LESSON: Bottle Rocket Truck (Grades 6-8)

+ OVERVIEW

In this design challenge, students will design a truck that is as efficient as possible for Jennifer's transportation company. Students will learn about Newton's Laws of Motion, with an emphasis on the first and third laws, and see a laboratory demonstration of a chemical reaction. The chemical reaction will occur between acetic acid and sodium bicarbonate, the same materials they will use for their design challenge. The students will be presented with the following problem: "Jennifer's transportation company is currently trying to figure out how to maximize the output of her trucks. They travel long distances with a lot of goods and do not want to waste any fuel." The students will put on their engineering hats to build a truck that will travel an exact distance on a single tank of gas. Students will engage in a STEM challenge to design a truck powered by a chemical reaction that will have to stop within a specific drop-off zone. Teams will be challenged with various payloads to earn bonus points if they can stop in the drop-off zone.

+ 2021 Science TEKS covered in this design challenge

Grade 6 TEKS: 6.1.B, 6.1.E, 6.1.G, 6.2.D, 6.6.E, 6.7.C

Grade 7 TEKS: 7.1.B, 7.1.E, 7.1.G, 7.2.D, 7.6.C, 7.7.D

Grade 8 TEKS: 8.1.B, 8.1.E, 8.1.G, 8.2.D, 8.6.E, 8.7.B

+ Math TEKS covered in this design challenge

Grade 6 TEKS: 6.3.D, 6.3.E

Grade 7 TEKS: 7.3.A, 7.3.B

+ 2022 Technology Applications TEKS covered in this design challenge

Grade 6 TEKS: 6.3.A, 6.3.B, 6.3.C

Grade 7 TEKS: 7.3.A, 7.3.B, 7.3.C

Grade 8 TEKS: 8.3.A, 8.3.B, 8.3.C

+ The students will be able to:

- Investigate how evidence of chemical reactions indicates that new substances with different properties are formed, and how that relates to the conservation of mass
- Demonstrate how unbalanced forces change the speed or direction of an object's motion
- Investigate and describe applications of Newton's three laws of motion
- Investigate how mass is conserved in chemical reactions and relate the conservation of mass to the rearrangement of atoms using chemical equations
- Solve a problem using the engineering design process

+ Students will use the following STEM fluency skills:

- Communication
- Collaboration
- Creativity
- Critical Thinking
- Resilience
- Time/Resource Management
- Innovation
- Adaptability

+ Materials needed for this design challenge:

> Water Bottle + Cap (750mL)	No cost
> Water	No cost
> Thumb Tack or Push Pin	No cost
> Tissue Paper	No cost
> Safety Goggles	No cost
> Laboratory Gloves	No cost
> Sodium Bicarbonate (max: 25 g)	$15 per 5 grams
> Acetic Acid (max: 125 mL)	$15 per 25 mL
> Lego Wheels (small)	$10 per wheel
> Lego Wheels (medium)	$20 per wheel
> Lego Wheels (large)	$30 per wheel
> Lego Axel	$5 per axel
> Lego Long Chassis (white pieces)	$50 per chassis
> Lego Short Chassis (blue pieces)	$25 per chassis
> Straws	$10 per straw
> Tape	$15 per roll
> Scissors	$10 per pair
> Rubber Band	$5 per band
> Thick Foam Sheet (6mm) or Cardboard	$50 per sheet
> Cardstock or Construction Paper	$25 per sheet

+ Materials needed by the facilitator:

- Projector and computer
- Slide deck for the lesson
- Copies of the scorecard for each group
- Tennis ball
- Lacrosse ball
- Timing device
- Digital scale
- Small Ziploc bag
- Sodium Bicarbonate (3g)
- Acetic Acid (25mL)
- Small paper cup (4oz.)
- Masking tape to mark the landing zone and drop line
- Pipette (Recommended 50mL)

SECTION	PROCEDURE Due to working with a chemical reaction, students will be wearing goggles and gloves as an additional safety measure.
INTRODUCTION	**Slide 1: Bottle Rocket Truck** **Slide 2: Newton's Laws of Motion** > Ask students if they know Newton's Laws of Motion. Ask for examples. ▪ Newton's First Law: An object in motion will remain in motion until actioned upon by an outside force. This means an object will either stay at rest, not move, or move in a straight line at a constant speed unless something causes it to change. Demonstrate this law to students by dropping a tennis ball. Ask students what was the outside force that stopped the tennis ball (The floor). ▪ Newton's Second Law: This is the mathematical formula: force equals mass times acceleration or F=ma. The second law states that acceleration occurs when an external force acts on the object. The greater the mass, the more force is needed to accelerate the object. Remind students that acceleration is a change in speed over time and that an object decelerating, slowing down over time, is still experiencing acceleration. Demonstrate this law to students by using a flat surface to push a tennis ball and a lacrosse ball. Students will be able to see the difference in the amount of effort and force required to move these balls across the surface. ▪ Newton's Third Law: For every action, there is an equal and opposite reaction. When force is applied in one direction, an equal amount of force is applied back. For example, rockets. When rockets burn fuel, the force is pushed towards the ground to make the rocket go up. Demonstrate this law to students by placing a lacrosse ball on a surface. Roll the tennis ball into the lacrosse ball and observe what happens. **Slide 3: Reaction in a Bag** > Conduct a reaction in a bag demonstration using acetic acid and sodium bicarbonate. Present evidence to students that indicates a chemical reaction occurred. ▪ Pour 25 mL of acetic acid into a mini paper cup. ▪ Put 3 g of sodium bicarbonate into a Ziploc bag. ▪ Put the mini paper cup of acetic acid into the Ziploc bag; make sure the cup stands upright and does not spill. ▪ Put the Ziploc bag on top of a digital scale and let the class know the mass of the materials.

	- Pick up the Ziploc bag and shake it to mix the acetic acid and sodium bicarbonate.
	- After the reactants are done mixing, ask students if the mass is less, the same, or more.
	  - Let students observe the Ziploc bag. Explain to students that since nothing is escaping from the bag, the mass will be the same.
	- Put the Ziploc bag back on the scale. Ask students if they think it will weigh the same, less, or more.
	- Let the class find the result through the scale.
	  - The weight on the scale should be slightly less, around 0.4 grams, than before. Ask students why they think this happened. Ask students if the mass is the same as the weight.
	    - Besides the chemical reaction, the only thing that changed in the sealed system was the *volume*. When the baking soda and vinegar combined, they created carbon dioxide gas, which inflated the bag.
	    - The expansion of the bag changed the weight of the overall bag because the entire experiment was submerged in a fluid: air.
	    - Just like water, air is a fluid, and fluids buoy up objects. The upward buoyant force on any submerged object is equal to the weight of the fluid displaced by that object—this is known as *Archimedes' principle*. By increasing the volume of the bag, it displaced more air, increasing the buoyant force on it and reducing its weight. Here's the thing to remember: Scales measure weight, not mass. The mass stayed the same due to the law of conservation of mass, but because of buoyancy, the weight went down!
	- Ask the class if they think this is a chemical or physical reaction. Why?
	  - Explain to the class that we observe evidence of a chemical reaction through the formation of gas.
	- Let the class know there is one other piece of evidence that indicates a chemical reaction occurred. Have the class guess what it could be.
	  - Allow a student volunteer to come up and feel the Ziploc bag.
	    - The liquid in the bag should feel a lot cooler. Explain to students that this is called an endothermic reaction, which means more energy is

	required when the chemical reaction occurs. As a result, the temperature drops. **Slide 4: Engineering Design 1** > Ask students the question: what is engineering? ▪ Explain to students that engineering is when engineers take what they know and apply it to solve problems by designing a product or process. ▪ For example, phones could only be used at home or in specific locations. Why is this a problem? (Needing to make a call outside the home). What solution did engineers design to fix that problem? (Cell phones). • *Teacher's Note: Any example can be used here, but focus on examples that students are familiar with.* **Slide 5: Engineering Design 2** > Ask students the question. What are some examples of engineering jobs? ▪ *Teacher's Note: If students have trouble giving examples, ask students who they think makes the things they use. Who makes refrigerators, cars, helmets, cell phones, and sneakers?* **Slides 6-8: Engineering Jobs 1-3** > Show students pictures related to engineering jobs connected to the challenge. > Mechanical Engineering ▪ Ask students what they see in the pictures. ▪ The people who work on cars, trucks, and machinery are called mechanical engineers. They design and build different ways to solve problems surrounding mechanical parts or processes. > Aerospace Engineering ▪ Ask students what they see in the pictures. ▪ The people who work on spacecraft and similar machinery are called aerospace engineers. They design and build space capsules, rockets, satellites, etc., and improve safety for travel. > Chemical Engineering ▪ Ask students what they see in the pictures. ▪ Chemical engineers use their knowledge of chemistry to develop products that improve our lives. Chemical engineers work in manufacturing, pharmaceuticals, healthcare, construction, food processing, electronic and advanced materials, business services, biotechnology, and environmental health and safety industries, among other fields.

	Slide 9: Engineering Design 3
	> Ask students the question. Who can be an engineer?
	  ▪ Anyone!
	
	Slide 10: Engineering Design Process
	> Ask students if they think all engineers solve their problems in one try. Explain to students that it takes many tries to get something correct in engineering. In engineering, there is no such thing as a mistake, only opportunities to learn. It is okay to fail. Just find the mistake and correct it. In engineering, there is never one correct solution. There are always many solutions to a problem and always improvements that can be made. The steps that engineers take to find these solutions are called the *engineering design process*.
	> Ask students to read the first big step (Identify).
	  ▪ What does identify mean? (To point out or find). Engineers design solutions: what do they need to know first before they can find the answer? (The problem)
	  ▪ How do people know when they have found the correct answer? In engineering, there are no correct answers, just better ones. Explain to students that there are expectations that engineers must meet called *criteria*. For example, when engineering a football, what does a football need to do? (Bounce, look a certain way, have laces, have air inside, etc.). Those things are all called criteria. By comparing the design to the criteria, an engineer knows a solution will work. Is a child-sized football the same as an adult football? The criteria for both footballs include leather, the white laces for fingers, and the shape. However, the two footballs would have different criteria for the size. The footballs are similar but different because of different criteria.
	  ▪ Once the criteria are understood for the design challenge, what could make it difficult for an engineer to design their solution? (Money, time, materials, etc.) Explain to students that these rules are called *constraints* or rules that engineers must follow. Engineers are given constraints they must follow when finding the solution to a problem. Think about football again. What are college and professional footballs made from? (Leather). What if instead, the rule (or constraint) was not to use leather, could another type of football be made instead? Many of the footballs for sale are made of rubber because the engineer had different constraints.
	> Ask students to read the next step (Imagine).
	  ▪ Ask students what imagine, or imagination, means. Are these things real or tangible? They may not be real, but they help give us ideas about what things could be. In this step, see what materials are available, then brainstorm, or think about possible ideas/solutions to the problems.

	▪ Explain to students that there are no right answers in engineering. Start with as many ideas as possible. > Ask students to read the next step (Plan). ▪ The third big step of the engineering design process is to plan out the idea. Make sure that what is designed can be repeated. A plan will help an engineer identify where mistakes happen so they can be fixed. ▪ When planning, begin with the brainstorming phase. Each team member will contribute their ideas, and then the team combines the different ideas! ▪ Once ideas are combined into a single group idea, determine what materials will be used for the solution and make sure the design has met the criteria and constraints of the project. > Ask students to read the next step (Create). ▪ The fourth step is to create! Since this is the very first creation, it is called a *prototype*. A prototype is a first or preliminary model of something from which other forms are developed or copied. A prototype is created to test the engineer's idea or concept. Engineers ask themselves, "Did the idea work the way we wanted it to?" After testing the idea, the engineer will make improvements to the prototype. > Ask students to read the last step (Improve). ▪ Finally, the last step is to improve. How does an engineer know if the prototype did well on the test? It must meet certain expectations and follow some rules. But how do engineers determine how well it met the expectations and how well it followed the rules? In school, how do you know if you mastered something? (Grades). The prototypes made today will be scored using a scorecard or rubric. By looking at the score, each team will determine if the design could be better. If improvements should be made, then the team will revisit the plan and decide what to do to improve the score. Remember, there are no correct answers in engineering, just better solutions.
IDENTIFY	**Slides 11-12: Identify** – Problem > Have students read the bolded section. ▪ Ask students to *identify the problem*. > Explain to students that they will put on their engineering hats to design a truck that can maximize its efficiency for transportation. **Slide 13: Identify** – Criteria (Desired Outcomes) > Ask students what criteria or desired outcomes mean. ▪ Explain to students that criteria are what engineers use to determine if they have successfully solved the engineering problem. > Ask students what determines if the solution is successful today.

	▪ A successful truck design should include the following: • Ability to be self-propelled by a chemical reaction occurring in the water bottle ○ *Teacher's Note: The thumb tack will hold the gas produced by the chemical reaction and then release it when the thumb tack is removed. There is a small enough gap where gas can be released but lacks enough force to push out the thumb tack entirely.* • Ability to travel 2.5 meters • Ability to not crash Bonus points will be awarded if the design can stop the truck at the appropriate distance with 50 mL, 100 mL, and 150 mL payloads of water. **Slides 14-15: Identify** – Constraints (Limitations) > Ask students what constraints or limitations mean. ▪ Explain to students that constraints are rules the engineers must follow. > Explain the constraints for this engineering design activity: ▪ <u>Time Limit</u>: Students will have 25 minutes to build the bottle rocket truck. • *Teacher's Note: The teacher will time the design challenge and give the students time checks periodically to assist the teams with their time management.* ▪ <u>Materials</u>: Students will only be able to use the materials available. ▪ <u>Budget:</u> Students will have $500.00 to complete this challenge. • *Teacher's Note: Fake money can be given to each group to represent their budget. Students would then go to the supply table and hand the teacher the money to "buy" their materials.* ▪ <u>Collaboration</u>: One design element from each team member must be used in the final design. Explain to students that a design element is taking one part of someone's idea and adding it to another. ▪ <u>Redesign</u>: Each team can test their prototype as many times as needed during the 25-minute design phase. Remind students what a prototype is. It is the first creation of our design. • *Teacher's Note: When a team is ready to test their design, they should raise their hand. The teacher will then ask them to come to the testing station and test their design. If the team receives a low score on any part of the design, the team should redesign if they still have time.*

IMAGINE	**Slide 16: Identify** – Explore Materials > Demonstrate the propulsion system for the bottle rocket truck. Take a water bottle with a thumb tack punched through the cap. Fill the water bottle with 100 mL of acetic acid and wrap 6 g of sodium bicarbonate with tissue paper. Place the tissue paper inside the water bottle and close it securely. Shake the water bottle and then remove the thumb tack to demonstrate how the energy released will allow for propulsion. The measuring will be done at the testing station. Students will design their trucks using this chemical reaction as the basis for self-propulsion. > Ask students which of Newton's laws this demonstrates. ▪ Newton's 3rd law **Slide 17: Imagine** – Brainstorm > Give students one minute to individually design and draw a plan of what they think their truck should look like. Emphasize that students should not talk during this minute or share ideas. Remind students their ideas will be used as design elements for the final design. > After a minute, give students five minutes to present and share their ideas with their group. Let students know that they should focus on key aspects of their idea that they like and want to be used as design elements for the final design when sharing. ▪ *Teacher's Note: If students are struggling with an idea for their design, provide ideas without giving the solution. For example, "This is a design that I tried earlier, but it failed. What could I do to improve it?" Emphasize that the design failed to reinforce that it is okay to fail and to let students know they cannot copy the design and expect success.*
PLAN	**Slide 18: Plan** – Gather Materials > Hand out the scorecard that will be used during the design challenge. Review the testing criteria with the class and answer questions. The testing criteria will inform their design decisions. > Have students collaborate to come up with a final design. Let students know they must include at least one element from each team member for their final design. > Review the design criteria: ▪ A successful truck design should include the following: • Ability to be self-propelled by a chemical reaction occurring in the water bottle • Ability to travel 2.5 meters • Ability to not crash Bonus points will be awarded if the design can stop the truck at the appropriate distance with 50 mL, 100 mL, and 150 mL payloads of water. > Students will need to select the materials to be used for the design and develop a budget for the project. Students will have $500 to "purchase"

	materials for their build at the classroom supply table. The prices used in this challenge can be found in the materials list. Students will raise their hands when they are ready to purchase materials. The teacher will make sure the appropriate amount of money is spent to purchase each material but will not guide students on following their budget. Students can go over budget, but remind them that they will lose points on their scorecard. ▪ *Teacher's Note: The mixture for the best result is 10.3 g of sodium bicarbonate and 70 mL of vinegar. To allow choice, students will be able to purchase pre-measured amounts of substances. Material costs are provided in a way to allow students to naturally reach these numbers in how much they purchase, but students will often spend more than what is required.* **Slide 19: Plan** – Team Member Responsibilities > Each team member must be given responsibility, such as materials manager, banker, head engineer, and quality control manager.
CREATE	**Slide 20: Create** – Design Your Truck > Let students know to have fun, be creative with their designs, and work together. > Remind students that being an engineer is not about getting the solution on the first try. There is no right answer, just better solutions. **Slide 21: Identify** – Criteria > Display the reminder slide for students to look at while working. **Slides 22-23: Create** – Test > Once students are ready to test, they will raise their hands and be brought to the testing station. At the testing station, with the supervision of the teacher, students will fill their trucks with acetic acid using a pipette. They will then measure their sodium bicarbonate using a zeroed digital scale that has tissue paper on top of it. The tissue paper is then rolled up in a way that will allow it to fit into the opening of the water bottle. The teacher will identify the starting line and destination line for the students. Students will open the bottle on their truck and put in the rolled-up tissue paper. They will then close the bottle and shake it until they can hear or feel the bottle expand. It is up to the students to determine when they want to release the energy stored inside their truck by removing the thumb tack from the bottle cap. Students will be able to hear the gas trying to escape from the thumb tack, so it cannot keep building pressure. The testing station should have walls on the sides and at the back, which are used to determine whether a "crash" occurred. The walls should be approximately 15" apart. > Students will calculate their scores when testing in front of the teacher. The teacher will go through each of the categories on the scorecard with the students. The students will mark their scores and calculate the total.

	> The teacher will recap the point total with the students and how many points the team received for each category to make sure it matches with what the students recorded. ▪ *Teacher Note: If a team scores low on the self-propulsion test, ask students about the ratio of sodium bicarbonate to acetic acid used. Challenge students to think about whether all of the sodium bicarbonate was used and how that might play a factor in generating the energy needed to move their truck. The goal is to make sure all the sodium bicarbonate is used to determine how to adjust the amount of acetic acid or sodium bicarbonate that should be used on retesting.*
IMPROVE	**Slide 24: Improve** – Redesign: Discussion > Students will reflect on their scores and discuss: • What worked? • *Teacher's Note: Focus on the ratio of the materials used. Ask students if the placement of the bottle mattered in the design of their truck.* • What did not work? • *Teacher's Note: Focus on the ratio of the materials used. Ask students if the placement of the bottle mattered in the design of their truck.* • What do you want to improve? • *Teacher's Note: Focus on engineering aspects with students. Ask students if they found a solution or just part of one. Reinforce that it is okay to not succeed on the first try and that engineering is about making improvements over time. Ask students how they would design their trucks differently if they had no rules, how? Ask students if working together was difficult. Learning to work together is very important and it is easier to find a solution with many ideas rather than just one idea.*