



A SCIENCE THAT SAVES LIVES

"CRASH SCIENCE" ADDRESSES THE LEADING CAUSE OF DEATH OF TEENS IN THE UNITED STATES

////// Linda Jones and Griff Jones //////////////////////////////////////

Sixty-seven deaths per week, nine per day, one every two hours: Motor-vehicle crashes are the number one killer of teenagers in the United States, and although fatalities have declined in recent years, almost 3,500 teenagers still die every year in motor vehicle crashes (NHTSA 2011). In fact, 35% of all deaths among 16- to 19-year-olds are related to motor vehicles (National Center

for Injury Prevention and Control 2006). This article outlines our attempt to use research from the emerging field of crash science to teach truly life-saving lessons.

Teenage crash research

In recent years, several agencies and organizations have collaborated on initiatives to reduce crashes, injuries,



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and deaths among teenage drivers. Spearheading these efforts have been the National Highway Traffic Safety Administration (NHTSA), a federal agency, and the Insurance Institute for Highway Safety (IIHS), a non-profit organization.

Statistics highlight the importance of their work:

Although teenagers drive less than all but the oldest (ages 70+) drivers, teenage crash rates and deaths are the highest of all drivers (Lyman et al. 2002). Sixteen-year-olds are at the highest risk for both crashes and deaths in motor vehicles. Their crash rate per mile driven is twice as high as that of the second highest risk group (18- to 19-year-olds).

Why are teenage drivers so prone to car crashes? The obvious explanation is lack of driving experience, but that's only partially responsible. Research has found that teenagers' lack of emotional and cognitive maturity increases risky driving practices, including speeding, tailgating, and not wearing seatbelts (Juarez et al. 2006; McCartt et al. 2009). A common misconception is that most teenagers who die in crashes are drivers. In fact, three of every five are passengers in vehicles driven by other teenagers (McCartt, Shabanova, and Leaf 2003).

One unusual study observed teenagers arriving at school in the morning and found seat belt use highest among teenagers

arriving in cars driven by adults and lowest among teenagers arriving in cars driven by other teens. Interestingly, about half of all teenage passengers don't wear seat belts even in cars driven by adults (IIHS 2002). As numerous studies have documented, seat belts save lives, and the likelihood of dying in a car crash significantly increases for unbelted occupants. In 2006, 4,842 teenage passenger vehicle occupants were killed in car crashes, and 58% of those teens were unrestrained at the time of the crash (NHTSA 2007).

Integrating crash research and core physics concepts

To address common unsafe teenage driving behaviors, we developed a combined design engineering project and web exploration activity to help students confront misconceptions about their chances of surviving a car crash. The web exploration activity can come before or after the design engineering project, depending on the amount of students' prior knowledge and experience with the physics of car crashes.

In the design engineering project, student pairs are challenged to create an egg-carrying paper car with a front end weak enough to absorb the energy of a high-speed crash yet strong enough to remain intact and protect the egg. Specif-

ics of the Paper Car Crash Design Challenge are available online (see “On the web”); Figure 1 shows our kit of supplies and a sample car.

To create a winning design, students must apply two physics concepts used in real-world vehicle safety engineering: *momentum* and *impulse*. Momentum is the mass of an object multiplied by its velocity. Momentum measures the difficulty of stopping a moving object. (It’s also a vector quantity with both magnitude and direction, and its direction is the same direction as the object’s velocity.) The greater the mass of a moving vehicle, the greater its momentum; likewise, the faster a vehicle moves, the greater its momentum. When a vehicle crashes and comes to a stop, its momentum drops to zero. Surviving a collision depends on managing this change in momentum.

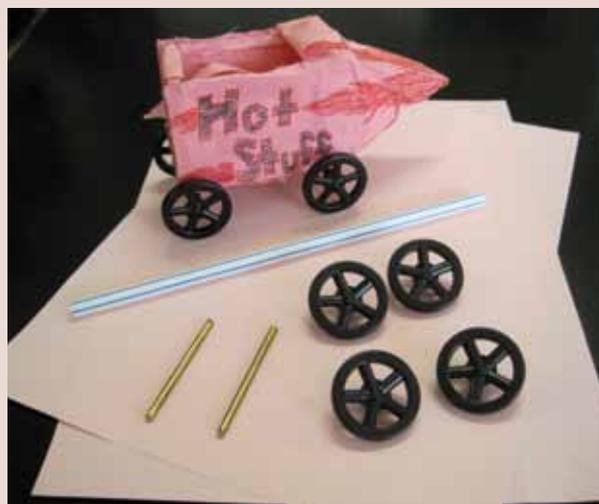
Impulse (J) is the net momentum change during a collision and is measured as the product of the average force (F) exerted on an object and the time interval during which it acts (Δt). In shorthand notation, we can write the magnitude of an impulse as $J = F_{avg} \Delta t$. An impulse can stop a moving vehicle with a variety of force and time combinations. Extreme combinations can have dramatically different effects on both the vehicle and its occupants. A simple example: An out-of-control car runs off a country road into a cornfield and slowly stops as it plows through cornstalks, causing only minor damage to the car and its occupants. In this situation, the change in momentum happens over a long time, producing a smaller average impact force on the car.

Now, consider a car that runs off the road into a big tree instead of cornstalks. In this case, the change in momentum occurs almost instantly, because the tree barely moves upon impact. The shorter impact time produces a larger average force of impact, which can result in extensive damage to the vehicle and its occupants. Looking more closely at this momentum-impulse relationship, we see that the two vehicles—with different combinations of duration of impact and force of impact—experience the same total impulse.

During our design activity, students discover that a car occupant can better survive a collision if the impulse results from gradually reducing momentum, spreading the impact force over a longer

FIGURE 1

Supplies used to build an egg-carrying paper car (numerous hot glue sticks not shown) and sample car.



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time. Similarly, they discover that the odds of serious injury (a cracked egg) or death (a broken egg) significantly increase if the impulse results from a large impact force applied over a short time. To clarify this concept, we discuss the difference in likely injuries when one falls on a concrete sidewalk versus on soft sand. The initial momentum before hitting the ground and the resulting impulse are the same in both cases, but because the soft sand gives during the collision, the impact is spread over a longer time, resulting in less injury.

And the race is on

Construct a 6 m racetrack by connecting two 3 m vinyl rain gutters using a rain gutter slip joint. Elevate one end of the track by setting it on the second-from-the-top step of a 6 ft. stepladder (Figure 2). Support the middle of the track at the slip joint with a lab stool. Use additional sets of gutters and slip joints to create multiple tracks for side-by-side racing.

In the activity, students first conduct preliminary runs to determine each vehicle’s final velocity (“velocity” involves direction, but since the cars move in a straight line, with no change in direction, “speed” and “velocity” are used interchangeably here) at the end of the ramp using a photogate. This automatic timing device, available from science equipment suppliers, uses an infrared diode and a photocell. We tape 7.62×12.7 cm (3×5 inch) index cards, short side at top, on the side of each car so the cards are tall enough to pass



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FIGURE 2

A 6 m crash test track can be constructed for approximately \$10 by connecting two 3 m vinyl rain gutters using a rain gutter slip joint supported in the middle by a stool.



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through the photogate (Figure 3). Students divide the width of the card (7.62 cm) by the time recorded on the photogate to determine final velocity in centimeters per second and convert this value to meters per second to calculate their vehicle's momentum. For the preliminary run, no barrier is placed at the end of the track, so cars roll freely and gradually stop. To simulate the approximate mass of a Grade A large egg, students place 60 g of plastic gram stacker masses in their cars, allowing them to measure their vehicle's momentum without the risk (and mess) of a broken egg.

On Crash Day, each design pair introduces and explains the design features of their vehicle, and all cars are measured to ensure they meet design specifications. A concrete block is placed against the lower end of the track to simulate a head-on collision. If photogates were not used the prior day to determine the vehicles' final velocity, then stopwatches are used to measure the vehicles' total time to the nearest hundredth of a second to travel the length of the track. To ensure more accurate and reliable timing, several students time each car, and the times are averaged for each car. (Although photogates are more accurate, stopwatches are a reasonable and less costly alternative.) Later in the activity, the average time is used to calculate the vehicle's average velocity and estimated momentum (see the project assessment data extension "On the web"). After each run, eggs are removed and inspected for damage. Cracks indicate occupant injury, and these vehicles are eliminated. Eggs from a few vehicles will likely break and splatter when ejected during vehicle impact with the block. (**Safety note:** Wash any raw egg from hands with soap and hot water.) Students always spontaneously compare these egg ejections to stories they have heard of unbuckled occupants being ejected from vehicles in real collisions.

The tie-breaker

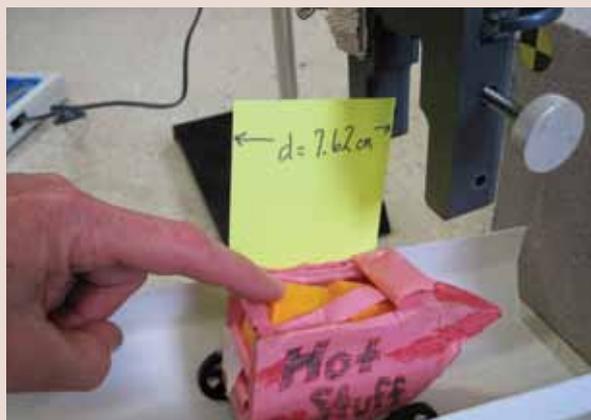
Often, more than one vehicle successfully survives the crash with an uninjured occupant. To further increase the level of challenge of the crash test, we conduct a second round with all intact eggs and vehicles from round 1 and elevate the track to the top step of the ladder to increase the velocity (and momentum) of the cars. In this teachable moment we use the concepts of potential and kinetic energy to explain how speeding results in more fatal crashes. With a greater starting height, the race cars begin with greater potential energy and a corresponding increase in kinetic energy as the cars reach the block. We use the formula for kinetic energy ($KE = \frac{1}{2}mv^2$) to explain why speeding is often fatal for teenage drivers. Since kinetic energy is proportional to the square of a vehicle's velocity, if velocity is doubled, the amount of kinetic energy in a collision is quadrupled.

We then discuss real-world application of these principles. To absorb the enormous amount of kinetic energy in high-speed crashes before it reaches occupants, automakers design front ends that crumple on impact. However, occupants must still wear seat belts, which are fastened to the safety cage, ensuring that both the safety cage and the occupant slow down at the same rate. Struggling with these conflicting constraints—constructing a front end weak enough to crumple while making the safety cage strong enough to protect the egg—helps students realize the vital role of seat belts. Their egg survives only if the crumple zone and the safety cage work well together, and the egg is "wearing its seat belt."

During the second run, most of the remaining cars' eggs break on impact with the concrete block. If multiple cars

FIGURE 3

An index card is taped to the vehicle, short side at top, to pass through a photogate. Students divide the width of the card by the time recorded on the photogate to calculate the vehicle's final speed.



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are successful after the second run, calculations of greatest momentum can determine a clear winner by multiplying the car's mass (converted to kilograms) by its final velocity.

As cars are eliminated, students point out the design features of more and less successful cars. They notice higher survival rates among designs that allow eggs to slow down gradually within the safety cage (using, for example, a collapsing folded paper accordion that functions like an airbag and cab-forward-shaped front ends that allow the egg to move forward into a narrowing cone). Students are quick to identify design flaws in cars with egg “fatalities” and discover that cars with stiff front ends do not crumple enough on impact, resulting in a higher impact force on the egg. (See “On the web” for additional project assessment information.)

Exploring real-world vehicle design concepts

To complement the design engineering project, students also examine vehicle safety engineering research using a three-part web-exploration activity (see “On the web”). For part 1, students investigate key vehicle design safety terms, including *crashworthiness*, *safety cage*, and *crumple zones*. For part 2, students analyze slow-motion videos of frontal offset crash tests at the IIHS website (see “On the web”). They then visit the NHSTA site and compare how each organization performs its crash tests. Finally, students compile crash test results for the same vehicle from both sites and analyze reasons for differences in the two sets of results. To conclude the unit, in part 3 of the web exploration activity, students create data tables summarizing statistics related to such topics as teenage crash rates and seat belt use; then they prepare a position statement reacting to any one piece of current or pending legislation designed to reduce teen driving fatalities (e.g., increasing the minimum licensing age, mandatory seat belt laws for teenagers, graduated licensing programs, and speed and tracking devices attached to teenagers' vehicles).

What's science got to do with it?

According to *A Framework for K–12 Science Education* (Dimension 3), students “should learn how science is utilized, in particular through the engineering design process, and they should come to appreciate the distinctions and relationships between engineering, technology, and applications of science” (NRC 2012, p. 201). Hands-on simulations of motor vehicle collisions are highly relevant examples of how science and engineering are mutually supportive. Exposure to crash science using both web-based research and design challenges helps teenagers see the links between engineering, technology, science, and society, as well as how an understanding of the laws of physics might someday save their lives. ■

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On the web

Insurance Institute for Highway Safety videos of frontal offset crash tests: www.iihs.org/ratings/frontal_test_info.html
Paper Car Crash Design Challenge instructions: www.nsta.org/highschool/connections.aspx
Project assessment information: www.nsta.org/highschool/connections.aspx
Web Quest activity worksheet: www.nsta.org/highschool/connections.aspx

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