

The Great Robot Race

PROGRAM OVERVIEW

NOVA follows the race to build an autonomous vehicle that can successfully complete a rugged, 212-kilometer course across the Nevada desert in the DARPA Grand Challenge 2005.



The program:

- notes that the race sponsor, the Defense Advanced Research Projects Agency (DARPA), hopes the competition will help create unmanned vehicles that can be used by the military.
- recalls the first Grand Challenge in 2004, in which the most successful vehicle—named Sandstorm and run by Carnegie Mellon University (CMU)—only traveled 11 kilometers.
- follows the CMU team as it prepares to run the race again this year with two entries, Sandstorm and Highlander, and a team of more than 100 members.
- points out the major challenge of the race—developing a system that will allow the robot to see.
- reviews the technologies used by some teams to help the robots see, including various laser range finders, such as a spinning laser, a laser mounted on a gimbal, and lasers combined with a video camera—all tied into software programmed to interpret data being received.
- showcases the diversity of vehicles and teams entered into the race, including a standard truck entered by a team headed by two brothers who run an audio speaker company, a six-wheel-drive vehicle led by a consortium of defense contractors, and a motorcycle team led by a group of engineering students and recent grads.
- contrasts the different approaches taken by a small Stanford University team with its entry, Stanley, to that of rival CMU.
- documents the qualification rounds in which a field of 40 vehicles is narrowed to 20.
- recounts the day of the race from when teams receive their course directions two hours before start time to the progress the vehicles make during their historic bids to complete the course.
- reports on the five teams that finished the race and explores the implications of successful completion of the Grand Challenge.

Taping Rights: Can be used up to one year after the program is taped off the air.

BEFORE WATCHING

- 1 The DARPA Grand Challenge involves building an autonomous ground vehicle that will race across 212 kilometers of unpaved roads in Nevada's Mojave Desert. Discuss what an autonomous vehicle is and have students brainstorm and predict some of the challenges the vehicles might face. (*An autonomous vehicle can perform tasks by itself for an extended period of time. The major challenge is to detect and stay on the road while avoiding obstacles that could disable the vehicle.*)
- 2 Organize the class into four groups and assign each group one of the following teams to track: Carnegie Mellon University (Red Team), Bruce and Dave Hall (Team Digital Audio Drive), Anthony Levandowski (Ghostrider), or Stanford University (Stanley). Have groups take notes on each team's members, hardware and software strategies, and resources.

AFTER WATCHING

- 1 Have students who took notes on the same team meet, compare their notes, and present what they learned to the class. How did the teams compare in terms of size, number, and makeup? What hardware choices did each team make? How did each team program its software? What were the similarities and differences among the strategies? What were the main reasons for each team's success or failure?
- 2 Have students consider future use of autonomous vehicles. What technical hurdles need to be overcome for these robots to work? What are some potential uses for these robots? What kind of changes, if any, would be needed to accommodate new robot uses, i.e., would new highways need to be built, or new laws formulated, for cars that drove themselves?

CLASSROOM ACTIVITY

Activity Summary

Students will design, build, and test a rubber band-powered car.

Materials for Each Team

- copy of “Off to the Rubber Band Races“ student handout
- copy of “Vehicle Construction“ student handout
- copy of “Performance Expectations“ student handout
- rubber band (1/4-inch x 3-inch) (for energy source)
- bamboo skewers, pipe cleaners, drinking straws, dowels, and/or other material (for axles)
- CDs, plain and corrugated cardboard, milk cartons, and/or other material (for body and wheels)
- masking tape, small nails or screws, glue, staples, and/or other material (for assembling vehicle)
- compass (for drawing circles for wheels)
- scissors

Materials for Class

- spring scale or appropriate balance for weighing the vehicles
- tape measure or meter stick
- several 250-gram masses or objects of equivalent mass (about 100 pennies)

Background

The purpose of this activity is for students to experience the process of designing and building a device to meet a set of design and performance criteria just as the teams competing in the DARPA challenge had to. The performance criteria have been specifically chosen to present students with sometimes competing requirements. Just as in real life, students may find that a winning solution to a problem must involve compromise—for example, while large wheels may mean more distance covered than smaller wheels, they also add mass to the vehicle.

The sample rubber band car shown in the student handout consists of two axles mounted with four wheels. The power source is the rubber band mounted around the axle. Winding up the wheels (in reverse so they will create a forward motion when released) winds the rubber band and stores potential energy. When released, the rubber band spins the axle and the wheels. How far the car travels depends upon how much potential energy is stored in the rubber band, how efficiently the potential energy is transferred, and how much friction the car encounters.

LEARNING OBJECTIVES

Students will be able to:

- brainstorm solutions to design challenges.
- build, test, and evaluate a rubber band-powered car.
- communicate the design approach to others.
- distinguish between potential and kinetic energy.

KEY TERMS

friction: The resistance of an object to the medium through which it is traveling, such as air or water, or that it is in contact with, such as a solid floor.

inertia: The tendency of a body at rest to stay at rest and a body in motion to remain in motion unless acted upon by an outside force.

kinetic energy: The energy due to the motion of an object.

potential energy: The energy an object has due to its position or internal condition rather than its motion.

CLASSROOM ACTIVITY (CONT.)

Procedure

- 1 Prior to vehicle construction:
 - Review the design rules and performance expectations.
 - Review each part of the model car with students.
 - Discuss the parts of the model car that might be changed to make it travel farther (wheels, power source, body design)
 - Explain that a front-wheel-drive car will have the rubber band winding around the front axle, a rear-wheel-drive car will have the rubber band around the rear axle, and an all-wheel-drive car will make use of both axles.
 - Discuss the materials that will be used to construct the vehicle. Students must all use the same-sized rubber band as their energy source, and all other materials must be made from everyday supplies, such as those listed in the materials list. Students cannot use store-bought wheels, axles, or car bodies.
 - Identify a relatively smooth surface where the vehicles will be tested.
- 2 Copy student handouts and gather and distribute the materials.
- 3 Require each team to draw three views of its proposed vehicle (side, top, and rear). This will help teams further think through their design prior to construction. Teams should use the example drawing in their handout for guidance in making this drawing. Have students design their vehicles.
- 4 Have students build, weigh, and test their vehicles. Decide on and tell students how much time they will have to work with their vehicles. Students can make as many changes to their vehicles as time allows, but must change and test only one variable at a time. Make sure to allow time for any glued parts to dry. Students should note on their three-view drawing any design changes they made when they built their vehicle.
- 5 Use the masking tape to mark the starting line and one-meter intervals down the course. As a class, decide on a consistent method for launching vehicles so that students do not add energy with a forward hand motion when the vehicles are launched.
- 6 Conduct the competition. Have each team carry out three or more trials of each of the last two performance expectations (farthest distance traveled and farthest distance traveled with load), and average the scores for each expectation. (If your class is large, have teams carry out two trials and choose the best trial for the final score.) You should act as scorekeeper, keeping each team's scores private.

STANDARDS CONNECTION

The “Off to the Rubber Band Races” activity aligns with the following National Science Education Standards (see books.nap.edu/html/nses).

GRADES 5–8
Science Standard B
Physical Science
Motions and forces

Science Standard E
Science and Technology
Abilities of technological design

GRADES 9–12
Science Standard B
Physical Science
Motions and forces

Science Standard E
Science and Technology
Abilities of technological design

*Video is not required
for this activity.*

Classroom Activity Author

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CLASSROOM ACTIVITY (CONT.)

- 7 Following the competition, have each team present its design approach. Have students consider the following questions:
 - What were the benefits of drawing your design before you built your vehicle?
 - What worked and what didn't work in each approach?
 - After each of your tests did your vehicle perform as expected? Explain.
 - What final modifications did you make to your vehicle? Why?
- 8 Announce the top three overall winners and the top three in each category. As a class, summarize the most successful characteristics of the overall winning designs and the most successful characteristics of those designs that were top in their performance expectation categories. What did the winning vehicles have in common? If students had another chance at design, what would they do for their next-generation vehicle? Have students support their reasoning.
- 9 As an extension, have students race their vehicles on a completely different terrain, such as grass or dirt. How did the vehicles perform? What changes would students make to the vehicles based on test results? Why?

ACTIVITY ANSWER

Student Handout Questions

- 1 Where does the energy to move the vehicle come from? *The potential energy stored in the rubber band, which received energy from the person who wound it.*
- 2 What affects the distance the vehicle travels? *Students should mention various types of friction (air resistance, resistance in the wheel bearings, etc.) as well as the circumference of the wheels, the strength of the rubber band, how much the rubber band was wound, and the mass of the vehicle.*
- 3 Describe one type of energy transfer in this activity. *Correct answers should make it clear that the energy still exists but in other forms. Three energy transfers that occurred were kinetic to potential energy when students wound the rubber band, potential into kinetic energy when the car was released, and kinetic into heat energy as friction slowed the car down.*
- 4 What was the most difficult part of this activity? *Any reasonable answer is acceptable here. The purpose of this question is to have students think about what they have done.*
- 5 If you were going to make improvements to your vehicle, what would they be? Why would you make them? *Many different answers are acceptable here, but more credit should be given for clear, detailed answers that are well thought out, well presented, and based on evidence.*

LINKS AND BOOKS

NOVA—The Great Robot Race

www.pbs.org/nova/darpa

Learn more about 12 of the teams that raced, discover some real-world applications for autonomous vehicles, see video extras, and view a slide show that reveals what racing robots see.

DARPA Grand Challenge '05

www.darpa.mil/grandchallenge

Provides an explanation of the event and its importance to the U.S. Defense Department.

Rubber Band Vehicle Competition

driscoll.brookline.mec.edu/

iMovieWorkshop/rubberbandvehicles.html

Presents a video clip of middle school students testing their rubber band vehicles.

Books

Absolute Beginner's Guide to Building Robots

by Gareth Branwyn.

Que Publishing, 2003.

Relates the history of robotics and provides detailed instructions on how to build three robots—from a simple one-motor walking machine to a programmable robot platform.

The New Way Things Work

by David Macauley.

Houghton Mifflin, 1998.

Provides detailed explanations and illustrations of how things work, including a section on digital technologies.

Robots

by Clive Gifford.

Smart Apple Media, 2006.

Describes what a robot is and looks at various ways that robots are used.

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Google™



HHMI



Off to the Rubber Band Races

The DARPA Grand Challenge involves designing and building an autonomous vehicle that races 212 kilometers across the Nevada desert. Today, you will face your own design challenge: Build a rubber band-powered vehicle that is light, can travel far, and can carry a load as far as possible. After you design, build, and modify your vehicle, you will put it to the test against other vehicles designed by your classmates.

Procedure

- 1 Brainstorm a rubber band-powered vehicle using the provided materials. Review your available materials.
- 2 Design your vehicle. Your vehicle must follow the “Design Rules” listed on this page. Use your “Vehicle Construction” handout for guidance.
- 3 Draw a diagram showing three views of your vehicle. Show the top, side, and rear of your vehicle and label the parts, including wheels, body, axles, rubber band, rubber band support, and cargo area.
- 4 Build your vehicle. Use any of your available materials to construct your vehicle.
- 5 Test your vehicle. Test all three criteria listed on your “Performance Expectations” handout. Record the results of your testing.
- 6 Modify your vehicle. Change one variable you think will improve your vehicle.
- 7 Test your vehicle again. Compare the results from the previous testing. If you would like, modify another variable, test again, and compare the results. You may make as many additional changes to your vehicle as time allows, but you may only modify and test one variable at a time.
- 8 Update your original diagram to reflect your final design. When it is your turn, do the number of trials assigned by your teacher. The vehicle winning the challenge will be the one scoring best on the list of expectations listed on your “Performance Expectations” handout.

Design Rules

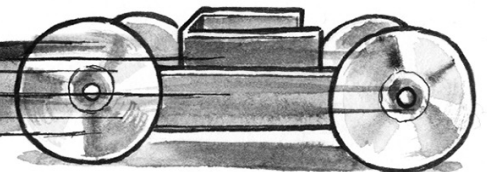
Your vehicle must be:

- built out of the materials provided
- powered by rubber bands
- constructed with at least one wheel

Questions

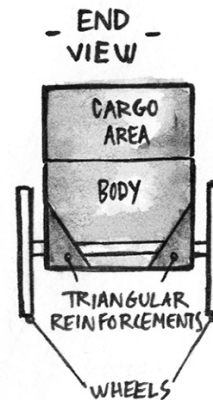
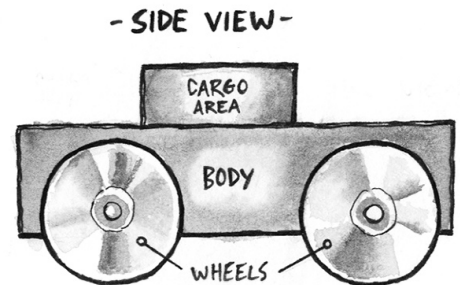
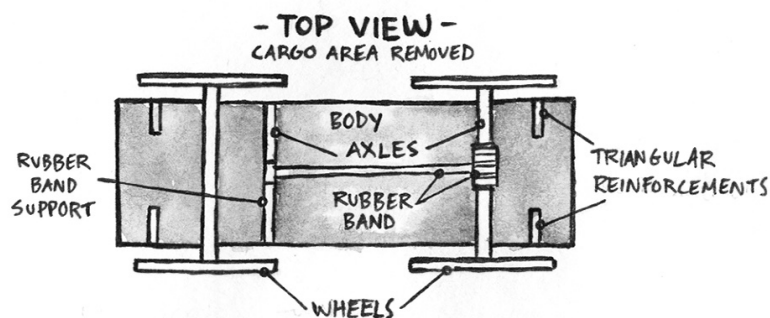
Write your answers on a separate sheet of paper.

- 1 Where does the energy to move the vehicle come from?
- 2 What affects the distance the vehicle travels?
- 3 Describe one type of energy transfer in this activity.
- 4 What was the most difficult part of this activity?
- 5 If you were going to make improvements to your vehicle, what would they be? Why would you make them?



Vehicle Construction

The car in the diagram below consists of two axles mounted with four wheels. The power source is the rubber band wound around the axle. Winding up the wheels (in reverse so they will create a forward motion when released) winds the rubber band thereby storing potential energy. When released, the rubber band spins the axle and the wheels.



Construction Hints

- Small triangular pieces of cardboard used to reinforce the connection between the sides and floor of the vehicle will greatly increase strength for little additional weight.
 - Glue will need to set overnight, so try to do all gluing at least a day before final testing.
 - Creasing the cardboard will make it resistant to bending at right angles to the crease. This adds strength for no increase in weight.
 - How far the car travels is dependent on how much energy is stored in the rubber band, how efficiently the energy is converted to forward motion (having wheels with good traction will be very helpful), and how much friction the car encounters
- (air resistance at these speeds is very small but friction in axle bearings will be quite significant).
- Wheels attached firmly to their axles ensure that when the axle turns, the wheel (or wheels) also turns.
 - If the rubber band is connected to the axle, it will act as a brake once it has stopped unwinding.
 - The car should make the best use of its potential energy in the wound rubber band. What you want is the most power you can get for the longest time, and the car needs to be light, but also strong enough so that it doesn't break apart.

Performance Expectations

The government agency that sponsored the autonomous vehicle race, the Defense Advanced Research Projects Agency, hopes to someday be able to use unmanned vehicles in military operations. An ideal vehicle for this use would be lightweight in order to be efficiently transported, be able to travel as far as possible on its given fuel supply, and be able to carry mission cargo. Given these objectives, each vehicle in your design challenge will be judged on the following criteria:

- weight (the lightest vehicle)
- maximum distance traveled (the vehicle that goes the farthest)
- load carrying capacity (the vehicle that can go farthest with a 250-gram load)

Maximum distance traveled will be measured from a point on the start line to the final resting point of the vehicle.

The winning vehicle in each of the above categories will have a score of 1, the second best vehicle a score of 2, etc. Thus the best possible score is 3 for a vehicle that won each of the above categories. The overall winner will be the vehicle with the *lowest* combined score.

Note that it is quite possible for a vehicle to win in two of the three categories and still lose overall by having a very high score in the third. For example: Vehicle A wins in the first two categories (2 points) but comes in last for a score of 10 in the third. Vehicle A's total score is 12 (1+1+10). Vehicle B comes in second, second, and third, respectively, and wins overall with a score of 7 (2+2+3).

