Fender Bender Physics

By Roy Q. Beven and Robert A. Raudebaugh

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—Roy Q. Beven

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—Robert A. Raudebaugh

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Supplemental Materials

Correlations with the *National Science Education Standards* for Grades 5–8

		MOUSETRAP CAR					CO_2 CAR						SPACEFRAME VEHICLE						
CONTENT STANDARD	**TOPIC**	**ACT 2**	**ACT 3**	**ACT 4/7**	**ACT 5**	**ACT 8**	**ACT 1**	**ACT 2**	**ACT 3**	**ACT 4**	**ACT 6/7**	**ACT 8**	**ACT 1**	**ACT 2**	**ACT 3**	**ACT 4**	**ACT 6**	**ACT 7**	**ACT 8**
(A) Science as Inquiry	Develop descriptions, explanations, predictions, and models using evidence			•							•					•		•	
	Communicate scientific procedures and explanations		•			•					•	•						•	•
	Understandings about scientific inquiry		•		•	•	•				•	•	•			•		•	•
(B) Physical Science	Motion and Forces	•			•			•	•	•				•	•				
	Transfer of Energy													•	•		•		•
(E) Science and Technology	Abilities of technological design		•	•			•				•	•	•			•		•	
	Understanding about science and technology						•				•		•						
(F) Science in Personal And Social Perspectives	Science and technology in society												•					•	•
(G) History and Nature of Science	Nature of science		•								•		•						

National Research Council. *National Science Education Standards.* Washington, DC: National Academy Press, 1996.

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The selection process involves four review stages:

1. First, a cadre of undergraduate science education majors searches the World Wide Web for interesting science resources. The undergraduates submit about 500 sites a week for consideration.

2. Next, packets of these Web pages are organized and sent to teacher-Webwatchers with expertise in given fields and grade levels. The teacher-Webwatchers can also submit Web pages that they have found on their own. The teachers pick the jewels from this selection and correlate them to the *National Science Education Standards*. These pages are submitted to the SciLinks database.

3. Then scientists review these correlated sites for accuracy.

4. Finally, NSTA staff approve the Web pages and edit the information provided for accuracy and consistent style.

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Teacher's Guide to Unit 1: The Mousetrap Car

The integration of science and technology can provide exciting learning opportunities for the middle school student. In this unit students design and build a vehicle that employs a mousetrap as a source of energy. Students participate in basic research, design, construction, and evaluation in a process of continuous inquiry, supported by record keeping and effective communication.

Overview

Students begin by investigating the force of a mousetrap's lever arm. They measure the relationship between the distance a mousetrap is opened and the force it exerts as well as the effect of the snapper-arm length on that force. Then students apply their findings to the design of a mousetrap car. To evaluate, students measure, graph, and describe the motions of their designs. Students read background information on force and motion and communicate their results to others.

Like a professional scientific investigation, this project relies upon the accumulation of accurate data. Students create their own database of definitions, concepts, and experimental results. Students create design requirements and specifications and learn how to incorporate sufficient detail in order to get a design approved. Students also develop sketching skills as a tool for designing and communicating ideas.

Finally, students gain the satisfaction of seeing their designs take shape from a prototype. Prototyping is a standard engineering process that involves testing a variety of materials to determine which ones best meet the requirements of a project. Working in teams, students evaluate data by comparing car designs and communicate their progress through reports and expository writing.

This unit on the mousetrap car shows students the dynamic relationship between scientific investigation and technology. Students use experimentation, testing, and evaluation at each step of the process. They learn that their progress must be measurable and

Materials

- Copy of student handout, "The Mousetrap Car Challenge," for each student
- Copies of each of the eight activities, plus *Brainstorming, Mind Mapping, The Design Process*, and *Sketching Guide* for each student
- One mousetrap per team
- One 10-N spring scale per team
- One 2.5-N spring scale per team
- One set of small wooden blocks (approximately 1 cm^2, 1.5 cm^2, 2 cm^2, and 2.5 cm^2) per team
- One meterstick per team
- One stopwatch per team
- One wheel-block assembly per team (2.5-cm x 10-cm wood block)
- One 61-cm x 244-cm piece of plywood
- Test block made of pine (15 cm in length with 2.5-cm x 10-cm cross section, equipped with holes and bushings) per team

continued on next page

Materials ***continued***

- Cardboard to stop the test block
- Drinking straws
- Four axle rods (wood, plastic, and metal—all about 5 mm in diameter and 12 cm in length) per team
- Two sections of brass tubing (10 cm in length and with an inside diameter of about 6 mm) per team
- Enough materials for each team's wheels, axles, and bushings (CDs, old records, lids, and anything else that is round)
- Large ball of string
- Chassis materials (wood scraps, tongue depressors, strips of plastic, metal rods)
- Hand tools (NO power tools in the middle school)
- Material for lever-arm extension (optional)
- Eye protection

must be communicated in operational terms. When questions arise, controlled investigations provide answers. A design portfolio is the authentic assessment of the inquiry process.

The culminating activity of the unit is a Great Race. If students race their vehicles, emphasize pride over competition. The unit should be fun—ending with friendly, cooperative team presentations of design portfolios and completed mousetrap vehicles.

Conceptual Development

To launch the unit, introduce the challenge of designing and building a mousetrap car by distributing the student handout, "The Mousetrap Car Challenge." The handout gives students an overview of expectations and a table for recording points earned. Tell students to make the handout the first page of their notebooks.

Don't assume your students have ever seen a mousetrap or a mousetrap car. Begin by building a mousetrap car yourself. Construct the simplest version of the vehicle and share it with the class. Let them see how it works. Some groups may build cars very similar to this basic version, but most will add their own innovations. In "Activity 1: Writing Design Briefs," you will show them how a mousetrap car operates—and how strong (and potentially dangerous) the spring of a mousetrap is. Let the arm close on a marshmallow to demonstrate the potential danger to a hand. Tell students that horseplay will not be tolerated.

Students begin their study by defining the goals and design requirements of building a mousetrap car. As apprentice engineers, they learn that the design process requires many sequential steps and careful analysis. They practice group brainstorming and begin systematic record keeping.

In "Activity 2: Measuring Force," you will have students measure the force exerted by a mousetrap. The manipulated variable is the distance the trap is opened. Students will discover that the force is directly proportional to the stress within the normal range of the trap. This is Hooke's law, which applies to all elastic materials, including the spring steel of the trap. This relationship can be incorporated into their mousetrap-car design. In later activities students investigate the effects of lengthening the lever arm on the trap and make decisions about the value of this modification in comparison to the added mass. These first controlled investigations should be conducted slowly and deliberately. Many middle schoolers are just beginning to develop the logical skills that they need to understand variables, controls, and proportion. Emphasize the importance of accuracy and careful measurement, and reinforce the connections between the experiments and the design process.

In Activity 3 students begin the design process using the data they have collected to develop sketches and specifications for their own design. In later activities they test materials for axles and bushings and develop consensus on design issues. They are encouraged to invent creative solutions to the challenge defined by their goals and product requirements. They document their progress in a notebook and ultimately in a design portfolio. The diagram below shows the instructional activities and how they link with the design process.

Mousetrap Design Challenge

Design Process With Associated Instructional Activities

DEFINE THE PROBLEM
Activity 1: Writing Design Briefs

SCIENTIFICALLY GATHER INFORMATION
Activity 2: Measuring Force
Activity 5: Measuring Lever-Arm Effects

EXPLORE IDEAS
Activity 4: Testing Wheels and Axles

DEVELOP THE DESIGN
Activity 3: Writing a Design Process Paper
Activity 6: Developing a Design

CONSTRUCT PROTOTYPE
Activity 7: Constructing a Prototype

SCIENTIFICALLY TEST AND EVALUATE
Activity 8: Measuring Motion

REDESIGN
Activity 3: Writing a Design Process Paper

Team Project Presentation

Tips for Making the Unit Work

Arrange the classroom for movement and active learning. If you have access to a technology lab, such as an old shop, you may wish to do the final construction in that larger space. Assign teams, and emphasize the roles of each member.

Collect a variety of materials to spark creativity. Many teachers publish wish lists in their school newsletters in advance of teaching the unit. Invest in plastic bins, or ask the school office to save paper boxes. Since safety depends upon organization, emphasize to students that all excess material must be discarded properly or returned to the appropriate bin for someone else to use. If your high school has a wood shop, you may be able to get students to create the wood blocks you need there.

Divide your students into teams carefully. Do not put advanced students or disruptive students together. Post a list of Vehicle Research Teams (VRTs) in advance, and emphasize that each team will be graded on how well they work together. Emphasize that responsibilities must be rotated so that everyone has an opportunity for each role.

Communicate high expectations. Tell students that you know they are capable of earning full credit on each activity. Discretely return incomplete work for improvement. Be very specific about the requirements of the portfolio. Review graphing and paragraphing skills, so that each student can achieve success.

Give praise and encouragement. Communicate affection with humor, self-disclosure, eye contact, and smiles. Because you care, students will work more carefully. To model real scientific teamwork, emphasize sharing rather than competing.

Give students responsibility. Allow students to demonstrate pride in their work by having sample mousetrap cars on display. Invite other adults into the room, and have them sit with a team while the students work. At the end of a class period, have students clean up the room and assume other housekeeping tasks. Rotate these jobs among the members of the class on a regular basis throughout the course of this unit.

Treat all students equally and fairly. Some students will be amazed that their cars actually roll at all, and others may be disappointed that their cars aren't doing as well as they hoped. Remind them that it is the process, not the product, that is important.

Physics Background

Most physics and engineering studies use the same conventions—definitions, terminology, symbols, etc. They help ensure that scientists around the world and over time speak the same language. Your students will have to learn this language too. Do not begin by giving out all the definitions as notes; teach definitions opportunistically, as needed. Encourage students to create a glossary section in their notebooks for definitions and symbols used in their force and motion investigations, such as those listed below, rather than scattering definitions and symbols in many locations.

Distance (d): the measure of the space between two objects or events, measured in meters (m)

Time (t): the measure of the interval between two events, measured in seconds (s)

Velocity (v): the rate at which distance increases over time plus the direction, measured in meters per second (m/s). **Formula:** **v = d/t**. (Remember that velocity must include a direction. All of these tests involve an increase in distance or a positive velocity.)

Force (F): a push or a pull, anything that causes an object to speed up, slow down, turn, or change shape, measured in newtons (N)

Friction (F_f): the force that opposes the movement of one substance over or through another, measured in newtons (N)

Lever Arm: the distance from the place a force acts to the place it pivots, measured in meters (m)

Machine: any device that can reduce a force (by increasing the distance over which it acts) or decrease the distance (by increasing the force). **(F)(d) = (f)(D)**. The mousetrap is a machine with a force that is smaller when the snapper (lever) arm is close to the spring and larger as the snapper arm is extended.

Product Requirement: the parameters specified (by the consumer or the challenge) for the product

Product Specification: the specific characteristics required to make an individual design work

Time Management

A suggested schedule for covering all the activities of this unit over the course of 20 school days (four five-day weeks) is given in the table below. It is based on class periods of 45 minutes.

Time Management for Mousetrap Car Unit

DAY NUMBER	ACTIVITY
1	Mousetrap Car Challenge Unit Overview
2	Activity 1: Writing Design Briefs
3	Activity 2: Measuring Force
4	Finish Activity 2: Measuring Force; Presentation: Force and Motion
5	Activity 3: Writing a Design Process Paper
6	Activity 4: Testing Wheels and Axles
7	Portfolio Presentation; Activity 5: Measuring Lever-Arm Effects
8	Finish Activity 5: Measuring Lever-Arm Effects; Presentation: Force Transformers
9	Activity 6: Sketching—Developing a Design
10	Finish Activity 6: Sketching—Developing a Design; Approve Designs
11	Activity 7: Constructing a Prototype; Portfolio Presentation
12	Design and Build Mousetrap Car
13	Design and Build Mousetrap Car
14	Design and Build Mousetrap Car; Portfolio Presentation
15	Activity 8: Measuring Motion
16	Finish Activity 8: Measuring Motion; Revisit Activity 3: Writing a Design Process Paper
17	Mousetrap Car Great Race
18	Portfolio Presentation
19	Presentations; Portfolios Due
20	Presentations; Portfolios Due

Unit Assessment Criteria

The most important reasons for assessment are to judge student understanding and to evaluate the effectiveness of instruction. Grades are secondary; hence, assessments that are embedded in a unit are far more valuable than tests coming at the end. Embedded assessments also are more likely to reflect the kind of knowledge that can be applied to real-world situations.

The process of designing and building a mousetrap car has few constraints and may result in a wide variety of designs and performances. Student-built cars that can travel a long distance are not the primary assessment criterion. Distance traveled and velocity are, however, the result of good use of experimental data in design. So you may choose to add extra points for performance as part of your complete assessment system.

Notebook

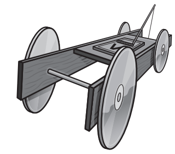
Because process is an important objective of the unit, place a high priority on an organized, neat notebook. Keeping a notebook may be a new skill for the middle school student. Have students leave the first pages of their notebooks blank. A few days into the unit, ask students to make tables of contents for their notebooks during class time. You can do a quick assessment by asking a student to find something, based upon the table of contents. If you give quizzes, allow students to use their notebooks; this will help them appreciate what they have already learned.

Design Portfolio

A second product of the unit is a student's design portfolio. It should include the goals and requirements, the prototyping process, sketches, specifications, and test results. A short writing assignment reflecting on the design process as a whole is a valuable component of this documentation. Some of the students' original ideas may first be recorded in their notebooks and then transferred into design portfolios at a later date.

Oral Presentation

The final oral presentation emphasizes the cooperative nature of engineering. Make sure that the presenters invite questions. Establish the rule that if you (the teacher) raise your hand, presenters should call on you before addressing others who have questions. Points for the oral presentation might be discussed when you distribute the student handout, "The Mousetrap Car Challenge."

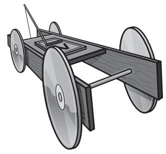


Introduction: The Mousetrap Car Challenge

Your challenge is to build a car powered by a mousetrap. You will be part of a Vehicle Research Team (VRT). Your vehicle must be no longer than 45 cm (excluding the snapper arm) and no taller than 30 cm. To build your car, you will collect data from experiments on force and motion. You also will keep a notebook and a design portfolio. This handout should become the first page of your notebook. The chart on the following page, to be filled in throughout the unit, shows the products and activities that will make up your project.

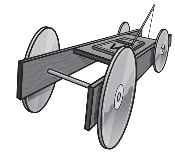
When your car is built, your VRT will be expected to show the car to the class. In your two– to five–minute presentation, you will report your vehicle's characteristics, including mass and velocity. Be sure to include answers to the following questions in your final team presentation:

- How much force can your mousetrap provide?
- How is the force of the mousetrap transferred to the wheels of the car?
- What data did you use to choose your chassis, wheels, and bushings?
- How does the speed of your car compare to the speed of a bicycle?
- How does your car meet the design requirements?
- How did the design of your car change as you built it?
- How could your vehicle be improved?



Unit Point Values and Grade Scale

PORTFOLIO TABLE OF CONTENTS	DATE ASSIGNED	POINTS POSSIBLE	POINTS EARNED
1 Unit Student Handout (this paper)			
2 Design Portfolio Technical Paper			
3 Assembled Design Portfolio			
4 Team Project Presentation			
5 Activity 1: Writing Design Briefs			
6 Activity 2: Measuring Force			
7 Activity 3: Writing a Design Process Paper			
8 Activity 4: Testing Wheels and Axles			
9 Activity 5: Measuring Lever-Arm Effects			
10 Activity 6: Developing a Design			
11 Activity 7: Constructing a Prototype			
12 Activity 8: Measuring Motion			
13 Notebook			
	TOTAL		
Performance Bonus (extra credit)			
Grade Scale			
		GRADE	



Activity 1:
Writing Design Briefs

Question: What will we need to design a car powered by a mousetrap?

Objectives

- To decide on the requirements of a successful vehicle
- To write a design brief that defines the major goals of the project

Materials

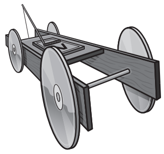
- Copies of *Brainstorming, Mind Mapping,* and *The Design Process*

Procedure

In this exercise you will begin to describe the design of your mouse-trap car in a way that will help your team work together efficiently.

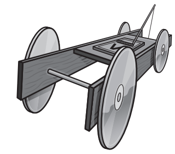
1. Watch your teacher's demonstration of the operation of a mouse-trap. The elastic material of the spring steel in the trap provides the force to catch a mouse. You can capture that force to power a car. Discuss with your team the rules you will need to make sure that no one is pinched by your mousetrap. Create a list of safety rules. Put them on the second page of your notebook.
2. Think about the problem. Begin by asking what a good mousetrap car should do. These are your goals. Engineers call these goals "product specifications." They may come from a contractor or from the marketing department of a company that employs an engineering firm. The class will discuss these goals together.
3. Put your goals on the third page of your notebook. Label them "Product Requirements." Here are some examples:
   - The car must roll.
   - The mousetrap must be connected to the wheels.
   - We must be able to cock the lever arm of the mousetrap.

   Some product requirements reflect the cost or difficulty of construction. For example, you might require that the car be built entirely from items that cost less than five dollars. This type of requirement would not necessarily affect the function of the design. Another requirement might be to build a car that could travel 100 kilometers an hour—but that would not be a realistic goal.



4. Write the design brief. This is a simple statement of what you have to do to make the best possible car. (This should not be more than one sentence and should summarize the requirements you have listed.) Discuss your sentence with your team before you write.

5. Create a sketch that will allow you to visualize your ideas. If you get new ideas when the class brainstorms together, you can create another sketch. Do not erase or throw away your first one. Just number each sketch in order. When you have a sketch that your team agrees on, label all its parts.



6. Determine the design specifications for your sketch. These are the things you will need to do to make your own design work. The whole class may have the same requirements, but your team's specifications will be unique. When you agree, make a list of these specifications here:

Teacher's Guide to Activity 1: Writing Design Briefs

In Activity 1 students use brainstorming and mind-mapping techniques to explore the requirements of the design problem; that is, those characteristics specified for the product. In the engineering world the requirements might be defined by the agency contracting a product (such as the National Air and Space Administration's requirements for a probe). Or requirements might be defined by a company's marketing department ("We need a cell phone smaller than a pack of cigarettes"). In the school environment these product requirements might be called goals.

Once the product requirements are established, engineers move on to brainstorming and development of prototypes. Today most prototyping is done by computer. In the classroom your students will begin with sketches. Students also will investigate the conditions necessary to build and test a prototype. These conditions are called product specifications, and they will differ for each team. Because science education is often based on finding the right answer, this stage may be your students' first opportunity to demonstrate their creativity.

Conceptual Development

This unit has many objectives that will be new for middle school students: distinguishing a product's design requirements from its specifications; brainstorming; developing a design in stages based on data acquisition, record keeping, and self-evaluation. You can support these goals by coaching and periodic discussions. *Brainstorming, Mind Mapping,* and *The Design Process* are supplementary student readings appropriate for Activity 1. You can assign them either at the outset or on alternate days.

Help students distinguish between design requirements and possible solutions in a class discussion. Use real-world examples from engineering. Use butcher paper or create transparencies so that you can re-post these requirements throughout the unit.

Although each team will have different solutions, try to develop class consensus on goals and requirements. Team solutions will be reflected in their drawings and their specifications. It will take some time for student teams to develop consensus on their specifications.

Explain to students that the design process is a process of inquiry and discovery—cyclical and evolutionary rather than linear in nature. Working drawings may be changed as new knowledge and insights emerge. Introduce a system through which students can number or date stages in the process. Encourage students to compare their sketches to the design requirements periodically. Provide input to keep students on track—it is easy for them to get far afield in this process. You might want to circulate among teams or have some teams leave their notebooks for checking each day.

Integrate your lesson with language arts. It is likely that students are learning process writing in language arts classes. Both design and writing may begin with brainstorming, but what an engineer calls a design might be called a rough draft in writing. If possible, use the same terms and help students relate language arts techniques to what they are doing in science.

Extensions

Students could gain practice in writing design briefs to solve problems by referring to materials they are reading for their language arts classes. For example, in C. S. Lewis' *The Lion, the Witch and the Wardrobe*, the travelers have to cross the land of Narnia. This is a perilous journey. Students could write design briefs to create devices to keep the travelers safe.

Art that accompanies science fiction also can provide ideas. Although there are currently no vehicles that carry humans on interplanetary journeys, we understand the design requirements for such vehicles. Many artists have suggested possible prototypes. Comparing such drawings can help students understand that there are many solutions to a problem.