Rev Your Engines!

Linking physical science and math with car labs

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Cheering and laughter filled the school hallway as a line of cardboard cars sped, collided, and even rolled backward during the first annual Rubber Band Car Drag Race. What sounded like an indoor sporting event was actually Day 2 of the weeklong "Car Lab Project" for physical science students.

As part of this project, students constructed rubber band cars, raced them, and worked through a number of automotive activities. The students engaged in this project certainly had fun, but they also used high-tech gear such as motion sensors and graphing calculators to gather data on the distance and time cars traveled and to generate time versus distance graphs for their cars. This project meets national standards for high school mathematics, science, and technology content (NCTM 2000; ITEA 2000; NRC 1996) while engaging students in cognitive activities and motor skills. (Editor's note: Visit *www.nsta.org/highschool/connections.aspx* for the standards connections.)

The Car Lab Project

Earning their driver's licenses and obtaining the freedom that automobiles provide are no doubt exciting for students. The activities described in this article make use of this natural excitement and link automobiles to important physical science and math ideas. The Car Lab activities were designed to integrate technology into an interdisciplinary topic, using probeware and graphing calculators. Although these physical science activities were designed to be taught as a unit, the specific content objectives can change according to the instructional goals of the teacher. Using a station format allows for rich student experiences with limited resources—each station requires only one technology probe and most materials are classroom lab staples, can be obtained from recycled materials, or can be purchased at local discount or grocery stores.

The Car Lab Project consists of six activities, four of which are set up as rotating laboratory stations:

- Rubber Band Car Design,
- Rubber Band Car Drag Race,
- Going the Distance,
- Piston Pressure,
- Color of Headlights, and
- Soda Can Radiator.

The Car Lab Project as described here is designed for a four-day period but can easily be extended or condensed according to individual objectives and time constraints. Teachers of various subjects may implement the project in different ways to suit their subject needs:

- A physical science teacher might decide to use the entire Car Lab Project as an introduction to teaching about forces and motion, which is interdisciplinary in that it requires analyzing motion mathematically and graphically, as well as computing acceleration through the use of technology (i.e., probeware).
- A physical science teacher may also use building the rubber band car and running drag races to teach potential and kinetic energy. The rubber band car could be used as an introduction to scientific inquiry, with each team designing an experiment to investigate one or more design variables (e.g., wheel size or rubber band length).
- A math teacher might use the car trials to have students develop and evaluate inferences and predictions that are based on data—both a science and mathematics standard.
- A technology teacher might use the design aspects of the activities to meet technology standards.

Therefore individual labs can be used as freestanding activities to meet science, mathematics, and technology standards, or the entire Car Lab Project can be used as a unit. (**Editor's note:** A list of materials for these labs can be found online at *www.nsta.org/highschool/connections.aspx*.)

Day 1: Rubber Band Car Design

The first lab period is spent in the design and construction of the rubber band cars (Figure 1). Students receive a piece of corrugated cardboard (for the body), wooden barbecue skewers (for the axles), several lengths and sizes of rubber bands, an assortment of drawn or precut thin cardboard wheels in various sizes, poster putty, and masking tape. To prepare for this lesson, teachers can collect shipping boxes for the corrugated cardboard and cereal or tissue boxes for the thin cardboard. They can also precut the cardboard into wheels if limited class time is an issue.

In the introduction of this activity, no content is presented and guidelines provided by the teacher are minimal. Students are asked to design a car that will go the fastest and/or farthest in a drag race. Each team receives a sheet with instructions to attach thin cardboard wheels to the skewer axle, and then attach the rubber bands to the back axle and the cardboard body (Figures 2 and 3, p. 38). Some teams immediately branch out on the basic design to add artistic elements, such as decorating and naming the car, and others ask to take the cars home to work on additional design features.

Students are excited about the design process, and there is much student discussion and debate in each car design group about wheel size and rubber band length. In early trials, teams quickly realize some of their design pitfalls—perhaps their car axles spin but the wheels do not, or the car moves backward, or the wheels spin but the car does not move forward on a linoleum floor. Lively group troubleshooting ensues, allowing students to debate the nature of the problems. Students tentatively begin to connect the problems and potential solutions to scientific or mathematical concepts. Some student reactions may include:

- "The wheels do not have any traction on the linoleum. What can we add to increase the friction?"
- "The wheels are wobbling, and the car is losing momentum. How can we stabilize the wheels?"
- "I wonder if having proportional wheels makes a difference in the car's speed."
- "Will twisting the rubber band more give it more energy?"

Redesign of the initial rubber band car prototypes quickly ensues. Additionally, students realize they can pick up design tips from watching other teams' vehicles, and teams often send spies to walk around the room, investigate other teams' designs, and watch trial runs of competitor cars in the hallway.

We are surprised at how quickly students typically want to race their cars. To take advantage of the incredible level of interest and excitement, we hold the Rubber Band Drag Car Race on Day 2.

Day 2: Rubber Band Car Drag Race

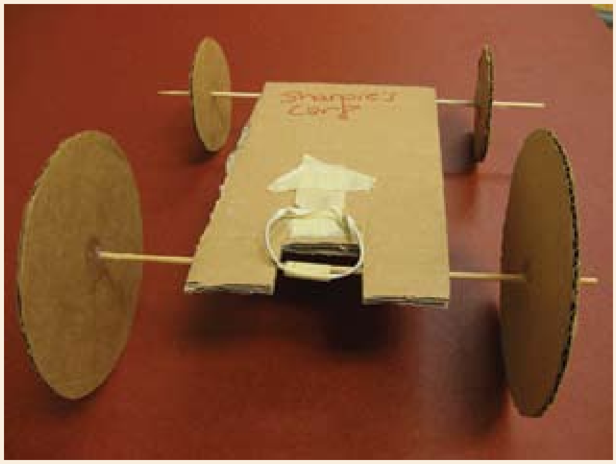
The race is an enjoyable experience for students, but it is also an opportunity for them to see how their car performs compared to those of others. Data collection may be done now, or set up as a separate station on Days 3 and 4. To collect data, students place their car directly in front of a motion detector attached to a graphing calculator. Then they start the program on their calculators to analyze data, and release the cars to start the race. The cars usually travel for about 3 seconds. By following a short set of prompts on the calculator, the velocity graph and slope are displayed. Students should sketch the graph on the team data sheet and note whether the graph is a straight or curved line. (**Note:** See Figure 3, p. 38, for data sheet.)

FIGURE 1

Rubber band car assembly.

FIGURE 2

An assembled car.



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The advantage of using this technology is that students can immediately see the graph and make decisions on the spot based on the data displayed. In addition, students can modify their designs and quickly observe the results using the calculator-based graphs. (**Note:** Most commercially available probes can be used with graphing calculators or laptops. Students also may create their own graph using data points collected with the calculator or by using a tape measure and stopwatch, a lower-tech way of obtaining the same information. However, manual graphs do not offer the instantaneous feedback available when using graphing calculators or computers to graph the data.)

Students can then modify their cars to improve their performance by trying different wheel sizes, weights, rubber bands, or other modifications indicated by the trials. Additional trials may be made at separate lab stations, or more races can be scheduled for the end of the week.

Days 3 and 4: The Car Lab Stations

Once the cars are built and the initial races are run, it is time to go to the stations. If teachers are using the entire set of labs, they should set up four different stations and have student teams rotate through them. Each station will take 20–25 minutes, and each team must be at a station. If teams are made up of 4 in a class of 28 students, for example, the teacher would need to add three additional stations. This can be accomplished by duplicating some of the stations, or adding other stations with computer simulations, videos, worksheets, or related websites, depending on the objectives. Extra stations may be added to reinforce more difficult concepts through repetition, differentiate learning styles (e.g., visual and auditory), and allow students to progress at different rates to new stations (Jones 2007). All four stations relate to cars, but only the Going the Distance station requires the use of the rubber band car created on Day 1.

Station 1: Going the Distance

At the Going the Distance station, students run several 3-second trials with the motion sensor attached to a graphing calculator to measure how far and how fast their car goes. (**Note:** Alternately, teams may use a tape measure or metersticks, a stopwatch, calculators, and graph paper for a distance versus time graph.) The purpose of this lab is to discover averages, experimental error, effects on distance, and potentially, a link to probability. To reinforce the nature of science, students who ask how many trials are needed might be encouraged to explore the value of making multiple trials. Building the cars gives students more control and ownership than using toy cars to study velocity and acceleration.

Station 2: Piston Pressure

In automobiles, pistons compress the gas in the engine cylinder, decreasing volume and increasing the pressure. At the Piston Pressure station, students use different sized pistons in a closed system to measure the change in pressure over time—this links to the pistons in an internal combustion engine. We have found it helpful to have a sample piston on hand. In the past, we have displayed a used motorcycle piston from a repair shop or diagrams of car engines.

In a typical automobile four-stroke engine, gasoline vapor first enters the engine cylinder in the *intake stroke*. During the *compression stroke,* the piston uses energy from the rotating crankshaft to compresses the gas in the engine cylinder, decreasing volume and increasing the pressure. Next, in the *combustion* or *power stroke,* the gasoline vapor is ignited by a spark from the spark plug,

FIGURE 3

Lab sheet for rubber band car.

Data Collection and Analysis ***Hypothesis:*** ***Data:***	**Name:**____________________ **Date:**____________________
Front wheel diameter (cm)	
Rear wheel diameter (cm)	
Rubber band length (cm)	
Trial 1	**Trial 2**
Weight:__________________ N	Weight:__________________ N
Number of wraps:	Number of wraps:
Sketch time versus distance graph:	Sketch time versus distance graph:
Velocity: ________________ m/s^2	Velocity: ________________ m/s^2

Questions:

1. Why is the slope of the time versus distance graph also velocity?

2. If the time versus distance graph is a straight line, what do you know about your car's velocity? Its acceleration?

3. If the time versus distance graph is a curved line, what do you know about your car's velocity? Its acceleration?

and the resulting expansion of the gas (due to temperature) drives the piston upward and provides the force needed to turn the crankshaft and ultimately propel the car. Gases remaining in the cylinder are then removed through a valve in the cylinder in the *exhaust stroke*. The movement of the piston is thus an excellent opportunity for teaching the gas laws in either chemistry or physical science classes (see "On the web" for an animation of gas moving through a two-stroke cycle and four-stroke automobile engine).

At this station, students first connect the pressure sensor to the graphing calculator (Figure 4). Then, using a syringe, they partially pull out the plunger piece to the top mark and record the total volume of air in the syringe and the Erlenmeyer flask on their data sheet. Students put the syringe into the open stem of the flask's stopper, record the initial atmospheric pressure, and start the calculator. When students push down on the syringe and hold the plunger down, they record the highest pressure read on the pressure sensor as the final pressure on the data sheet. Their initial (V_1) and final volumes (V_2) and initial pressures (P_1) may be inserted into the equation $P_1V_1=P_2V_2$ (Boyle's law), and the computed final pressure (P_2) (theoretical) may be compared to the experimental (measured) final pressure. (**Note:** Inclusion of the Erlenmeyer flask adds another shape used to calculate the volume, enhances the math concepts, and also acts as a buffer to the system. Alternately, the probe's tubing can be connected directly to the syringe, with only the syringe volume used in the formula.)

Different sized syringes and Erlenmeyer flasks make up the system and can be measured for volume in various ways depending on the amount of math

FIGURE 4

Graphing calculator and gas pressure sensor with syringe apparatus.

and precision desired in the lesson. This activity potentially lends itself to a discussion of measurement, sources of mathematic error (percent) and measurement uncertainty, or experimental design (human) error. Additional replications of the experiment may be done to further explore error. The flasks and syringes are marked with volume, and teachers can facilitate discussion by introducing the idea of using a graduated cylinder and water to check the volume (lesson adapted from Volz and Sapatka 2000).

Station 3: The Color of Headlights

At the Color of Headlights station, students use a lamp with a variety of interchangeable colored bulbs. They attach one of the bulbs to the lamp and turn on a light sensor that is attached to a graphing calculator. Holding the light sensor as close to the bulb as possible without touching it, students turn on the lamp, wait for the reading to stabilize, and record the light intensity in lux (lx), the SI unit for light intensity (Figure 5). The sensor's sensitivity to light intensity for different colors approximates the response of the human eye. (**Safety note:** The lightbulb will heat quickly, so students must be cautioned not to touch the bulb.)

Using a pot holder, students change the bulb and record values for the other colored bulbs. The purpose of this station is to recognize the difference in light intensity for various colors, but the activity can also be linked to interdisciplinary content standards for electromagnetism, wavelength (expressed using scientific notation), and energy. Students can be asked to decide what color of lightbulb might be the best for headlights.

Station 4: Soda Can Radiator

In the Soda Can Radiator activity, students—wearing safety goggles—measure the change in the water temperature as fuel is burned under a "radiator" (actually, a calorimeter; Figure 6, p. 40). An aluminum soda can containing a measured amount of water is used as a calorimeter, which simulates an automobile radiator by absorbing energy released from the fuel. The "fuel" is a cheese puff. (**Safety note:** Because students light the cheese puff on fire, it will be burning and very hot. Students should be cautioned to stay far enough back, wear goggles, and not touch the hot can, supporting rod, or ring after burning.) We use cheese puffs because they are easy to attach to a pin, burn easily, and calorie information on the bag is easily calculated for one puff. Other fuel alternatives include a peanut or cashew. (**Safety note:** If nuts are used, be sure that no students are allergic.)

A temperature probe attached to a graphing calculator measures the change in temperature over time, as the cheese puff burns. By obtaining the mass of the fuel before and after the combustion, students can determine the energy used and heat released during the experiment using a balance and graduated cylinder. A thermometer can be used if a temperature probe is not available. The teacher can ask students to use changes in temperature and mass to calculate the energy absorbed by the "radiator," using the formula $\Delta Q = mc\Delta T$, where

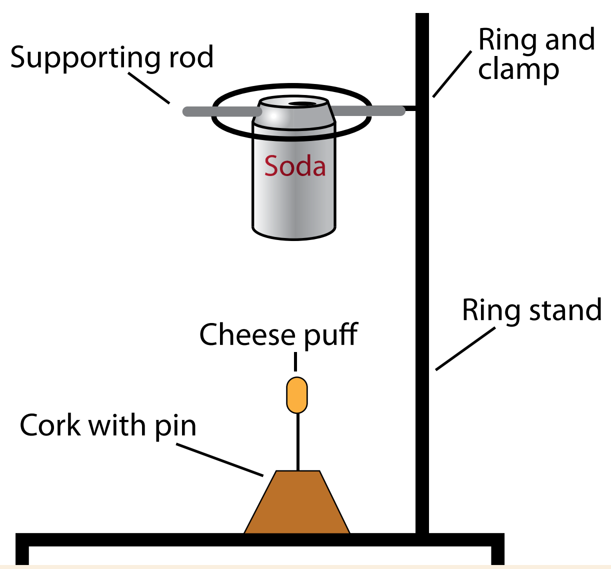
- ΔQ = change in heat energy,
- m = mass (of water),
- c = specific heat (of water), and
- ΔT = change in temperature (of water).

FIGURE 5

Taking measurements with the red bulb and light intensity probe.

FIGURE 6

Soda Can Radiator Lab setup.



Students then calculate the energy released by each gram of fuel, by dividing the energy absorbed (ΔQ) by the mass of cheese puff burned.

Calorie information from the packaging of the cheese puff may be used to calculate errors from heat lost to the surroundings. This lab also may be used as a starting point for a discussion on alternative fuels (see "On the web").

State inspection

A possible fifth station is the State Inspection. Many states require automobiles to pass an annual state inspection test, in which fuel emissions and mechanical components of vehicles are checked. Playing off this idea, students need to "pass inspection" for each of the four stations, in addition to constructing their rubber band car and running drag races. Students must demonstrate the use of the probeware at each of the four stations and show recorded data to receive a check-off on that part of the inspection. (**Note:** Alternately, if no probeware is used, teachers can check off recorded data for each station.)

As teachers rotate around the room they can check off portions of the State Inspection Sheet with a marker or adhere stickers to the completed stations to formatively assess students' progress on the activities. (**Note:** The State Inspection Sheet is available online at *www.nsta.org/highschool/connections.aspx*.) Teachers may also use the generic teacher rubrics or student check sheets available online (see "On the web") or develop a quiz that tests students on conceptual learning. In addition, teachers may want to lead a whole-class discussion of analysis and results for each station. The winning car may be displayed with honor in the classroom or noted in the school's morning announcements.

Ready, set, go!

Revving up excitement for science and mathematics is not always easy, especially with teenagers. By pairing mathematics and science concepts through one interdisciplinary unit on cars, students participate in a set of activities that they can get excited about, which makes teaching more enjoyable. The Car Lab Project also allows more tech-savvy students to assist their teammates.

For teachers inexperienced in these technologies, the probeware and graphing calculators used in these activities are relatively easy to learn, and workshops are readily available, such as those at NSTA Conferences on Science Education. Through these interdisciplinary car labs, teachers can meet selected science and math learning objectives in the context of the natural excitement students feel about automobiles and driving. We hope these labs will rev your students' engines about science and math! ■

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On the web

Car Lab Project directions and data sheets: *http://21ctl.fi.ncsu.edu/msms/autolabs.html*

Piston animations:

Two-stroke engine: *videos.howstuffworks.com/user/4729-two-stroke-cycle-engine-video.htm*

Four-stroke engine: *http://auto.howstuffworks.com/engine1.htm*

Data set for information on alternative fuels: *http://21ctl.fi.ncsu.edu/msms*

Teacher rubrics and student check sheets: *http://21ctl.fi.ncsu.edu/msms*

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