their Testing My Design sheets from their testing. Make sure to have students leave room to add rows to their Motion Storyboards. This may make a good homework assignment.
2. Students look at a Motion Storyboard that adds a third row, one that describes the motion of the coaster car in relation to the forces and net force. Review reflection questions to build flexibility with Motion Storyboards, pp. 64-65

3. The students will review how net force acting on an object can be zero, yet an object will remain in motion. This is counterintuitive and something not witnessed very easily on earth. The reflection questions on pp. 67 will help them see other examples that demonstrate this occurrence, pp. 66-67.

<u>Homework Possibility</u>
1. Reflection questions on pp. 63, 65, 67.

Day 10 **Date:**

<u>Student Pages</u>: 68-73 and 77

<u>Goals</u>
1. Conduct a quick velocity experiment and calculate avg. velocity.
2. Learn about acceleration

<u>Overview of Day 10 Activities</u>
1. A review of velocity and average velocity occurs. Students look at how an object may travel far, but have a low velocity, and vice-a-versa. Students then plan an experiment to conduct what would measure the differences between avg. velocities of two differing designs, pp. 68-71.
2. Students will calculate the avg. velocity of two coaster car designs. They will collect data to help them answer the Reflection questions on page 71.
3. Class begins to discuss acceleration. They complete the Motion Storyboard to incorporate the description of acceleration, and then write description of the relationship between net force and changes in an object's motion, pp. 72-73.
4. Revisit Rules of Thumb and see if their explanations can be revised based on the new things that have been learned (skip if running overtime).

<u>Homework Possibility</u>
1. Reflection Questions on page 71.
2. Individually, use what's been learned to design best Coaster Car.

Days 11 and 12 **Date:**

<u>Student Pages</u>: 74-75

<u>Goals</u>
- Connect forces and net force with acceleration.
- Learn to graph Distance v. Time.
- Design best Coaster Car and hold Pin-Up Session.

<u>Overview of Activities</u>
1. Students will review the case of a biker to understand how forces and net force determine acceleration as they fill in a Motion Storyboard in the text, p. 74.

2. Students then pull out the Motion Storyboard they created earlier for their coaster cars. They add two rows to the bottom of the storyboards to reveal the velocity and acceleration of their cars at each point, p. 75.
3. Students learn to graph distance v. time. They learn how to analyze a D v. T graph to understand how the car traveled, pp. 78-81
4. Students return to their Coaster Cars and plan their final designs. It's important here that students understand that they will be judged based on the soundness of their decisions. So, push them to articulate their design decisions, and for each one, why they believe it is a good idea. They should justify each design decision with appropriate data that has been collected, rules of thumb that have been derived, and/or scientific concepts they've been learning.
5. On second day, students should share and discuss the Motion Storyboards they did for homework to review their assessment of velocity and acceleration during their coaster car runs.
6. Students present their ideas for their best Coaster Cars in a Pin-up Session. Remember that the Pin-Up Session is not merely for exchanging ideas, but rather provides the opportunity for students to show the class that their decisions are informed by the data that has been collected in the past, the rules of thumb that have been derived, and the science they've been learning. Push them to justify each decision they've made and to point to the particular rule of thumb or science concept they are using to make each of their decisions.
7. Reassess the Rules of Thumb created during earlier coaster car Poster Sessions, 5-10 mins.
8. Move on to building their final Coaster Cars.

<u>Homework Possibility</u>
Motion Storyboard edits and the graphing on pp. 78-81.

Days 12 and probably at least part of 13 **Date:**

<u>Student Pages</u>: Continue 74-81

<u>Goals</u>
- Complete Coaster Cars

<u>Overview of Day 11 Activities</u>
1. Groups construct, measure the performance of, refine, and finish their final Coaster Car. No need for Gallery Walks between iterations. They should be going for a well-running car so that they can have a good base to work from in the rest of the unit. If their materials are falling apart, give them new materials. It is important that they have a robust, well-running car at the end of this module.

<u>Homework Possibility</u>
Review for test or quiz, pp. 82-83.

Day 13 and/or 14 **Date:**

Student Pages: 82-85

Goals
- Final Coaster Cars Run
- Whiteboarding session

Overview of Day 12 Activities
1. The class gathers to watch each group run their car down the ramp. Each group presents any changes they made to their design, justifying each new design decision. Each group presents a Motion Storyboard with appropriately-sized arrows representing the forces working on their cars.
2. The class reviews the Whiteboard they created earlier, and edits it appropriately to update the learning issues, facts, and ideas.
3. The class goes over the questions on pages 82 and 83
4. They make the transition (pages 84 and 85) from Coaster Cars to the next part of the challenge.

Homework Possibilities
- Review for the end of sub-unit assessment (test or quiz). Pages 82-83 might help.
- Project report – documenting and justifying design decisions, using vocabulary, rules of thumb, concepts, and data derived during the module.

Day 14 or 15 **Date:**

Goals
1. Test or Quiz

VEHICLES IN MOTION 5.1
DAY-BY-DAY LESSON OUTLINES
BALLOON CAR CHALLENGE
Total of _______ days

Balloon Car Introduction: Balloon Car Construction and Messing About, MR

Student Pages: 86 – 97

2 days

Goals

- Introduce the Balloon Car Challenge and relate it to overall Antartica Challenge. Discussion of Problem Specifications, Constraints/Criteria, and what might need to be learned to successfully complete the Balloon Car Challenge
- Construct basic Balloon Engine and see initial run of this car..
- Messing About with Balloon Car followed by Whiteboarding to identify and discuss ideas about how to make the car go farther by applying what they already know about forces. Students gain familiarity with new car type, and they try to identify possible changes to make.
- Identify possible variables to test with the Balloon Car.

Materials: coaster car chassis, balloons, large starws, hot glue/glue gun, tape, styrofoam cups.

Overview of Activities:

1. The class reviews the Balloon Car Challenge. Have students restate the challenge aloud to verify understanding of it. Identify possible constraints and criteria and potential difficulties in achieving the challenge, pp. 88-93. Update the Whiteboard if necessary.
2. Students construct balloon engines using the instructions in the book, pp. 94-96. Teachers may want to give each group two cups to build the tower they feel it is necessary given the students current coaster car designs. This will raise the engine off the chassis a bit more, however, some teachers use this to get at friction issues more. Then, student run the Balloon Car 3-4 times to see how it works. See Homework Possibility below.
3. "Messing About" – Using pp. 97, students make some very quick changes to the design (pieces) of the balloon engine. They use different sized straws to construct their engines. Students use the Messing About Design Diary pageto record notes and observations of these differennt engine types.
4. Variables to Test – Following a discussion of the Messing About experience, the class convenes to identify possible variables that could be changed on the Balloon Car. These variables will be used to design and run experiments to collect data on car performance. For now, the students identify the Learning Issues they have regarding the car's features. You may want top update your whiteboard with these Learning Issues, or you may want to create a simeple list of variables to test.

Homework Possibilities

2. Students prepare for Messing About by completing homework on pp. 97.

Force Pairs and Balloon Engines, PJC

Student Pages: 98-105

Days: ????

Goals:

- Continue exploring forces as the result of interactions between objects using force arrow diagrams
- Understand that both objects participate in the interaction and so each experiences a force
- Begin seeing non-obvious forces, especially from distortion of passive objects (like floors)
- Understand how balloons create a propulsion force through unbalanced forces

Materials:

None required except book.

Overview

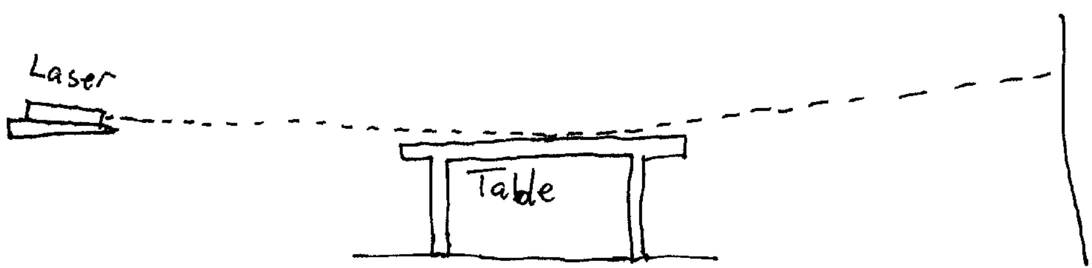
1. **Force arrow diagrams** should be thought of as a tool for understanding forces, not as something to study in themselves. Students should be encouraged to draw diagrams to understand force situations at every possible opportunity. Translating what they think into the diagram will make their understanding more precise, and will also provide you a means for pointing out missing members of force pairs.

2. **Well separated diagrams** are essential for laying the groundwork for **Newton's Third Law,** to come later. It is ok to draw both objects together (as with the foot and soccer ball on page 99 of the student book). However, you should also separate the diagram into two separate diagrams, one for the foot and one for the ball, well apart from each other on the board. This is necessary to see that **there are two different forces acting on two different objects**, and that they **cannot be combined** in calculating a net force.

3. **Force pairs are everywhere**. You can then, for each one, draw the *other* forces on each object (e.g. gravity, friction, ground pushing up). This allows you to explicitly identify forces that are pairs and forces that are not pairs resulting from the interaction between the foot and the ball. You can also identify the other forces as part of force pairs resulting from interactions with other objects not under consideration (e.g. if there is a force of gravity from the earth on the ball, there is also a force of gravity from the ball on the earth; if there is a force of friction from the ground on the foot, there is also a force of friction from the foot on the ground). You can use both pictures on the top of page 99 to explore all the different interactions and force pairs.

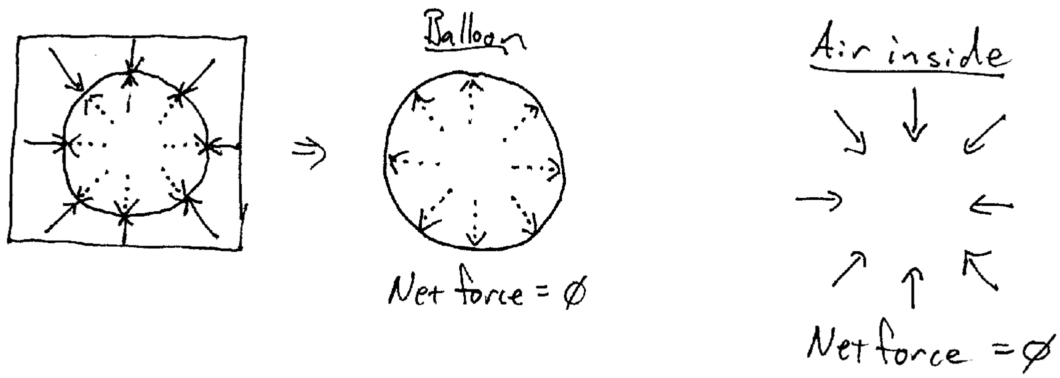
4. **Passive forces**. This is one of the most difficult concepts for students to grasp. In English, force is a verb. In physics, it is a noun. Similarly, students have a tough time grasping that an object with no obvious source of power (like a table or floor) is capable of exerting a force. A way of approaching this is hinted at on the bottom of page 98 (Forces in Pairs) with the mattress example. You can flesh this out a bit with a few simple demonstrations:

a. *Establish that some passive objects can exert a force because they have been distorted in some way.* A couple of obvious examples are rubber bands and springs. Have students pull on them and feel the force. Pull with a spring scale and measure the force. See that the greater the distortion, the greater the force, and that you can do this vertically, horizontally, or even upside down and get the same result (Sets the stage for normal forces from floors, walls and ceilings).
b. *See that this can happen with surfaces as well.* The mattress example is a good one. Another that you can do in class and look at the distortion is to use a large embroidery hoop to hold various materials (saran wrap, aluminum foil, rubber/vinyl sheets (e.g. shelf paper), cloth, etc.). Place various weights on the surface and see that it bends, and that it bends more with a larger weight, and that "stiffer" surfaces bend less with the same weight, and that they all have a breaking point when they have been distorted too much. You can also poke at it with your finger and feel the restoring force. Draw an analogy with the springs and rubber bands -- the surface is exerting a force because it has been bent and it wants to "spring back."
c. *Floors/tables are just really stiff surfaces.* You can lead them to this reasoning, but with a laser pointer and a mirror, you can also see it. Tape the laser pointer to a cardboard box or piece of wood cut at a very shallow angle, almost horizontal. Allow it to reflect off of a table and create a spot on the wall across the room (you may need to put a mirror on the table to get a reflection). Press down or stand on the table near the mirror and watch the spot on the wall move slightly up. This is because the table is bent, moving the mirror slightly down, so the angles of incidence and reflection are both larger.

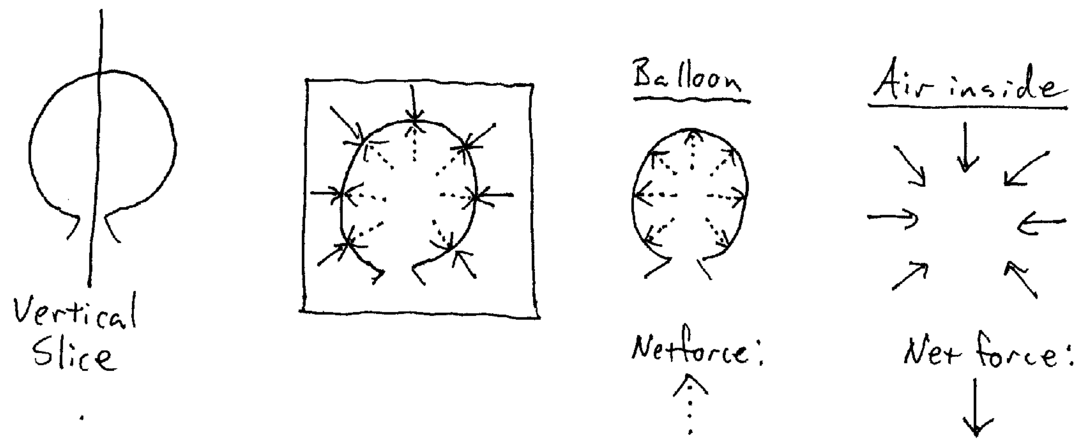


d. *Walls are no different from floors and tables.* Use two bathroom scales, back to back, one of the with the "stand on" surface against a wall in a doorway with the scale visible through the open door. The other scale will be pointing into the classroom and can be pushed on by a student. The student can read the force they are pushing with directly from their scale, and you can read the force that the wall is pushing back with from the scale that is touching the wall. It is worth noting that they are the same size since this will prepare the way for Newton's Third Law later. This activity is described at the bottom of page 100 (Forces in Pairs Continued).

5. **Balloons are three dimensional rubber bands (sort of)**. The picture on page 103 makes this analogy by taking a thin slice through the balloon. This picture needs to be redrawn into well separated force diagrams. The solid arrows are the force of the balloon on the air. The dotted arrows are the force of the air on the balloon. They need to be separated into solid-only and dotted-only pictures, and then show that the net force on each is zero.



It is worth drawing another balloon that is sliced vertically so that there is an open hole on one end. This will scaffold what the students are required to produce. **The diagrams asked for on page 105** (Force of Propulsion Continued) should involve something like this: Students have a deep intuition about balanced forces, and you can exploit that here to understand how balloons work. Now, your solid-only picture is missing an arrow at the bottom (because there is an opening in the balloon there). Your dotted-only picture is also missing an arrow there since there is nothing for the air to push on. That gives you an unbalanced force on the air (solid arrows) pointing backwards so that is the net force on the air. Similarly, you have an unbalance force on the balloon (dotted arrows) pointing upward so that is the net force on the balloon.



6. **Balloons are different from rubber bands in one important way.** There is an important difference between balloons and rubber bands, and you can appeal to experience to see it. Pull a rubber band and feel how hard it pulls back -- the greater the stretch, the greater the force. Try to blow up a balloon. You have to blow hardest right at the beginning. This means the balloon pushes back on the air the most when it is the *least* stretched. Some students may notice this later with their balloon cars when you can see a well-built, low friction car get a little kick just as the balloon is running out of air.

Homework Possibilities

1. The homework from Forces in Pairs is really essential. You may require two things: a picture like the foot-and-soccer-ball on pg. 99 showing the interaction and the paired forces (with written explanation); and a well separated force diagram for each object showing all the forces on each and identifying which are paired.

2. *Advanced* A very useful pedagogical method is to work the logic backwards. You can provide students with well separated force arrow diagrams in which force pairs are identified but the interacting objects are not. Ask them to come up with a situation that fits the diagrams. The easiest way to generate these is to think of some examples and draw the diagrams for them. But be aware that there is generally more than one right answer. Some students may come up with a correct situation that is not the one you used to create the diagrams.

3. Generate some design ideas for a balloon car.

4. Think of some other examples of objects that behave like balloons. Explain them using both force arrow diagrams and written explanations.

Balloon Car Experiments, Poster Session, and Rules of Thumb, MR

Student Pages: 106 – 110

3 Days

Goals
- Identify and design Balloon Car experiments.
- Conduct Balloon Car experiments: Velocity Test and Acceleration Test. Net Force Test is optional. While running experiments, students consider and evaluate Fair Testing issues for their experiment(s).
- Prepare and conduct a Poster Session, follwed by the first Rules of Thumb Session of Balloon Car.

Materials:
- Balloon Car
- Extra Balloons, Glue Sticks, Straws (especially the very wide straws), stopwatches, and measuring tapes.
- "My Experiment" Design Diary Sheets

Overview of Activities
1. From the list of variables the students created days ago, each group selects a variable to test with their Balloon Car. Students should plan and discuss their experiments before conducting them. Using the My Experiment sheets, each student records the procedure for their experiment as they plan it.
2. Students will need to test the variable across two measures. First, students should measure the average acceleration (through multiple trials) of the variable setting. Then, they will need to find the average distance traveled. A third option is to have students measure the force of propulsion. This can be done if the teacher has small scale spring scales that measure 1-5 newtons of force. Attach the spring scale to the bck of the car via a paper clip, and run the engine. Note: Teachers may want to try this at first. The differences between variable settings may produce subtle differences in force measurements, but large differences in acceleration and distance due to the size of the spring scale. Students should record their findings on their My Experiment sheets. While running experiments, the students should read or reference fair testing issues highlighted on pages 107-109. If need be, have them return to the fair testing pages in section 3 of the launcher text.
3. As students are working on their experiments, they can prepare the poster for the Poster Session. Each group will share their data and the lessons learned from their experiments in a Poster Session following the experiments. The poster will need to have the question they were researching, the data they collected and analyzed, and a conclusion or possible answer to their question. The conclusion can also be in the form of a recommendation for designing with their varibale. This recommendation would serve as the groups Rule of Thumb. Teachers should suggest that students try to explain or justify the Rule of Thumb with science they have been learning or already learned in coaster car. Page 110 provides a guide to help teachers and students prepare for the Poster Session and the Rules of Thumb Session.

4. Each group presents their experiments in a Poster Session. Teacher and students should constructively question and scrutinize the work of each group. The class should discuss and debate (although, not at great length) the Rule of Thumb suggested by each group. The teacher should record the Rules of Thumb on a poster or transparency. The poster session discussion should focus on how well the group performed their experiments and tests. Also, the teacher should try to realte the findings to the science the class has discussed. Once the Poster Session is complete, students record the Rules of Thumb on their My Rules of Thumb sheet. Some Rules of Thumb will be difficult to explain or justify (under the Why the Rule Works column), but that's fine for now. Later in Balloon Car, there will be opportunites for them to edit the sheet. Try to use open-ended, student-centered, guided questioning through out this. This will help you read the class's understanding of the experiments and the science they have been learning.

Homework Possibilities

- The poster foor the Poster Session
- Completion of the My Experiment sheets
- Creating a Rule of Thumb from each experiment

Experimental Results, Net Force and Acceleration, PJC

Student Pages: 112-119

Days: ????

Goals:

- Continue exploring forces as the result of interactions between objects using force arrow diagrams
- Distinguish acceleration from velocity.
- Understand that no single force is responsible for the motion of an object.
- Begin seeing the connection between *net* force and acceleration (not velocity) at a qualitative level
- It it arises, understand that mass may also affect acceleration but don't emphasize it yet.

Materials:

None required except book.

Overview

2. **Connect individual forces to net force to acceleration using diagrams.** This is the main point of this section. Begin with simple systems and eventually build to application to the balloon car using motion storyboards. You should do enough examples so that students begin to see the same sequence of steps occuring over and over:
3. An interaction picture (e.g. the balls at the bottom of page 112) with identified force pairs, which leads to
   b. Well separated force diagrams showing all the forces acting *on each object* (the first row of the tables on page 112-113), which lead to
   c. Net force diagram *for each object* from adding up all the forces *on that object*, which leads to
   d. Acceleration diagram showing acceleration *for each object* in the direction of *it's* net force.

4. **Recall passive forces.** They still won't have it yet, and will be associating force with motion. This is going to be important for the example on page 115. You will have to recall all the examples of surfaces distorting from the Forces in Pairs pages to understand how a stationary car can exert a force. Let them try first and then lead them to correct as needed by recalling the previous section.

5. **Use the force/acceleration diagrams and motion storyboards as tools to understand other things, not as objects of study in themselves**. One way to do this is, at the end, to connect it back to the original situation by asking for a verbal or

written summary of the story that is being told. Attempting to articulate what the diagram means will also help them to better understand what is being depicted in it.

6. **We shall NOT "overcome."** There is a strong tendency among both students and teacher to say that one force has been "overcome" by another. This is a locution most commonly used in regard to friction. *It is very bad.* Students already have a tendency to think of force as a unitary concept and to associate motion with *single* causes rather than the *net effect of multiple causes.* Whenever a student says that "force A has been overcome by force b," you should pause and ask for clarification. Make them articulate an alternative explanation in terms of multiple forces and their net effect.

7. **When in doubt, look for interactions.** Students are going to have difficulty identifying all the forces. This skill takes lots of practice. The most common problem involves associating force with movement ("the force of its motion.") You should use these as opportunities to emphasize the association between forces and interactions – if you cannot identify another object that is being interacted with, then there is no such force (this is just the case with "the force of its motion" which regards force as possessed by the moving object rather than arising from some interaction between it and another object). There may be some problems with gravity, but you can point out that results from a long distance interaction with the Earth – go to the Moon and the gravitational force on the same object will be different.

<u>Homework Possibilities</u>

8. These are tough ideas, and it is important to get lots of practice. You can assign page 114 to be done again for several more examples. You may let them choose some, but you should choose others that will emphasize the roles of passive forces, constant velocity motion, and stationary objects. E.g.: a ball sitting on a table; a ball rolling along a table (do ball and table; include friction); a ball rolling along a table that is on roller skates (do ball and table); a ball that is rolling down a table tilted just enough tocompensate for friction (do ball and table); a rolling ball that collides with a wooden block; etc.

9. *Advanced* Work the logic backwards. Provide some filled-out force diagrams and motion storyboards and ask them to draw (and explain in writing) an experimental situation that would fit.

Return to Balloon Car Challenge: Build and Test the Best, MR

Student Pages: 120-123

2-3 Days

Goals
1. Review the Balloon Car Challenege.
2. Plan a Best Balloon Car design.
3. Build and test a best Balloon Car.
4. Have students share designs and receive feedback.

Materials:
- Balloon Car
- Materials for building Balloon Cars
- Combining "Forces in the Real World" sheet
- Testing My Design sheets
- Gallery Walk Notes sheet

Overview of Activities
1. Students return to the Whiteboard to update it. The class reviews the experiments to update any learning issues or facts. Also, the class identifies other new questions to explore.
2. Students plan a final Balloon Car Design. Each student shares their ideas for the final design with their group. The group then settles on a final design idea. The group creates a Pin-Up to be shred with the rest of the class. It should include a drawing of the final idea and captions and labels explaining and/or justifying the design decisions. Then, each group shares their Pin-Up with the rest of the class. Page 121 and the Pin-Up pages from Section 3 of the Launcher text will be useful in guiding students through this activity.
3. Have students review pages 122-123. Students look at examples of "Combined Forces". Then, students are afforded the opportunity to experiment with forces acting in a variety of direction, all at once, on the car. These pages are meant to, in the end, focus on combining all variables tested during the class's experiments, and then combining the best settings of those variables to maximize propulsion force and net force.
4. Students build and test their designs. During each iteration, have students complete a Testing My Design sheet to keep a record of their design experiences. Try to have a Gallery Walk to share design ideas and discuss problems that are being encountered. As students complete Testing My 2/3/04esign sheets for each design, they can create a Motion Storyboard from the average of the data they collect. See bottom of page 121 for more details on completing Motion Storyboards.

Homework Possibilities
- Combining "Forces in the Real World" sheet, pp. 122 in text.
- Pin-Up poster
- Completion of the Testing My Design sheets and the Motion Storyboards

Combining Forces, MR

Student Pages: 122-123

Balloon Car Presentation and Distance Challenge, MR

Student Pages: 124-125

1 Day

Goals

- Present and run Best Balloon Cars in the Distance Challenge.
- Use force and motion concepts in describing the design changes and the performance of their cars.
- Observe and take notes on the design and performance of others' cars.
- Critique designs using force and motion concepts.

Materials:

- Balloon Cars
- Gallery Walk Observations Design Diary sheets

Overview of Activities

1. Students present their final design. They should explain other ideas they considered, ones they tested and ruled out, and what aspects of their current design will lead to success in the Distance Challenge. Each group should run their car, and the distance traveled should be measured. Afterwards, the class should discuss how the more successful cars designed around the science ideas from the Balloon Car unit. Discuss how forces and accelration played a role for successul and unsuccessful groups. Page 125 provides information for the students to prepare for their presentation and those of other groups. Also, pp. 125 details what students should do while other groups are presenting.

Balloon Car : Using Graphs To Tell Stories, PJC

Student Pages: 126-128

Days: ?????

Goals:

- Begin to understand how velocity graphs describe motion
- Connect the graphical description with verbal descriptions and motion storyboards.

Materials:

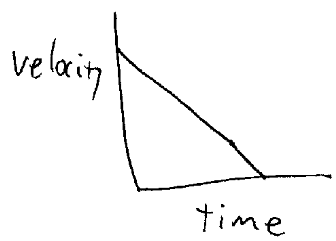
- Books

Overview

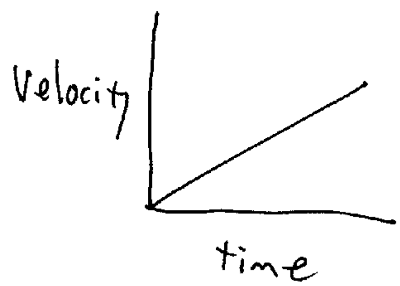
1. **All of the points in the previous section still apply to presentations**. In particular, you will have to be on the lookout for failure to recognize the roles of multiple forces and net force, failure to recognize passive forces, and the "overcome" locution.

2. **Use force diagrams and motion storyboards as tools in the presentations.** Students should be encouraged to incorporate these descriptive tools as part of their presentation. However, they should also explain each of them in words, not just say "and here is my picture."

3. **Velocity graphs depict behavior, NOT path followed**. There is a strong urge to interpret the picture drawn on a graph as a picture of the path followed in space. If you ask for a graph of the velocity for the coaster car as it goes down a ramp, you are as likely to get this (**incorrect**):

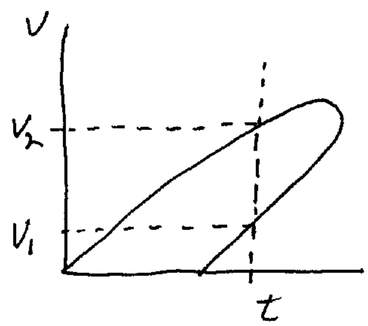


as this (**correct**):

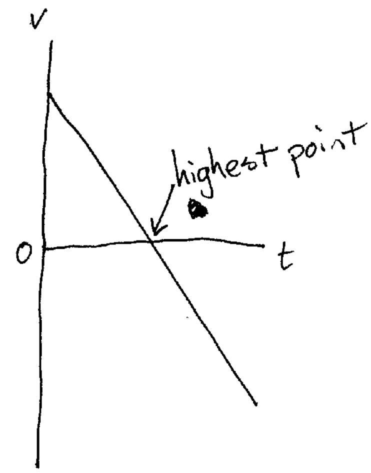


4. **You can't go backward in time**. This is related to point 3. For example, if asked to graph something that goes out and then comes back (e.g. a ball tossed in the air), you are likely to see something like this:

But note that this implies the ball has two different velocities at the same time:



Basically, the issue here is that we are using distance to *represent* time, and in this respect that representation is imperfect. You have to require that a **pen never be moved to the left** since time only flows in one direction. The correct graph of the ball would look like this:



5. **You can't stop time either**. A related problem with graphs is that there is a strong tendency to think that a graph for a motionless object can be drawn with a motionless pen (i.e. a point). This is also due to the imperfect mapping in which distance on the paper represents time. You have to require that the **pen never stops moving to the right.** A motionless object is therefore represented by a horizontal line along the time axis.

6. **Velocity graphs are NOT distance graphs**. A horizontal line at a nonzero value on a distance graph represents a stationary object whereas on a velocity graph it represents a moving object.

7. **Compare with distance graphs**. Refer back to the material on page 80-81 under Graphing Motion. It may be worthwhile to sketch velocity graphs from the three distance graphs there. Articulate a story in words that describes how fast each car is moving as time goes by. Then sketch a graph that matches the story. You should find that the velocity graph describes how "steep" the distance graph is at each point (i.e. its slope, though you may not want to get into that).

<u>Suggested Homework</u>

1. Gallery Walk Summary design diary page. This provides students with an opportunity to reflect on their Gallery Walk Notes and translate them into force and motion language.

2. Take two or three of the cars that performed differently and draw velocity graphs that show the differences.

3. Provide some additional velocity graphs and ask for stories that articulate the differences between how the objects are moving.

** OPTIONAL DAY**, MR

Student Pages: 130-131

Goals

1. Present and run Best Balloon Cars in the Tug-of-War Challenge.

Materials:

- Balloon Cars

Overview of Activities

1. Students attach a paper clip as a hitch to their Balloon Car. The teacher cuts a 1 meter length of string and ties a paper clip to each end. The individual cars are then “hitched” to each other, pointing in opposite directions. The engines are readied, and a Tug-of-War is conducted. Have each group compete against each other. Interesteingly enough, the Balloon Cars that did well in the Distance Challenge may not do well in this activity, or they might. When you tie the cars together, the cars becomne one system with a single net force acting on the sytem. The ngine for each car contributes to the size and direction of the net force. Cars whose net force is large may not last long enough to win the challenge! Use page 131 to guide your discussion during this exciting day of class.

Homework Possibility

- Questions on pp. 131.

Adding Mass to Your Car & Investigating Stall Load, PJC

Student Pages: 132-135

Balloon Car Presentation and Distance Challenge, MR

Student Pages: 136-137

1 Day, or part of the previous day's activities

Goals
- Whiteboarding session
- Review Balloon Car module

Overview of Activities
1. The class reviews the Whiteboard they created earlier, and edits it appropriately to update the learning issues, facts, and ideas.
2. The class goes over the questions on pages 136 and 137

Homework Possibilities
- Review for the end of sub-unit assessment (test or quiz). Pages 136-137 might help.
- Project report – documenting and justifying design decisions, using vocabulary, rules of thumb, concepts, and data derived during the module.

VEHICLES IN MOTION 5.1
DAY-BY-DAY LESSON OUTLINES
BALLOON CAR CHALLENGE
Total of 16-18 days

Balloon Car Introduction: Balloon Car Construction and Messing About, MR

Student Pages: 86 – 97

2 days

Goals
- Introduce the Balloon Car Challenge and relate it to overall Antarctica Challenge. Discussion of Problem Specifications, Constraints/Criteria, and what might need to be learned to successfully complete the Balloon Car Challenge
- Construct basic Balloon Engine and see initial run of this car..
- Messing About with Balloon Car followed by Whiteboarding to identify and discuss ideas about how to make the car go farther by applying what they already know about forces. Students gain familiarity with new car type, and they try to identify possible changes to make.
- Identify possible variables to test with the Balloon Car.

Materials: coaster car chassis, balloons, large straws, hot glue/glue gun, tape, Styrofoam cups.

Overview of Activities:
1. The class reviews the Balloon Car Challenge. Have students restate the challenge aloud to verify understanding of it. Identify possible constraints and criteria and potential difficulties in achieving the challenge, pp. 88-93. Update the Whiteboard if necessary.
2. Students construct balloon engines using the instructions in the book, pp. 94-96. Teachers may want to give each group two cups to build the tower they feel it is necessary given the students current coaster car designs. This will raise the engine off the chassis a bit more, however, some teachers use this to get at friction issues more. Then, student run the Balloon Car 3-4 times to see how it works. See Homework Possibility below.
3. "Messing About" – Using pp. 97, students make some very quick changes to the design (pieces) of the balloon engine. They use different sized straws to construct their engines. Students use the Messing About Design Diary page to record notes and observations of these different engine types.
4. Variables to Test – Following a discussion of the Messing About experience, the class convenes to identify possible variables that could be changed on the Balloon Car. These variables will be used to design and run experiments to collect data on car performance. For now, the students identify the Learning Issues they have regarding the car's features. You may want top update your whiteboard with these Learning Issues, or you may want to create a simple list of variables to test.

Homework Possibilities
1. Students prepare for Messing About by completing homework on pp. 97.

Force Pairs and Balloon Engines, PJC

Student Pages: 98-105

2 Days

Goals:

- Continue exploring forces as the result of interactions between objects using force arrow diagrams
- Understand that both objects participate in the interaction and so each experiences a force
- Begin seeing non-obvious forces, especially from distortion of passive objects (like floors)
- Understand how balloons create a propulsion force through unbalanced forces

Materials:

None required except book.

Overview

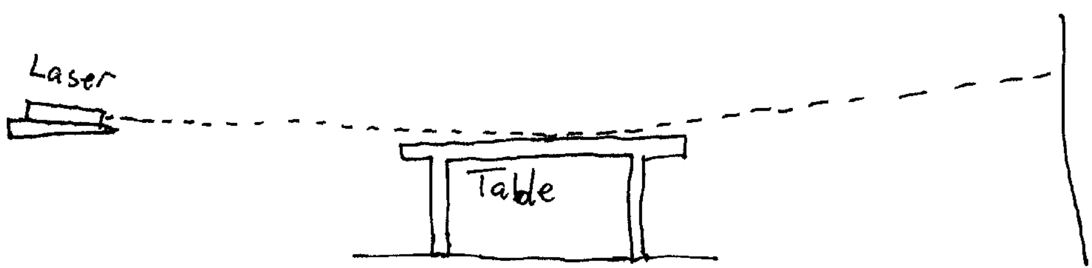
1. **Force arrow diagrams** should be thought of as a tool for understanding forces, not as something to study in themselves. Students should be encouraged to draw diagrams to understand force situations at every possible opportunity. Translating what they think into the diagram will make their understanding more precise, and will also provide you a means for pointing out missing members of force pairs.

2. **Well separated diagrams** are essential for laying the groundwork for **Newton's Third Law,** to come later. It is ok to draw both objects together (as with the foot and soccer ball on page 99 of the student book). However, you should also separate the diagram into two separate diagrams, one for the foot and one for the ball, well apart from each other on the board. This is necessary to see that **there are two different forces acting on two different objects**, and that they **cannot be combined** in calculating a net force.

3. **Force pairs are everywhere**. You can then, for each one, draw the *other* forces on each object (e.g. gravity, friction, ground pushing up). This allows you to explicitly identify forces that are pairs and forces that are not pairs resulting from the interaction between the foot and the ball. You can also identify the other forces as part of force pairs resulting from interactions with other objects not under consideration (e.g. if there is a force of gravity from the earth on the ball, there is also a force of gravity from the ball on the earth; if there is a force of friction from the ground on the foot, there is also a force of friction from the foot on the ground). You can use both pictures on the top of page 99 to explore all the different interactions and force pairs.

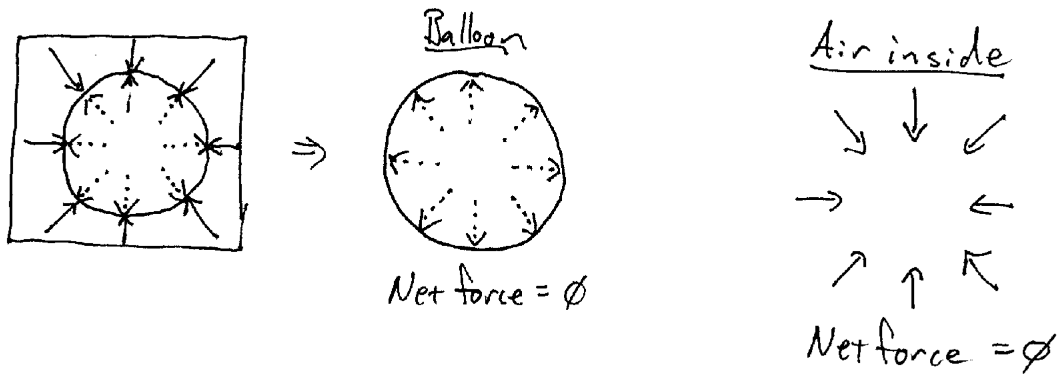
4. **Passive forces**. This is one of the most difficult concepts for students to grasp. In English, force is a verb. In physics, it is a noun. Similarly, students have a tough time grasping that an object with no obvious source of power (like a table or floor) is capable of exerting a force. A way of approaching this is hinted at on the bottom of page 98 (Forces in Pairs) with the mattress example. You can flesh this out a bit with a few simple demonstrations:

a. *Establish that some passive objects can exert a force because they have been distorted in some way.* A couple of obvious examples are rubber bands and springs. Have students pull on them and feel the force. Pull with a spring scale and measure the force. See that the greater the distortion, the greater the force, and that you can do this vertically, horizontally, or even upside down and get the same result (Sets the stage for normal forces from floors, walls and ceilings).
b. *See that this can happen with surfaces as well.* The mattress example is a good one. Another that you can do in class and look at the distortion is to use a large embroidery hoop to hold various materials (saran wrap, aluminum foil, rubber/vinyl sheets (e.g. shelf paper), cloth, etc.). Place various weights on the surface and see that it bends, and that it bends more with a larger weight, and that "stiffer" surfaces bend less with the same weight, and that they all have a breaking point when they have been distorted too much. You can also poke at it with your finger and feel the restoring force. Draw an analogy with the springs and rubber bands -- the surface is exerting a force because it has been bent and it wants to "spring back."
c. *Floors/tables are just really stiff surfaces.* You can lead them to this reasoning, but with a laser pointer and a mirror, you can also see it. Tape the laser pointer to a cardboard box or piece of wood cut at a very shallow angle, almost horizontal. Allow it to reflect off of a table and create a spot on the wall across the room (you may need to put a mirror on the table to get a reflection). Press down or stand on the table near the mirror and watch the spot on the wall move slightly up. This is because the table is bent, moving the mirror slightly down, so the angles of incidence and reflection are both larger.

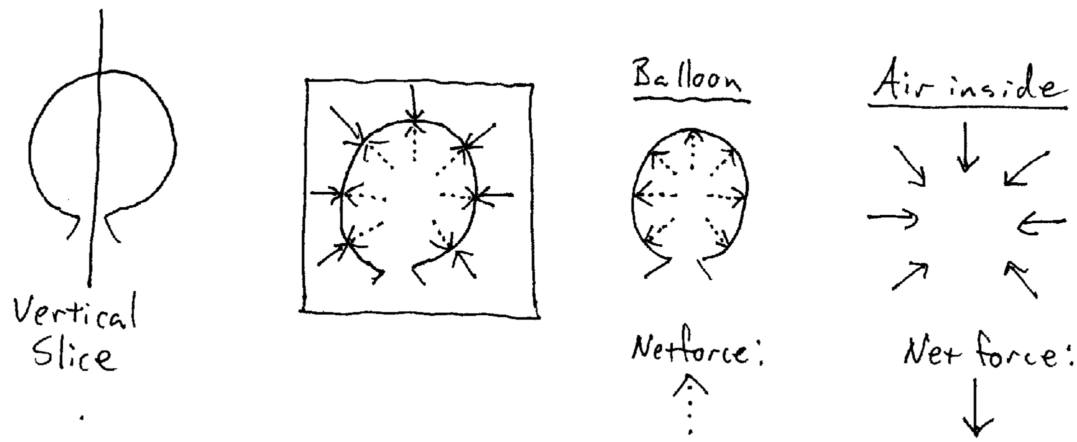


d. *Walls are no different from floors and tables.* Use two bathroom scales, back to back, one of the with the "stand on" surface against a wall in a doorway with the scale visible through the open door. The other scale will be pointing into the classroom and can be pushed on by a student. The student can read the force they are pushing with directly from their scale, and you can read the force that the wall is pushing back with from the scale that is touching the wall. It is worth noting that they are the same size since this will prepare the way for Newton's Third Law later. This activity is described at the bottom of page 100 (Forces in Pairs Continued).

5. **Balloons are three dimensional rubber bands (sort of)**. The picture on page 103 makes this analogy by taking a thin slice through the balloon. This picture needs to be redrawn into well separated force diagrams. The solid arrows are the force of the balloon on the air. The dotted arrows are the force of the air on the balloon. They need to be separated into solid-only and dotted-only pictures, and then show that the net force on each is zero.



It is worth drawing another balloon that is sliced vertically so that there is an open hole on one end. This will scaffold what the students are required to produce. **The diagrams asked for on page 105** (Force of Propulsion Continued) should involve something like this: Students have a deep intuition about balanced forces, and you can exploit that here to understand how balloons work. Now, your solid-only picture is missing an arrow at the bottom (because there is an opening in the balloon there). Your dotted-only picture is also missing an arrow there since there is nothing for the air to push on. That gives you an unbalanced force on the air (solid arrows) pointing backwards so that is the net force on the air. Similarly, you have an unbalance force on the balloon (dotted arrows) pointing upward so that is the net force on the balloon.



6. **Balloons are different from rubber bands in one important way.** There is an important difference between balloons and rubber bands, and you can appeal to experience to see it. Pull a rubber band and feel how hard it pulls back -- the greater the stretch, the greater the force. Try to blow up a balloon. You have to blow hardest right at the beginning. This means the balloon pushes back on the air the most when it is the *least* stretched. Some students may notice this later with their balloon cars when you can see a well-built, low friction car get a little kick just as the balloon is running out of air.

<u>Homework Possibilities</u>

1. The homework from Forces in Pairs is really essential. You may require two things: a picture like the foot-and-soccer-ball on pg. 99 showing the interaction and the paired forces (with written explanation); and a well separated force diagram for each object showing all the forces on each and identifying which are paired.

2. *Advanced* A very useful pedagogical method is to work the logic backwards. You can provide students with well separated force arrow diagrams in which force pairs are identified but the interacting objects are not. Ask them to come up with a situation that fits the diagrams. The easiest way to generate these is to think of some examples and draw the diagrams for them. But be aware that there is generally more than one right answer. Some students may come up with a correct situation that is not the one you used to create the diagrams.

3. Generate some design ideas for a balloon car.

4. Think of some other examples of objects that behave like balloons. Explain them using both force arrow diagrams and written explanations.

Balloon Car Experiments, Poster Session, and Rules of Thumb, MR

Student Pages: 106 – 110

3 Days

Goals
- Identify and design Balloon Car experiments.
- Conduct Balloon Car experiments: Velocity Test and Acceleration Test. Net Force Test is optional. While running experiments, students consider and evaluate Fair Testing issues for their experiment(s).
- Prepare and conduct a Poster Session, followed by the first Rules of Thumb Session of Balloon Car.

Materials:
- Balloon Car
- Extra Balloons, Glue Sticks, Straws (especially the very wide straws), stopwatches, and measuring tapes.
- "My Experiment" Design Diary Sheets

Overview of Activities
1. From the list of variables the students created days ago, each group selects a variable to test with their Balloon Car. Students should plan and discuss their experiments before conducting them. Using the My Experiment sheets, each student records the procedure for their experiment as they plan it.
2. Students will need to test the variable across two measures. First, students should measure the average acceleration (through multiple trials) of the variable setting. Then, they will need to find the average distance traveled. A third option is to have students measure the force of propulsion. This can be done if the teacher has small scale spring scales that measure 1-5 Newtons of force. Attach the spring scale to the back of the car via a paper clip, and run the engine. Note: Teachers may want to try this at first. The differences between variable settings may produce subtle differences in force measurements, but large differences in acceleration and distance due to the size of the spring scale. Students should record their findings on their My Experiment sheets. While running experiments, the students should read or reference fair testing issues highlighted on pages 107-109. If need be, have them return to the fair testing pages in section 3 of the launcher text.
3. As students are working on their experiments, they can prepare the poster for the Poster Session. Each group will share their data and the lessons learned from their experiments in a Poster Session following the experiments. The poster will need to have the question they were researching, the data they collected and analyzed, and a conclusion or possible answer to their question. The conclusion can also be in the form of a recommendation for designing with their variable. This recommendation would serve as the groups Rule of Thumb. Teachers should suggest that students try to explain or justify the Rule of Thumb with science they have been learning or already learned in coaster car. Page 110 provides a guide to help teachers and students prepare for the Poster Session and the Rules of Thumb Session.

4. Each group presents their experiments in a Poster Session. Teacher and students should constructively question and scrutinize the work of each group. The class should discuss and debate (although, not at great length) the Rule of Thumb suggested by each group. The teacher should record the Rules of Thumb on a poster or transparency. The poster session discussion should focus on how well the group performed their experiments and tests. Also, the teacher should try to relate the findings to the science the class has discussed. Once the Poster Session is complete, students record the Rules of Thumb on their My Rules of Thumb sheet. Some Rules of Thumb will be difficult to explain or justify (under the Why the Rule Works column), but that's fine for now. Later in Balloon Car, there will be opportunities for them to edit the sheet. Try to use open-ended, student-centered, guided questioning through out this. This will help you read the class's understanding of the experiments and the science they have been learning.

Homework Possibilities

- The poster for the Poster Session
- Completion of the My Experiment sheets
- Creating a Rule of Thumb from each experiment

Experimental Results, Net Force and Acceleration, PJC

Student Pages: 112-119

2 Days

Goals:
- Continue exploring forces as the result of interactions between objects using force arrow diagrams
- Distinguish acceleration from velocity.
- Understand that no single force is responsible for the motion of an object.
- Begin seeing the connection between *net* force and acceleration (not velocity) at a qualitative level
- It arises, understand that mass may also affect acceleration but don't emphasize it yet.

Materials:

None required except book.

Overview

1. **Connect individual forces to net force to acceleration using diagrams.** This is the main point of this section. Begin with simple systems and eventually build to application to the balloon car using motion storyboards. You should do enough examples so that students begin to see the same sequence of steps occurring over and over:
2. An interaction picture (e.g. the balls at the bottom of page 112) with identified force pairs, which leads to
    b. Well separated force diagrams showing all the forces acting *on each object* (the first row of the tables on page 112-113), which lead to
    c. Net force diagram *for each object* from adding up all the forces *on that object*, which leads to
    d. Acceleration diagram showing acceleration *for each object* in the direction of *it's* net force.

3. **Recall passive forces.** They still won't have it yet, and will be associating force with motion. This is going to be important for the example on page 115. You will have to recall all the examples of surfaces distorting from the Forces in Pairs pages to understand how a stationary car can exert a force. Let them try first and then lead them to correct as needed by recalling the previous section.

4. **Use the force/acceleration diagrams and motion storyboards as tools to understand other things, not as objects of study in themselves**. One way to do this is, at the end, to connect it back to the original situation by asking for a verbal or written summary of the story that is being told. Attempting to articulate what the diagram means will also help them to better understand what is being depicted in it.

5. **We shall NOT "overcome."** There is a strong tendency among both students and teacher to say that one force has been "overcome" by another. This is a locution most commonly used in regard to friction. *It is very bad.* Students already have a tendency to think of force as a unitary concept and to associate motion with *single* causes rather than the *net effect of multiple causes.* Whenever a student says that "force A has been overcome by force b," you should pause and ask for clarification. Make them articulate an alternative explanation in terms of multiple forces and their net effect.

6. **When in doubt, look for interactions.** Students are going to have difficulty identifying all the forces. This skill takes lots of practice. The most common problem involves associating force with movement ("the force of its motion.") You should use these as opportunities to emphasize the association between forces and interactions – if you cannot identify another object that is being interacted with, then there is no such force (this is just the case with "the force of its motion" which regards force as possessed by the moving object rather than arising from some interaction between it and another object). There may be some problems with gravity, but you can point out that results from a long distance interaction with the Earth – go to the Moon and the gravitational force on the same object will be different.

<u>Homework Possibilities</u>

7. These are tough ideas, and it is important to get lots of practice. You can assign page 114 to be done again for several more examples. You may let them choose some, but you should choose others that will emphasize the roles of passive forces, constant velocity motion, and stationary objects. E.g.: a ball sitting on a table; a ball rolling along a table (do ball and table; include friction); a ball rolling along a table that is on roller skates (do ball and table); a ball that is rolling down a table tilted just enough to compensate for friction (do ball and table); a rolling ball that collides with a wooden block; etc.

8. *Advanced* Work the logic backwards. Provide some filled-out force diagrams and motion storyboards and ask them to draw (and explain in writing) an experimental situation that would fit.

Return to Balloon Car Challenge: Build and Test the Best, MR

Student Pages: 120-123

3 Days

Goals
1. Review the Balloon Car Challenge.
2. Plan a Best Balloon Car design.
3. Build and test a best Balloon Car.
4. Have students share designs and receive feedback.
5. Revise and create Rules of Thumb

Materials:
- Balloon Car
- Materials for building Balloon Cars
- Combining "Forces in the Real World" sheets
- Testing My Design sheets
- Gallery Walk Notes sheets
- My Rules of Thumb sheets

Overview of Activities
1. Students return to the Whiteboard to update it. The class reviews the experiments to update any learning issues or facts. Also, the class identifies other new questions to explore.
2. Students plan a final Balloon Car Design. Each student shares their ideas for the final design with their group. The group then settles on a final design idea. The group creates a Pin-Up to be shred with the rest of the class. It should include a drawing of the final idea and captions and labels explaining and/or justifying the design decisions. Then, each group shares their Pin-Up with the rest of the class. Page 121 and the Pin-Up pages from Section 3 of the Launcher text will be useful in guiding students through this activity.
3. Have students review pages 122-123. Students look at examples of "Combined Forces". Then, students are afforded the opportunity to experiment with forces acting in a variety of direction, all at once, on the car. These pages are meant to, in the end, focus on combining all variables tested during the class's experiments, and then combining the best settings of those variables to maximize propulsion force and net force.
4. Students build and test their designs. During each iteration, have students complete a Testing My Design sheet to keep a record of their design experiences. Try to have a Gallery Walk to share design ideas and discuss problems that are being encountered. As students complete Testing My Design sheets for each design, they can create a Motion Storyboard from the average of the data they collect. See bottom of page 121 for more details on completing Motion Storyboards.
5. Class reviews the Rules of Thumb created earlier in the module. The students have learned some specific and technical science knowledge regarding force, net force, and acceleration. This Rules of Thumb session should focus on three things: 1)Students verify or edit existing Rules of Thumb based on the two rounds of experiments, 2)Teachers should model, expect,

and encourage the use of more scientific language in creating and explaining the Rules of Thumb students generate, and 3)Students should create new Rules of Thumb from the second round of experiments, attempting to more fluently relate the science concepts they have been learning to their recommendations. Record new Rules of Thumb on the class Rules of Thumb list and have students edit and record new Rules of Thumb on their My Rules of Thumb sheet.

Homework Possibilities

- Combining "Forces in the Real World" sheet, pp. 122 in text.
- Pin-Up poster
- Completion of the Testing My Design sheets and the Motion Storyboards

Balloon Car Presentation and Distance Challenge, MR

Student Pages: 124-125

1 Day

Goals
- Present and run Best Balloon Cars in the Distance Challenge.
- Use force and motion concepts in describing the design changes and the performance of their cars.
- Observe and take notes on the design and performance of others' cars.
- Critique designs using force and motion concepts.

Materials:
- Balloon Cars
- Gallery Walk Observations Design Diary sheets

Overview of Activities
1. Students present their final design. They should explain other ideas they considered, ones they tested and ruled out, and what aspects of their current design will lead to success in the Distance Challenge. Each group should run their car, and the distance traveled should be measured. Afterwards, the class should discuss how the more successful cars designed around the science ideas from the Balloon Car unit. Discuss how forces and acceleration played a role for successful and unsuccessful groups. Page 125 provides information for the students to prepare for their presentation and those of other groups. Also, pp. 125 details what students should do while other groups are presenting.

Balloon Car : Using Graphs To Tell Stories, PJC

Student Pages: 126-128

1 to 2 Days

Goals:
- Begin to understand how velocity graphs describe motion
- Connect the graphical description with verbal descriptions and motion storyboards.

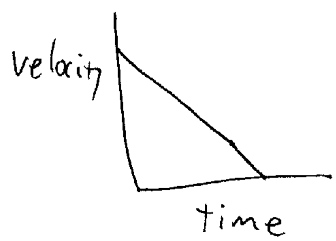
Materials:
- Books

Overview

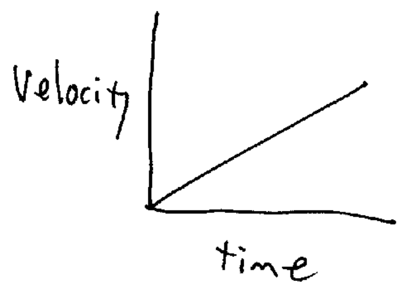
1. **All of the points in the previous section still apply to presentations**. In particular, you will have to be on the lookout for failure to recognize the roles of multiple forces and net force, failure to recognize passive forces, and the "overcome" locution.

2. **Use force diagrams and motion storyboards as tools in the presentations.** Students should be encouraged to incorporate these descriptive tools as part of their presentation. However, they should also explain each of them in words, not just say "and here is my picture."

3. **Velocity graphs depict behavior, NOT path followed**. There is a strong urge to interpret the picture drawn on a graph as a picture of the path followed in space. If you ask for a graph of the velocity for the coaster car as it goes down a ramp, you are as likely to get this **(incorrect)**:

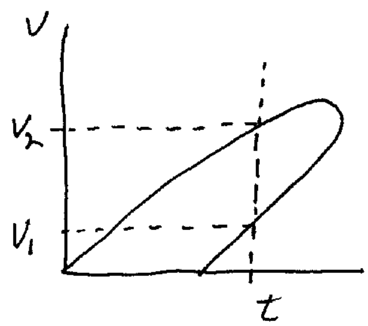


as this (**correct**):

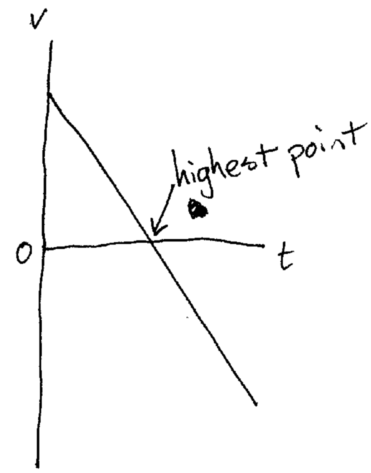


4. **You can't go backward in time**. This is related to point 3. For example, if asked to graph something that goes out and then comes back (e.g. a ball tossed in the air), you are likely to see something like this:

But note that this implies the ball has two different velocities at the same time:



Basically, the issue here is that we are using distance to *represent* time, and in this respect that representation is imperfect. You have to require that a **pen never be moved to the left** since time only flows in one direction. The correct graph of the ball would look like this:



5. **You can't stop time either**. A related problem with graphs is that there is a strong tendency to think that a graph for a motionless object can be drawn with a motionless pen (i.e. a point). This is also due to the imperfect mapping in which distance on the paper represents time. You have to require that the **pen never stops moving to the right.** A motionless object is therefore represented by a horizontal line along the time axis.

6. **Velocity graphs are NOT distance graphs**. A horizontal line at a nonzero value on a distance graph represents a stationary object whereas on a velocity graph it represents a moving object.

7. **Compare with distance graphs**. Refer back to the material on page 80-81 under Graphing Motion. It may be worthwhile to sketch velocity graphs from the three distance graphs there. Articulate a story in words that describes how fast each car is moving as time goes by. Then sketch a graph that matches the story. You should find that the velocity graph describes how "steep" the distance graph is at each point (i.e. its slope, though you may not want to get into that).

<u>Suggested Homework</u>

1. Gallery Walk Summary design diary page. This provides students with an opportunity to reflect on their Gallery Walk Notes and translate them into force and motion language.

2. Take two or three of the cars that performed differently and draw velocity graphs that show the differences.

3. Provide some additional velocity graphs and ask for stories that articulate the differences between how the objects are moving.

** OPTIONAL DAY**, MR

Student Pages: 130-131

Goals

1. Present and run Best Balloon Cars in the Tug-of-War Challenge.

Materials:

- Balloon Cars

Overview of Activities

1. Students attach a paper clip as a hitch to their Balloon Car. The teacher cuts a 1 meter length of string and ties a paper clip to each end. The individual cars are then “hitched” to each other, pointing in opposite directions. The engines are readied, and a Tug-of-War is conducted. Have each group compete against each other. Interestingly enough, the Balloon Cars that did well in the Distance Challenge may not do well in this activity, or they might. When you tie the cars together, the cars become one system with a single net force acting on the system. The engine for each car contributes to the size and direction of the net force. Cars whose net force is large may not last long enough to win the challenge! Use page 131 to guide your discussion during this exciting day of class.

Homework Possibility

- Questions on pp. 131.

Adding Mass to Your Car & Investigating Stall Load, PJC

Student Pages: 132-135

1-2 Days

Goals:

1. Investigate how mass affects the motion of a car
2. Refine understanding of how weight and friction are related
3. Experimentally measure the stall load of the balloon car

Materials:

1. Balloon cars
2. Small standard masses (e.g. washers, nuts, clothespins, etc.)
3. Spare balloon engines

Overview

1. **Mass has three ways of affecting the performance of a car.** First, **gravitational force** depends on the mass -- more mass means more force. Second, **acceleration** is affected by mass through Newton's Second Law -- more mass means less acceleration. In a frictionless world, these effects would exactly balance and the movement of the car would be unaffected by its mass. Third, **friction** is affected by mass but not directly -- the more *normal force*, the more friction. The correct logical sequence is on the top of page 135.

2. **Single variable vs. multiple variable reasoning.** Students readily understand that "heavier means more gravity" and will sometimes argue that heavier cars go faster, even on a level track. This is phenomenological reasoning based on using a single measure of "bigness." It may be useful to redraw the force and net force diagrams on the bottom of page 134 for the case of (a) much smaller friction, and (b) a hypothetical world with no friction, and explore how the mass would affect the motion of the car in each of those cases using the relationship between net force and acceleration. They should be challenged to think of other situations in which mass causes slowness.

3. **Without friction, the car would never be motionless.** This asymptotic behavior is hard for kids to grasp. Stall load appeals phenomenologically because everything we have experience with always comes to a stop. This is related to the "overcoming" locution mentioned in a previous section -- sometimes you will hear that the engine force has been "overcome" by the mass. This phrasing is as bad here as it is elsewhere, and an appeal to force and net force diagrams is in order (as in the previous note #2). **This is the most important point in this section** and is the basis for the answer to reflection question 4. You should not leave this section unless this idea has appeared in the class statement on force. Unfortunately, since there is no frictionless world, you will have to get there by: (1) appeal to force diagrams instead of direct experience; and (2) comparing cars of similar mass but different stall loads, which should make the role of friction in stall load apparent (try them as coaster cars and verify that the one which coasts the furthest also has the largest stall load).

Balloon Car Presentation and Distance Challenge, MR

Student Pages: 136-137

1 Day, or part of the previous day's activities

Goals
- Whiteboarding session
- Review Balloon Car module

Overview of Activities
1. The class reviews the Whiteboard they created earlier, and edits it appropriately to update the learning issues, facts, and ideas.
2. The class goes over the questions on pages 136 and 137

Homework Possibilities
- Review for the end of sub-unit assessment (test or quiz). Pages 136-137 might help.
- Project report – documenting and justifying design decisions, using vocabulary, rules of thumb, concepts, and data derived during the module.

Rules of Thumb

The use Rules of Thumb practice (or ritual) in LBD in way for teachers to help students make links between their design/experiment experiences and the abstract science concepts they learn during a unit. Rules of Thumb are student derived statements that usually summarize how a design decision or idea is explained or justified by a science concept. The key aspects to the Rules of Thumb practice are:

1. Iterative development of the statements, the Rules of Thumb.
2. The teacher and peer review of Rules of Thumb generated by students.
3. Frequent engagement in the practice within a sub-unit of an LBD unit.
4. The use of "*science talk*" during class and individual discussions that mimics that Rules of Thumb pattern of speech and content.

When students generate a display for their poster session to share experimental results, they are usually expected to share or state a conclusion to their experiment in reference to the variable(s) they were testing. This conclusion is the primordial version of a Rule of Thumb. Let's look at the example of a group that tests the effect of double ballooning the balloon engine on their model car in VIM. The group performs an experiment, and they discover that the distance traveled via the double-ballooned engine is , on average, three time greater than a single balloon engine. They end their presentation with the conclusion, "Use a double-walled balloon to make your car travel the greatest distance." Obviously , there is

VEHICLES IN MOTION 5.1
DAY-BY-DAY LESSON OUTLINES
RUBBER BAND CAR CHALLENGE
Total of 10-12days

Rubber Band Car Introduction, MR

Student Pages: 140 – 145

0.5 - 1 Day

Goals
- Introduce the Rubber Band Car Challenge and relate it to overall Antarctica Challenge. Discussion of Problem Specifications, Constraints/Criteria, and what might need to be learned to successfully complete the Rubber Band Car Challenge
- Review students' ideas of force and motion

Overview of Activities:
1. The class reviews the Rubber Band Car Challenge. Have students restate the challenge aloud to verify understanding of it. Identify possible constraints and criteria and potential difficulties in achieving the challenge, pp. 88-93. Update the Whiteboard if necessary.
2. On pages 144-145, students rewrite many of the statements they have been generating throughout the unit. If you look at the descriptions six statements requested, they cover the ideas expressed in Newton's First and Second Laws. In the coming pages, students will learn these laws formally, attempting to relate them to the statements they write on these pages. It may be necessary for the students to look back through the text and re-discover the statements they have been writing. These statements can even be developed by the groups they sit in, but make sure that each student records the statement in this case. It may be worthwhile for students to share their statements in class and discuss them.

Homework Possibilities
- Finish writing their statements.

Newton's First and Second Laws, PJC

Student Pages: 146-153

Continued from the day before, 1 Day

Goals:
- Formalize the understanding of Force and Motion acquired from coaster and balloon cars (see overview).
- Connect formal statement of Newton's Laws with motion storyboards and force arrow diagrams
- Revisit analysis of coaster and balloon car motion to reduce remaining misconceptions
- Connect Newton's Laws with student Rules of Thumb

Materials:
- Book
- Coaster and balloon car for demonstrations

Overview

1. **Newton's Laws formalize previous student statements.** The overall goal should be a reaction along the lines of "we already knew that." Take students' definitions of force, and statements about the relationship between force and motion (found in homeworks and motion storyboards from previous sections) and restate them in the language of Newton's Laws. This will afford the opportunity to revisit poor representations of force and motion remaining from the previous work. In particular:

   1. If any students still have force arrow representations that associate force with velocity, you can discuss them again. Always remember to direct students' attention toward *interactions* as a key to finding forces -- any forces they draw that are *not* associated with interactions (e.g. the "force of its motion") you should explicitly lead students to exclude from force arrow diagrams. This will help resolve inconsistencies between their net force arrows and the motion observed in the cars.
   2. A related idea is that a force is "used up" in propelling the car -- the force goes away at the moment the car stops. Alternatively, some students argue that the force of friction is gradually building up until it exactly balances the "force of its motions" at the moment the car stops. Both of these are inconsistent with Newton's Laws, and now is the time to revisit and attempt to correct them. You can show that friction is constant (it doesn't "build up" at all) by using a spring scale to drag a block around. Then use the interaction argument to associate the *constant* net force with the *slowing down of the car*, not with its forward motion. Reiterate the "force associate with change of motion" idea.

2. **Student "force" is different from physics "force."** It is ok to acknowledge that the definition of force used in Newton's Laws is different from the definition that students learned from everyday experience. However, it should also at the same time be noted that

the Newtonian definition is leading to a more accurate understanding of how forces actually affect motion in the real world.

3. **Correct previous motion storyboards and force arrow diagrams based on Newton's Laws.** This makes an excellent homework assignment.

4. **Rewrite Rules of Thumb in the language of Newton's Laws as appropriate.** Design rules of thumb may not be amenable to this treatment but rules about force and motion are. It may be necessary to correct some rules of thumb at this time, but be sure to look again at what coaster and balloon cars actually do to make sure that more careful observation is consistent with the corrections.

5. **Demonstrations of force and acceleration.** A bathroom scale is very useful here. By using the bathroom scale to push things around, you can measure the force. One problem with observations on the cars is that they have been tuned to run a great distance so it is hard to see how the velocity is changing -- it doesn't change very quickly. By pushing much more massive objects, you can make the changes more visible.

1. In particular, you can push a student sitting in a rolling office chair (or have a student push you). Push with a constant force as measured by the bathroom scale and observe the speeding up of the chair. Stop pushing and see that the chair continues to go but now slowing down. Do a motion storyboard and force arrow diagrams for this experiment, associating a push > friction with the speeding up and friction alone with the slowing down. Draw an analogy with the balloon car and the coaster car storyboards and diagrams.
2. Change the friction by pushing an ordinary chair without wheels (you can cut holes in tennis balls and put them on the legs to avoid scratching the floor). This requires much greater bathroom scale force to get the same acceleration as with the rolling chair, and you get much less acceleration when you use the same amount of force. Draw storyboards and force diagrams to show the difference with the previous experiment (friction arrow should be larger).
3. Ask students to extrapolate to a hypothetical world in which you could completely eliminate friction. Describe what would happen in words, and also draw motion storyboards and force arrow diagrams that illustrate what they think will happen. Discuss in the context of Newton's laws and correct accordingly.

6. **Don't forget to ask students what they think.** It is unlikely that all students believe all of what Newton's Laws say about force and motion. They should be encouraged to invent situations in which Newton's Laws "don't apply" which you can then explain using Newtonian language. It you don't feel comfortable doing this on the fly, you can give it as a homework assignment and discuss it a day or two later after preparing answers.

7. **Always emphasize that the forces of interest are acting on a *specific object* as a result of a *specific interaction* it is experiencing.** This is a major point where student ideas of force differ from physical ideas. For instance, on the Newton's First Law page in the student book, the force diagrams at the bottom of the page are for the soccer ball only,

and for the barbell only. Forces on the elephants are not included. Forces on the weightlifter are not included. Since these forces act on different objects, they are irrelevant for the object you are interested in for each picture.

Homework Possibilities:

- Explain parachutes using Newton's Laws. Do a motion storyboard and force arrow diagrams for them.
- Justify Rules of Thumb using Newton's Laws.
- Revisit and correct previous motion storyboards and force arrow diagrams.
- Summarize how your understanding of force has changed since the beginning of Vehicles. What were the most important experiences that caused it to change? How has your understanding of the connection between force and motions changed, and why?

Newton's Laws and Graphs, PJC

Student pages: 154-155

1 Day

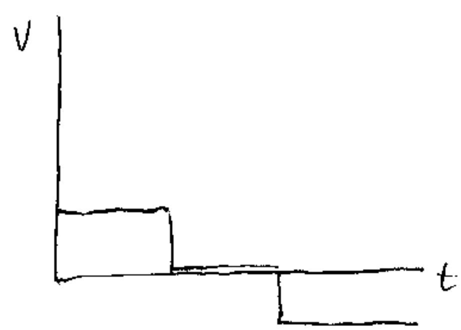
Goals:
- Connect pictorial and verbal descriptions of motion.
- Visually emphasize the connection between force and velocity *change*.

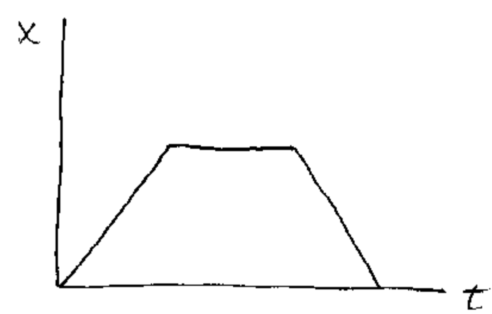
Overview

1. **Graphs do not show the path followed.** This was a point in the previous section on graphs and will probably need to be revisited here. The velocity graph goes up when the car is going faster, not when it is going uphill. A horizontal distance graph means the car is stationary but a horizontal velocity graph does not.

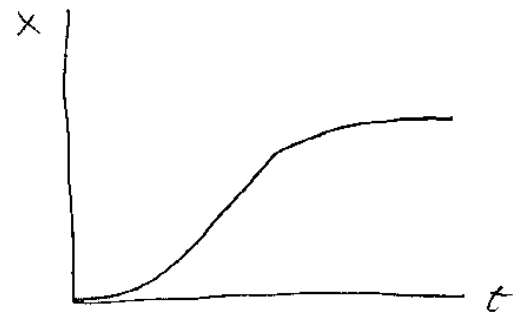
2. **Experience the graphs kinsethetically**. Ask students to walk in the way depicted by various position and velocity graphs. You will have to observe carefully and correct their movement with reference to the graph. If you are not comfortable doing this "on the fly," then prepare a few graphs beforehand or make sure you understand the ones in the book. Make sure they are speeding up, slowing down, and standing still at the right times. Also, make sure you have at least one set of velocity vs. time and position vs. time graphs that depict the same motion. Discuss how the graphs represent the same thing differently. Here are a couple of examples:

Walking at a steady speed/standing still/walking backwards at a steady speed





Speeding up/walking at a steady speed/slowing down



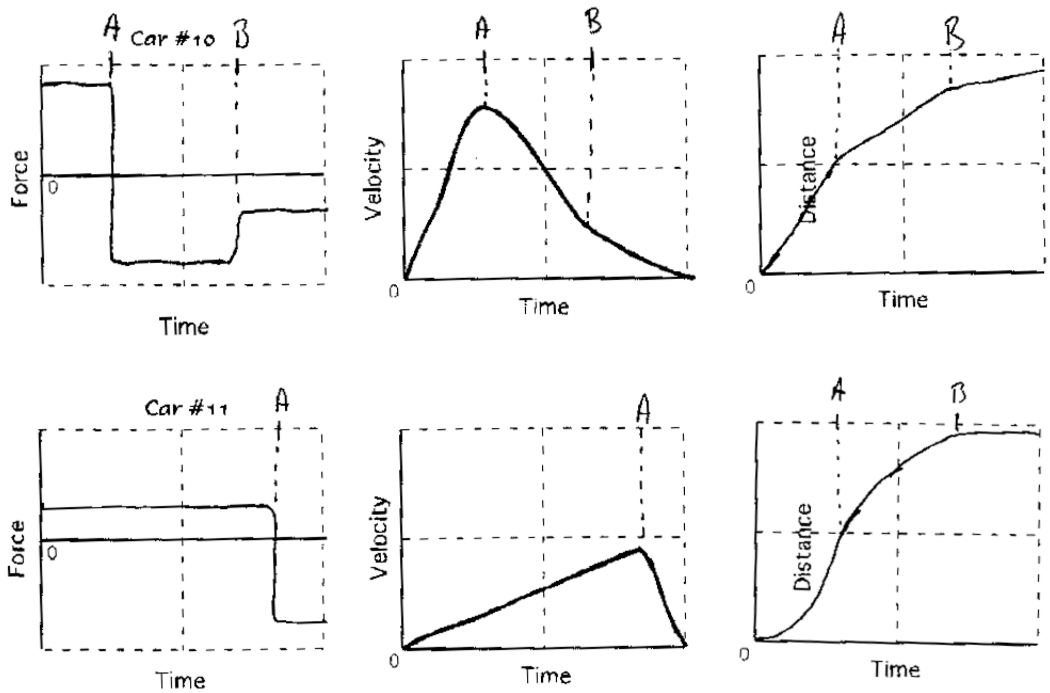
3. **Carefully discuss the three graphs at the bottom of the Newton's Laws and Graphs page (car #8 and Car #9 velocity and net force).** It is crucial that students see that:

1. whenever there is a force, the velocity *must* change
2. whenever there is not a force, the velocity is constant
3. when velocity and force are both positive, the velocity is getting larger
4. when velocity is positive and force is negative, the velocity is getting smaller
5. these statements are the same no matter what the mass; the effect of mass is to decrease the *amount* of velocity change but not the fact that it is changing

Explicitly connect each of these observations with Newton's first and second laws.

4. **Associate each phase of the graphs of velocity and force with the appropriate portions of the motion storyboards and force arrow diagrams.**

5. **Graphs for cars 10 and 11.**



<u>Homework Possibilities</u>

- Graphs, associated storyboards, force arrow diagrams and Newtonian stories for any simple motion situations. You can use Vehicles or Apollo or any standard physical science book to find situations that will be viable.

<u>Balloons and "Best Engines", PJC</u>

<u>Student pages:</u> 156-163

1 Day

<u>Goals:</u>

- To understand how the size of the balloon force varies
- To see how well the balloon engine matches the constraint of the test track

<u>Overview</u>

1. **Balloons do not produce a constant force.** The force produced by a balloon car is the

reverse of the force you must produce to blow the balloon up -- At the beginning of the run, the balloon force is small. As the balloon deflates, the force increases. Just before it runs out of air entirely is when the balloon force is largest. This means that the force graphs should be sort of parabolic, rising to a maximum value before dropping rapidly to zero.

Refer back to the notes on Force Pairs for more information on how balloons function. It is worth reminding the class at this point.

2. **Differences between the performance of the cars must be due to other factors.** Differences in mass (weigh them to find out if this accounts for discrepancies) are possible as are differences in internal friction (do a spin test on the wheels), alignment of the axles, or friction with the floor. Also possible factors are differences in the construction of the engines themselves (straw length or angle relative to the ground).

3. **Balloon force does not match test track very well.** Since the balloon produces the largest force at the end of the run and the smallest force at the beginning, having the hills at the beginning may be lethal for the balloon engines. Just at the point when the car needs the largest force to get over a hill is when the engine is producing the smallest force. Testing should show this. The Best Engine rules of thumb should reflect this design constraint.

Homework Possibilities

- Imagine some situations in which the balloon would be a good engine.
- Come up with some possible designs for better engines for this test track. Support the designs with plausible force graphs.

Rubber Band Car Construction and Messing About, MR

Student Pages: 164 – 169

1.25 Days

Goals
- Construct basic Rubber Band engine and see initial run of this car..
- Messing About with Rubber Band Car followed by Whiteboarding to identify and discuss ideas about how to make the car go farther by applying what they already know about forces. Students gain familiarity with new car type, and they try to identify possible changes to make.
- Update the Whiteboard with ideas and learning issues raised from the Messing About experience.

Materials:
- Coaster Car Chassis
- Extra wing-nuts and hex-nuts, metal wire, hand tools, varying wheels (container lids, CDs, toy wheels, etc.)
- Messing About Observation Notes sheet

Overview of Activities
1. Students construct rubber band engines using the instructions in the book, pp. 164-167. Make note of the fact that there are two mechanisms for attaching the rubber band to the axle. Each post (J-Post and X-Post) have advantages and disadvantages, let students decide which they prefer. Then, student run the Rubber Band Car 3-4 times to see how it works. See Homework Possibility below.
2. "Messing About" – On page 168 there are hints to remind students what Messing About is intended to do. Students may want to fill out Messing About Observation sheets from the Design Diary pages.
3. The class reconvenes to discuss the observations from Messing About. They update the Whiteboard, and as it states in the text, encourage students to develop their Newtonian Law vocabulary as they discuss the car and it's design features. Following a discussion of the Messing About experience and the Whiteboarding, the class convenes to identify possible variables that could be changed on the Rubber Band Car. These variables will be used to design and run experiments to collect data on car performance. For now, the students identify the Learning Issues they have regarding the car's features. You may want top update your whiteboard with these Learning Issues, or you may want to create a simple list of variables to test.

Newton's Third Law and Rubber Band Engines, PJC

Student Pages: 170-173

0.75 Day

Goals:

- To formalize understanding of force pairs and Newton's Third Law.
- To justify rules of thumb using the third law.
- To understand how the third law is crucial in the operation of a rubber band car, and the role of friction in that operation.
- To understand that there are two different objects and two different forces involved in Newton's third law, but that only one of these forces is important in determining the motion of each object.

Overview

1. **What Newton's Third Law says.** Every force results from an interaction. Every interaction is between two identifiable physical objects. Each object participates equally in that interaction; neither one is more important than the other. Each object experiences the same size force as a result of their interaction. Each of those forces acts on a different object. To understand the motion of an object, consider only the force that acts on it, not the force that acts on the other object.

2. **What Newton's Third Law does not say.** (a) The net force is not always zero. Though the force pairs in the third law are oppositely directed, they do not sum to zero since they act on different objects. You cannot add the forces acting on object A to the forces acting on object B. (b) Forces do always come in pairs, even from interaction with passive objects like walls and floors (see previous discussion of force pairs for more on passive forces, worth recalling at this point). (c) All objects do not move the same. You need to use the Second Law to find out what the acceleration will be, and that also involves mass.

3. ***Never say "For every action there is an equal and opposite reaction."*** The fact that it is a cute poem is the only reason in favor of this statement. There are a number of reasons for against it. (1) You are talking about forces. You have been carefully developing force language for some weeks. Why muddy the waters by introducing "action," a term that has not been defined and probably has a variety of meanings to your students? What is an "action?" If it is a force, then say force and keep it simple. If it is not a force, then what is it? Newton's laws are about forces so speak of forces. (2) It hides most of the content of the third law. What does the force/action act on? Is it the same object or different objects? (3) How can it be equal if it is opposite?

Say what you mean. Here is Newton's Third Law: *For every interaction between objects, each object experiences a force. Those two forces are the same size but act in opposite directions.*

4. **Students will not believe the equality of forces until they see it**. Do lots of demonstrations. Fundamental equipment: two bathroom scales. Be sure to zero them when you are holding them upright. You will use each scale to measure a force from a different object by sandwiching them back to back between the two objects. Basic idea: you and I will press the backs of our scales together and push, each measuring our force from the scale we are holding. Do lots of variations. Challenge students to come up with a situation in which one force has to be larger than the other. Put one person on a skateboard, or a rolling office chair. Use people of different masses. One person push and the other just stand in the way. Measure the force exerted by a wall by placing a scale in a doorway so that you can see the reading, and pushing it with the other scale. One person stand still and another run into them with a scale (this will be tricky to get a good reading from). I used to bet my students $50 to nothing. I always won.

5. **The third law makes the rubber band car go.** The balloon car could be understood as a push of the balloon against the air, in a sense against something external to itself. The rubber band car pulls on itself. The challenge, then, is to understand how this can make it move forward. Friction between the wheels and the ground is the crucial point. Without friction, it would go nowhere (indeed, that is why the basic rubber band car spins out -- not enough friction). As the wheels rotate, they rub against the ground, creating friction. The friction *on the ground* is backwards. The friction *on the wheels* is forwards. Note that this is a force pair. It is the friction *on the wheels* that makes the car accelerate. The ground also accelerates but, since the mass of the Earth is enormous, that acceleration is microscopic accordingly to Newton's Second Law.

6. **Newton's Third Law applies to all forces, even gravity**. Gravity results from a long distance interaction with the Earth. The Earth also has a gravitational force on it, and yes that force is the same size as the force on the other object. The *effect* of the force on the Earth is dramatically different, however, since the mass of the Earth is so very large.

7. **Newton’s Third Law tells you that a force exists. Newton's Second Law tells you about the effect of the force**. This is why forces of the same size can have widely varying effects since Newton's Second law uses mass along with force to determine the acceleration.

Rubber Band Car Experiments and Poster Session, MR

Student Pages: 174

2-3 Days

Goals
- Design and conduct Rubber Band Car experiments.
- Prepare and conduct a Poster Session, followed by a Rules of Thumb Session of Rubber Band Car.

Materials:
- Rubber Band Car
- Extra Rubber Band, Glue Sticks, Straws (especially the very wide straws), stopwatches, and measuring tapes.
- "My Experiment" Design Diary Sheets, My Rules of Thumb Sheets

Overview of Activities
1. From the list of variables the students created days ago, each group selects 1-3 variables to test with their Rubber Band Car. Many groups will experiment on the same variables, and this makes for good Poster Session discussion. If time is an issue, continue to have students select only one variable to test. Major variables here are wheel size, rubber band length (this can be adjusted by linking multiple rubber bands), ruler-post position, and number of wind-ups. Students should plan and discuss their experiments before conducting them. Using the My Experiment sheets, each student records the procedure for their experiment as they plan it.
2. Students will need to test the variable across two measures. First, students should measure the average acceleration (through multiple trials) of the variable setting. Then, they will need to find the average distance traveled. A third option is to have students measure the force of propulsion. This can be done if the teacher has small scale spring scales that measure 1-5 Newtons of force. Attach the spring scale to the back of the car via a paper clip, and run the engine. Note: Teachers may want to try this at first. The differences between variable settings may produce subtle differences in force measurements, but large differences in acceleration and distance due to the size of the spring scale. Students should record their findings on their My Experiment sheets. While running experiments, the students should read or reference fair testing issues highlighted in section three of the Launcher materials. If need be, have them return to the fair testing pages in section 3 of the launcher text.
3. As students are working on their experiments, they can prepare the poster for the Poster Session. Each group will share their data and the lessons learned from their experiments in a Poster Session following the experiments. The poster will need to have the question they were researching, the data they collected and analyzed, and a conclusion or possible answer to their question. The conclusion can also be in the form of a recommendation for designing with their variable. This recommendation would serve as the groups Rule of Thumb. Teachers should suggest that students try to explain or justify the Rule of Thumb with science they have been learning or

already learned in coaster car. Page 174 provides a guide to help teachers and students prepare for the Poster Session and the Rules of Thumb Session. Encourage and model the vocabulary discussed with each of Newton's Laws. Raise expectations for this type of behavior during this and the last module of the VIM unit.

4. Each group presents their experiments in a Poster Session. Teacher and students should constructively question and scrutinize the work of each group. The class should discuss and debate (although, not at great length) the Rule of Thumb suggested by each group. The teacher should record the Rules of Thumb on a poster or transparency. The poster session discussion should focus on how well the group performed their experiments and tests. Also, the teacher should try to relate the findings to the science the class has discussed, especially Newton's Laws! Once the Poster Session is complete, students record the Rules of Thumb on their My Rules of Thumb sheet. Some Rules of Thumb will be difficult to explain or justify (under the Why the Rule Works column), but that's fine for now. Later in Rubber Band Car, there will be opportunities for them to edit the sheet. Try to use open-ended, student-centered, guided questioning through out this. This will help you read the class's understanding of the experiments and the science they have been learning.

****Note:** The expectation is that students are more able to plan, conduct, and manage experiments with design features of these cars. Most groups will probably be able to run and present 1-2 experiments in a two-day period. Also, the Poster Session and Rules of Thumb Session should be more familiar and their fluency should be developed at this point. These assumptions were considered in suggesting the duration of and iterations in this module. If students are making errors in their testing procedures, then more time will be needed to complete experiments and develop Rules of Thumb.

<u>Homework Possibilities</u>

- The poster for the Poster Session.
- Completion of the My Experiment sheets.
- Creating a Rule of Thumb from each experiment.

Return to Rubber Band Car Challenge: Build and Test the Best, MR

Student Pages: 175

2 Days

Goals
- Review the Rubber Band Car Challenge.
- Plan a Best Rubber Band Car design.
- Build and test a best Rubber Band Car.
- Have students share designs and receive feedback.
- Revise and create Rules of Thumb

Materials:
- Rubber Band Car
- Materials for building Rubber Band Cars
- Testing My Design sheets
- Gallery Walk Notes sheets
- My Rules of Thumb sheets

Overview of Activities
1. Students return to the Whiteboard to update it. The class reviews the experiments to update any learning issues or facts. Also, the class identifies other new questions to explore.
2. Students plan a final Rubber Band Car Design. Each student shares their ideas for the final design with their group. The group then settles on a final design idea. The group creates a Pin-Up to be shred with the rest of the class. It should include a drawing of the final idea and captions and labels explaining and/or justifying the design decisions. Then, each group shares their Pin-Up with the rest of the class. Page 175 and the Pin-Up pages from Section 3 of the Launcher text will be useful in guiding students through this activity, focusing students to justify and explain design decisions using Newton's Laws
3. Students build and test their designs. During each iteration, have students complete a Testing My Design sheet to keep a record of their design experiences. Try to have a Gallery Walk to share design ideas and discuss problems that are being encountered. As students complete Testing My Design sheets for each design, they can create a Motion Storyboard from the average of the data they collect.
4. Class reviews the Rules of Thumb created earlier in the module. The students have learned some specific and technical science knowledge regarding force, net force, and acceleration. This Rules of Thumb session should focus on three things: 1)Students verify or edit existing Rules of Thumb based on the two rounds of experiments, 2)Teachers should model, expect, and encourage the use of more scientific language in creating and explaining the Rules of Thumb students generate, and 3)Students should create new Rules of Thumb from the second round of experiments, attempting to more fluently relate the science concepts they have been learning to their recommendations. Record new Rules of Thumb on the class Rules of Thumb list and have students edit and record new Rules of Thumb on their My Rules of Thumb sheet.

Homework Possibilities
- Pin-Up poster.
- Completion of the Testing My Design sheets and the Motion Storyboards.

Rubber Band Car Presentation and Wrap-Up, MR

Student Pages: 175

1 Day

Goals
- Present and run Best Rubber Band Cars on the test track
- Use force and motion concepts in describing the design changes and the performance of their cars.
- Observe and take notes on the design and performance of others' cars.
- Critique designs using force and motion concepts.
- Review Rubber Band Car module

Materials:
- Rubber Band Cars

Overview of Activities
1. Students present their final design. They should explain other ideas they considered, ones they tested and ruled out, and what aspects of their current design will lead to success in the challenge. Each group should run their car on the test track, and the distance traveled should be measured. Afterwards, the class should discuss how the more successful cars designed around the science ideas from the VIM unit. Discuss how Newton's Laws played a role for successful and unsuccessful groups.
2. The class goes over the questions on page 177. An additional option is to review a brief biography of Isaac Newton on pp. 176.

Homework Possibilities
- Review for the end of sub-unit assessment (test or quiz). Page 177 might help.
- Project Report – documenting and justifying design decisions, using vocabulary, rules of thumb, concepts, and data derived during the module.