Float like a Cadillac, sting like a BEAMer

Rebecca Bernstein | Fall 2024

Field(s) of Interest: Mechanical engineering, physics, computer science

Brief Overview (1-3 sentences):
Mentees will explore real-world engineering concepts related to automobiles, including new innovations in the car industry. Mentees will build sling-shot cars, add safety features to their cars designed to protect an egg, and simulate self-driving cars through an interactive activity.

Agenda:

- Introduction (5 min)
- Module 1: Life is a highway (20 min)
- Module 2: I can't even parallel park (10 min)
- Module 3: I crashed my car into the bridge… I don't care (20 min)
- Conclusion (5 min)

Main Teaching Goals/Key Terms:

- ➔ Chassis
- ➔ Axle
- ➔ Wheel
- ➔ Potential energy
- ➔ Kinetic energy
- ➔ Aerodynamic efficiency
- ➔ Friction
- ➔ Impact force
- ➔ Energy absorption
- ➔ Restraint system
- ➔ Crash test
- ➔ Autonomous navigation
- ➔ Sensor
- ➔ Algorithm
- ➔ Machine learning

Background for Mentors

Module 1
• Parts of a car:
  ○ Chassis
  ○ Axle
  ○ Wheel
• Potential energy
• Kinetic energy
• Aerodynamic efficiency
• Friction
	A car **chassis** is a load-bearing structure that supports a vehicle's load and provides a framework for attaching other components like the engine, transmission, wheels, and suspension. It must be designed to withstand various stresses, including those from bad road conditions, braking, acceleration, and cornering forces. There are various types of chassis designs, including the ladder frame chassis which is strong and common in trucks, the monocoque chassis which improves fuel efficiency and safety in passenger cars, and the space frame chassis which is common in sports cars because it is both lightweight and rigid. The **axle** of a car is the rod that connects two **wheels** together and attaches them to the chassis. The wheels rotate around the axle and drive the forward and reverse motion of a car.
	
	
	Figure 1: Ladder frame chassis
	
	Potential energy is stored energy, while **kinetic energy** is the energy of motion. In cars, potential energy is stored in the chemical bonds of fuel. During combustion, these bonds break, releasing potential energy and converting it into kinetic energy that propels the car forward. However, in the slingshot car that the mentees will build, potential energy is stored in the stretched rubber band, which is converted into kinetic energy when released. While energy is stored as chemical potential energy in real cars and elastic potential energy in slingshot cars, the transfer of energy from potential to kinetic is analogous in both cases.
	
	When cars are built, aerodynamics (how air interacts with a moving object) is carefully considered. A well-designed aerodynamic shape reduces air resistance, allowing a vehicle to move more efficiently, leading to an improved **aerodynamic efficiency**. As a result, the vehicle can move faster or travel farther with less energy, leading to improved performance and fuel efficiency. **Friction** is the resistance that an object encounters when moving over another surface. Different road conditions can affect the level of friction between a car's wheels and the road surface. For example, wet or icy roads reduce friction, leading to a loss of traction and control.

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Module 2

- Autonomous navigation
- Sensor
- Algorithm
- Machine learning

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In recent years, there have been important innovations in automobile engineering, especially in the development of self-driving cars. These vehicles are designed with advanced programming that enables **autonomous navigation**, allowing them to navigate and move independently without human intervention. For successful autonomous navigation, self-driving cars must be equipped with various **sensors**, which are devices that gather data about the surroundings. Some examples of these sensors in self-driving cars include cameras and GPS systems.

An **algorithm** is a set of step-by-step instructions that guides a computer in executing a specific task. After a self-driving car gathers data about its surroundings, an algorithm processes this information and provides the instructions for the car to make informed decisions based on that data. For example, if a camera detects a red light, the algorithm instructs the car to stop. However, algorithms are usually much more complex, as they must process and analyze data from multiple sensors.

Machine learning algorithms play an important role in self-driving cars by enabling them to learn from data and make decisions based on data without explicit programming. These algorithms analyze huge amounts of information gathered from the vehicle's sensors, identifying patterns and trends that inform their actions. As the car operates in various conditions, the algorithms continuously improve their performance through experience, improving its decision-making capabilities over time.

Figure 3: Elon Musk’s new robotaxi, an autonomous car set to come out by 2027

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Module 3 ● Impact force ● Energy absorption ○ Crumple zone ○ Airbag ● Restraint system ● Crash test ● Engineering design process	When a collision occurs, an **impact force** causes a rapid change in the velocities of the two colliding objects over a very short period of time. This impact force is related to the kinetic energy of the objects, the distance over which the force is applied, their momentum, and the time during which the force acts. The relationship can be expressed as: $F_{impact} = \frac{\Delta KE}{\Delta d} = \frac{m\Delta v}{\Delta t}$ **Energy absorption** refers to the process in which a material or structure dissipates energy during a collision. When an impact force occurs, kinetic energy from the moving object is transferred to the material, which absorbs this energy through mechanisms such as deformation and heat dissipation. In automobiles, specific features are engineered to absorb energy during a collision. These features reduce the impact force transmitted to the occupants, minimizing damage and injury. One such feature is a **crumple zone**, which dissipates energy during a collision by intentionally crumpling, converting some of the kinetic energy into heat. Crumple zones also extend the time over which the impact force is applied. Another energy-absorbing feature in an automobile is an **airbag**, which is a bag that inflates within milliseconds after a collision. An airbag provides an energy-absorbing surface between a vehicle's occupants and the vehicle's hard surfaces, preventing occupants from hitting the hard surfaces. The airbag dissipates energy by compressing as it absorbs the force of the collision. A **restraint system** is designed to hold occupants within a vehicle in place during a collision, minimizing movement and preventing ejection from the vehicle. Seat belts keep occupants securely in place by tying them down to their seats. When airbags deploy, they further minimize movement by creating a cushioning barrier that slows the occupant's forward momentum. In the real world, engineers perform **crash tests**, where they deliberately crash a vehicle under controlled conditions in order to evaluate and improve its ability to withstand a collision. They place dummies and sensors inside of the vehicles to ensure that they collect the data required to measure all necessary safety variables. The **Engineering Design Process** is the series of steps that engineers follow to come up with a solution to a problem, usually including multiple stages of trial and error. Crash tests typically occur during the testing phase of the Engineering Design Process, which is an important step in ensuring that vehicles meet safety standards.

Introduction

Cars and other automobiles are an important part of our daily lives. Thus, this lesson provides an opportunity for mentees to explore relevant engineering concepts and engage in hands-on applications through the engineering design process. Additionally, this lesson introduces mentees to new technologies that are shaping the future of transportation.

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<td>Concepts to Introduce

Parts of a car: cars are a part of everyday life, so ask mentees what parts of a car they notice when they are riding in a car or see cars driving down the street
Safety features: mentees may be familiar with common safety features in cars such as seat belts or airbags
Self-driving cars: ask mentees if they have seen any of the self-driving cars in the bay area
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<td>Questions to Pique Interest

If you were to build a car, what features would you include?
Also, more specifically what safety features would you include?
Why do you think it is important for cars to have built in safety features like seat belts and airbags?
How do you think a car can drive all by itself without anyone touching a steering wheel or pedal?
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<td>Scientists, Current and Past Events

Engineer John Hetrick invented the airbag in the 1950s after a severe car accident inspired him to create a safety cushion; airbags are now a legally required feature that has saved many lives
Tesla recently announced the Robotaxi, a self-driving car set to release in 2026
https://www.sfchronicle.com/bayarea/article/tesla-taxi-bay-area-19861706.php
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<td>Careers and Applications

Mechanical engineering
Software and AI development
Transportation policy
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Module 1: Life is a highway

Mentees will build a slingshot car to demonstrate the key components of a car and how they allow for motion. This is a build activity.

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Teaching Goals

1. **Parts of a car:**
    a. **Chassis:** The load-bearing frame that supports a vehicle's structure.
    b. **Axle:** A rod around which a wheel rotates.
    c. **Wheel:** Circular component that rotates around an axle and works in combination with the axle to enable a vehicle to roll forward or backward.
2. **Potential energy:** Energy stored in an object due to its position, condition, or structure.
3. **Kinetic energy:** Energy an object possesses due to its motion, which arises from the conversion of potential energy into motion.
4. **Aerodynamic efficiency:** A measure of how effectively an object reduces air resistance (drag) while maximizing thrust as it moves through the air. High aerodynamic efficiency indicates that a vehicle can move faster or travel farther with less energy, leading to improved performance and fuel efficiency.
5. **Friction:** The resistance that an object encounters when moving over another surface, which opposes its motion and slows it down.

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Materials

- 20 x Popsicle sticks per group
- 2 x Wooden dowels
- 2 x Straws
- Tape
- 4 x Plastic wheels
- 1 x Rubber bands
- Wooden pencils

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Different Methods for Teaching
1. The video can be extremely useful to get mentees attention! If there is a way to connect to the projector/smartboard in the classroom, try doing that so that the mentees can follow step by step.

Video link
https://www.youtube.com/watch?v=JNFLFWj9I88

Procedure

1. Use popsicle sticks and tape to build a frame that will support a slingshot car.
   a. One example is a rectangle frame (Figure 1) which you can show to mentees as an example, but let the mentees be creative with their own designs!
2. Take a wooden dowel and insert it through a straw to create the axle. Slide a wheel onto each end of the dowel through its center hole, positioning one wheel on each side of the straw. Tape the ends of the dowel to prevent the wheels from falling off (Figure 2). Make two axle and wheel structures per car.
3. Position each axle and wheel structure on opposite sides of the frame with the wheels extending outward. Tape each straw to the underside of the frame, creating the finished chassis (Figure 3).
   a. Make sure the wheels are aligned (axles are parallel) so that the slingshot car moves straight!
4. Tape a rubber band to the front of the slingshot car, which should be one of the sides with an axle and wheel structure (Figure 4).
5. Use popsicle sticks and tape to build additional structure on top of the chassis.
   a. One example is shown in Figure 5, but let the mentees be creative with their own designs!
   b. For advanced sites, think about what type of structure could increase aerodynamic efficiency!
6. To create the launcher, tape a pencil to the floor (Figure 6).
7. To launch the slingshot car, hook the rubber band onto the pencil's eraser. Holding onto the back of the car, pull the car backwards so that

Figure 1: *Slingshot car frame example*

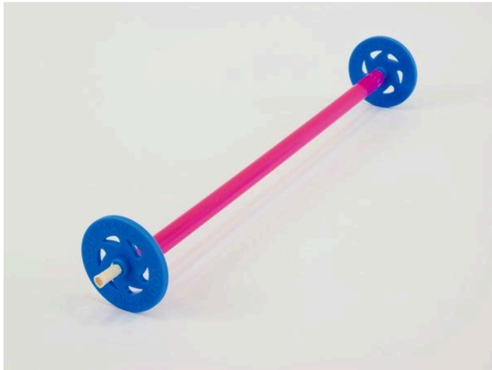


Figure 2: *Axle and wheel structure*

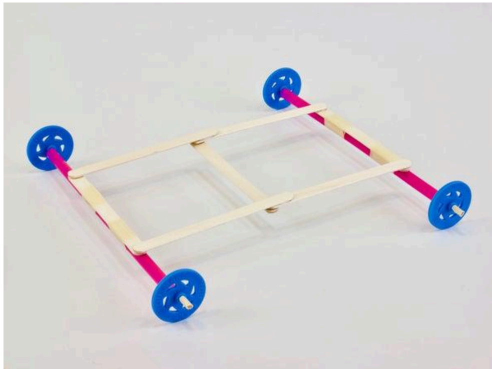
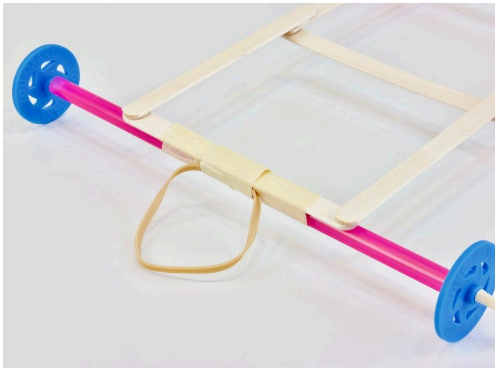


Figure 3: *Slingshot car chassis example*



the rubber band stretches, and then let go (Figure 7).

8. For advanced sites, launch the car on different surfaces and observe the difference in motion. For example, does the car move faster on hard ground or carpeted surfaces?

Figure 4: *Rubber band attachment*

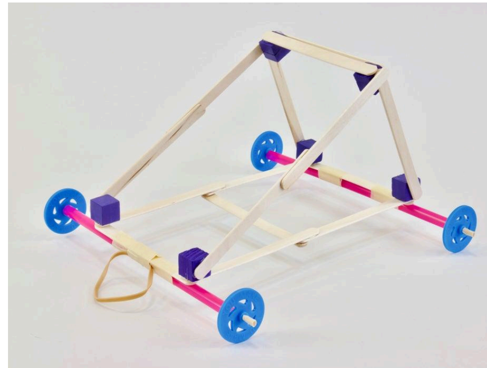


Figure 5: *Finished slingshot car example*

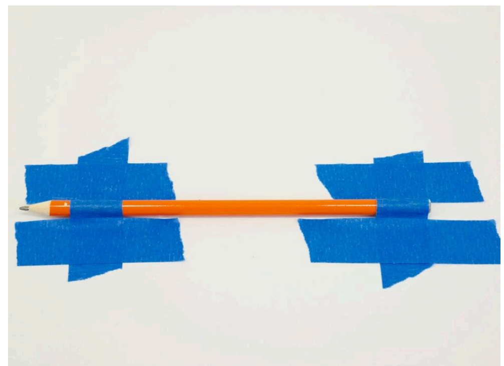


Figure 6: *Pencil launcher*

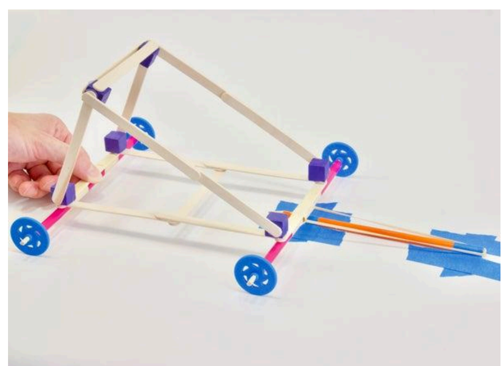


Figure 7: *Launching the slingshot car*

Classroom Notes

If possible, go outside to launch the slingshot cars because they move very fast so you may need more space!

Module 2: I can't even parallel park

Mentees will learn about self-driving cars through an interactive activity where they will simulate how self-driving cars operate.

Teaching Goals	Materials
1. **Autonomous navigation:** The ability of vehicles or robots to navigate and move independently without human intervention. 2. **Sensor:** A device such as a camera or GPS that gathers data about the surroundings. 3. **Algorithm:** A set of step-by-step instructions that guides a computer in executing a specific task. 4. **Machine learning:** The use and development of computer systems that are able to learn from data and make decisions based on data without explicit programming. Machine learning algorithms improve their performance over time through experience.	• Masking tape • Items from around the room

Different Methods for Teaching

1. We don't want the mentees to see the path before they go on it! To ensure that the path remains a mystery, while also going through the lesson in a timely manner, have some of the mentors work on setting up the path while the other mentors are teaching module 1, to maximize time.

Procedure

1. Mentors: Lay out tape on the floor to outline a winding path with turns. Additionally, set up obstacles using items from around the room.
    a. Make sure none of the mentees see the path! Lay out the path outside while the mentees are inside or lay out the path in a separate section of the room away from the mentees.
2. Place mentees in pairs. Have one partner close their eyes while the other partner leads them over to the start of the path with their slingshot car.
    a. The partner closing their eyes represents the car while the other

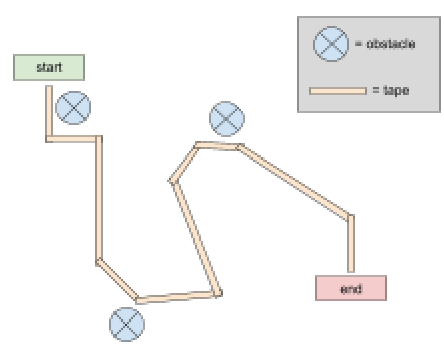


Figure 1: *Tape obstacle course example*

partner represents the sensor. 3. Have the mentee that is closing their eyes push their car along the path while the mentee that has their eyes open gives verbal instructions on how to navigate and avoid the obstacles. a. This can be a race between pairs to see who makes it to the end of the path the fastest! 4. For advanced sites or if time permits, have each pair go twice. Time each round and see if the mentees can make it to the end of the path faster on the second attempt. This is analogous to machine learning!	

Classroom Notes

If possible, do this activity outside so that you can make a bigger obstacle course! Also, skip this module if you don't think there will be enough time for the third module.

Module 3: I crashed my car into the bridge... I don't care

Mentees will add safety features to their slingshot cars from Module 1 to protect an egg, and then conduct a crash test with an egg seated in their car to see if the egg breaks. This is a build activity.

Teaching Goals

1. **Impact force:** The force experienced by an object when it collides with another object over a very short period of time.
2. **Energy absorption:** The process in which a material or structure dissipates energy during a collision, minimizing damage or injury. Crumple zones and airbags are examples of energy-absorbing features in automobiles.
3. **Restraint system:** A safety feature in vehicles designed to protect occupants during a collision by minimizing movement and preventing ejection from the vehicle (eg. seatbelts).
4. **Crash test:** Deliberately crashing a vehicle under controlled conditions in order to evaluate and improve its ability to withstand a collision.

Materials

- Confetti eggs (5 per site)
- Plastic eggs (5 per site)
- Plastic portion cups
- Ziploc bags
- Assorted materials:
    - Pipe cleaners
    - Cotton balls
    - Sponges
    - Cardboard pieces
    - Paper
    - Popsicle sticks, straws, tape, rubber bands can be used from module 1

Different Methods for Teaching

1. It's possible that the mentees could get triggered by the topic of car crashes. It's okay to mention it, but just be mindful of this! To do so, try focusing more on the teaching goals and science behind safety features, rather than talking about car crashes directly.

Procedure

1. Secure a plastic portion cup into the slingshot car from Module 1 to create a seat for an egg.
2. Place a plastic egg into the plastic portion cup.
3. Use the engineering design process to build safety features that will protect the egg during a collision.
    a. Examples of safety features include using a straw as a bumper and a rubber band as a seatbelt.
    b. While the plastic egg may have different properties than the confetti

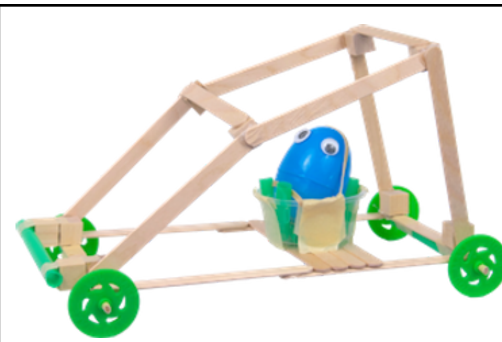


Figure 1: *Slingshot car with plastic egg and safety features example*

egg, it serves as a tool for the trial-and-error testing phase of the engineering design process. Similarly, real crash tests use dummies, which also differ from actual human occupants. 4. Place a confetti egg in a ziploc bag and seal the bag. Replace the plastic egg in the car with the sealed confetti egg. 5. Perform a crash test by launching the slingshot car at a wall. See if the confetti egg breaks upon impact or if it is protected by the built-in safety features.	

Classroom Notes
If possible, go outside to perform the crash test so that you have a longer path for the car to travel in order to create a bigger collision!