LESSON PLAN

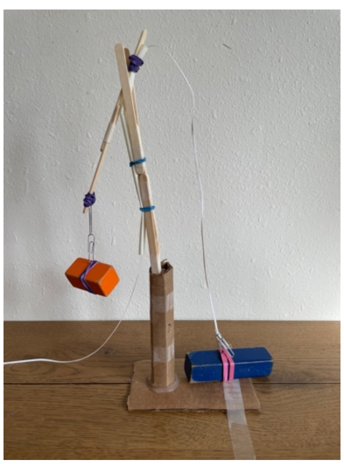
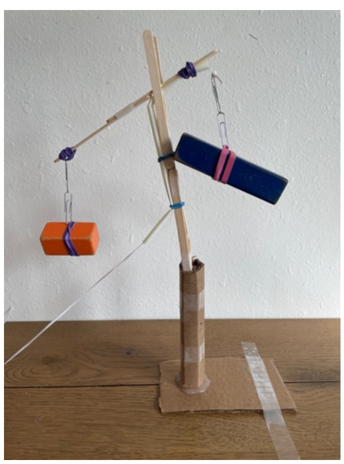
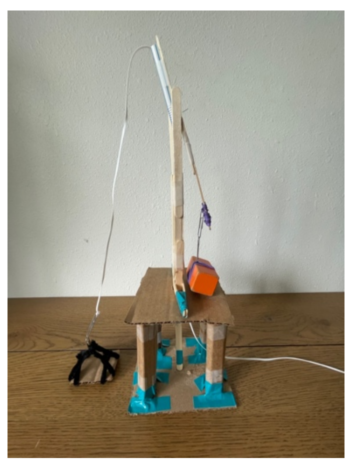
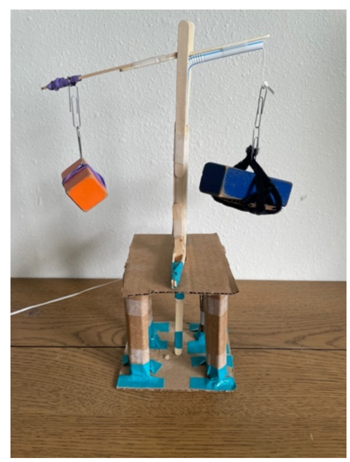
Forces in Action: Crane Design (Grades 6-8)

+ OVERVIEW

In this design challenge, students will be tasked with developing a crane used for loading and unloading payloads from vessels at a port. They will explore the relationship between force and motion by applying the engineering design process and Newton's Three Laws of Motion. Students will be presented with the following scenario: "A port's crane has broken down! This broken dockside crane is essential for loading and unloading payloads from vessels. Today, you will take on the role of engineer to create an initial design for a new crane."

Students will practice their engineering and teamwork skills to assist the port in designing a functional crane. By engaging in this STEM challenge, students will design a crane capable of lifting and moving a payload. Teams will receive bonus points if their crane can successfully handle two additional challenges, lifting a heavier payload and functioning effectively under adverse weather conditions, like high winds.

+ Crane Examples

+ 2021 Science TEKS covered in this design challenge

Grade 6 TEKS: 6.1.B, 6.1.E, 6.1.G, 6.2.A, 6.2.D, 6.5.C, 6.5.G, 6.7.A, 6.7.C

Grade 7 TEKS: 7.1.B, 7.1.E, 7.1.G, 7.2.A, 7.2.D, 7.5.C, 7.5.G, 7.7.D

Grade 8 TEKS: 8.1.B, 8.1.E, 8.1.G, 8.2.A, 8.2.D, 8.5.C, 8.5.G, 8.7.B

+ Math TEKS Covered in this design challenge

Grade 6 TEKS: 6.1.A, 6.3.D

Grade 7 TEKS: 7.1.A, 7.3.A

Grade 8 TEKS: 8.1.A

+ 2022 Technology Applications TEKS Covered in this Design Challenge

Grade 6 TEKS: 6.3.A, 6.3.C

Grade 7 TEKS: 7.3.A, 7.3.C

Grade 8 TEKS: 8.3.A, 8.3.C

+ The students will be able to:

- Solve a problem using the engineering design process
- Analyze how differences in scale, proportion, or quantity affect a system's structure or performance
- Analyze and explain how factors or conditions impact stability and changes in objects, organisms, and systems
- Identify and explain how forces act on objects, including gravity, friction, magnetism, applied forces, and normal forces, using real-world applications
- Identify simultaneous force pairs that are equal in magnitude and opposite in direction that result from the interactions between objects using Newton's Third Law of Motion
- Analyze the effect of balanced and unbalanced forces on the state of motion of an object using Newton's First Law of Motion
- Investigate and describe how Newton's three laws of motion act simultaneously within systems such as in vehicle restraints, sports activities, amusement park rides, Earth's tectonic activities, and rocket launches.

+ 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

> Payload	Free
> Counter Weight	Free
> Scissors	$5 per pair
> Duct Tape	$20 per roll
> Cardboard	$10 per sheet
> String	$3 per foot
> Toilet Paper Roll	$10 per roll
> Straws	$2 per bundle of 5
> Scotch Tape	$5 per roll
> Chenille Sticks	$2 per stick
> Popsicle Sticks	$2 per bundle of 10
> Rubber Bands	$5 per rubber band
> Paperclips	$2 per paperclip

+ Materials needed by the facilitator:

- Projector
- Computer
- Internet access or download video
- Slide deck for the lesson
- Copies of the scorecards (one per group)
- Payload
- Sample of a crane mechanism

+ FACILITATION GUIDE

SECTION	PROCEDURE
INTRODUCTION	**Slide 1: Forces in Action: Crane Design** > Introduce today's lesson on crane design. **Slide 2: Newton's Laws** > Introduce Newton's Three Laws of Motion. > Newton's First Law states that an object in motion will remain in motion until actioned upon by an outside force. > Newton's Second Law states that force equals mass times acceleration (F=ma). > Newton's Third Law says for every action there is an equal and opposite reaction. **Slide 3: Towe Cranes** > Play the video "How Do Cranes Work" by Mr. Technology. ▪ Encourage students to think about how cranes are used in various industries. Ask them to provide examples of where they have seen cranes in use and what types of tasks they perform. ▪ Discuss how the information in the video can be applied to their crane design. Ask students to think about how they can incorporate similar principles and mechanisms in their own projects. **Slide 4: Parts of a Crane** > Discuss the various parts of a crane, their functions, and how they relate to Newton's Three Laws of Motion. ▪ Counterweight: Is used to balance the crane by offsetting the weight of the payload being lifted. It prevents the crane from tipping over by providing a counterforce to the payload. The counterweight demonstrates Newton's Third Law, which states that for every action, there is an equal and opposite reaction. The weight of the payload is balanced by the counterweight. ▪ Vertical Column: Provides the main structural support for the crane. It supports the jib and cabin, allowing the crane to lift and move payloads. The stability of the mast is an example of the First Law of Motion. Which states that an object at rest will stay at rest unless acted upon by an external force. The strong foundation keeps the crane stable. ▪ Cables supporting the Jib: The cables support the jib and help in lifting the payload. They distribute the payload's weight evenly and provide stability. The tension in the cables is an application of Newton's Third Law, providing the necessary counterforce to lift the payload.

- Jib (Boom): The jib is the horizontal arm of the crane that carries the payload. It extends from the mast and moves payloads horizontally. The movement of the jib when lifting and lowering loads demonstrates Newton's First Law, as the payload will move in the direction of the applied force.
- Trolley: The trolley moves along the jib to position the payload. It allows the load to be moved horizontally along the jib. The trolley's movement exemplifies Newton's Second Law, as the force applied by the operator moves the mass of the payload.
- Pulley System: The pulley system is used to lift the payload. It changes the direction of the force applied by the cables, making it easier to lift heavy payloads. The pulley system uses Newton's Second Law, as the applied force is distributed to lift the mass of the payload.
- Pivots: Pivots allow the crane to rotate and move payloads to different locations. They provide rotational movement, enabling the crane to swing the jib around. The rotation of the crane around its pivot demonstrates Newton's First Law, where the crane remains in motion until acted upon by an external force.

Slide 5: Engineering Design

- 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 6: Engineering Design

- 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 7-9: Engineering Jobs

- Show students pictures related to engineering jobs connected to cranes.
- Crane Design Engineer
    - Designs and oversees the development of cranes, ensuring they meet safety and performance standards.

- This role is critical in creating cranes that can efficiently lift and move heavy payloads while maintaining structural integrity.

> Mechanical Engineer
  - Specializes in the mechanical systems of cranes, including the motors, gears, and hydraulics that allow the crane to move and lift payloads.
  - This role is responsible for ensuring the mechanical parts are designed for efficiency and durability

> Structural Engineer
  - Focuses on the structural components of crane systems, ensuring they can withstand various loads and stresses
  - This role is responsible for ensuring the mechanical parts are designed for efficiency and durability

Slide 10: Engineering Design

> Ask students the question. Who can be an engineer?
  - Anyone!

Slide 11: 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; there are 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

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	to do to improve the score. Remember, there are no correct answers in engineering, just better solutions.
IDENTIFY	**Slide 12-13: 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 crane to move a payload. **Slide 14: 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 how we will know if we are successful engineers today. ▪ A successfully designed crane will do the following: ▪ Lift the payload at least 8 inches off the ground ▪ Move the payload without dropping or damaging it ▪ Demonstrate stability without tipping or collapsing ▪ Place payload accurately within a marked area Bonus points will be awarded if the crane can lift a heavier payload or function effectively during high winds for 5 seconds (fan speed set to high). • *Teacher's note: Let students see and/or feel fan speed se to high.* **Slide 15-16: Identify** - Constraints (Limitations) > Ask students what constraints or limitations mean. ▪ Explain to students those constraints are rules the engineers must follow. > Explain the constraints for this engineering design activity are: ▪ <u>Time Limit</u>: Students will have 30 minutes to build the crane. ▪ <u>Materials</u>: Students can only use the materials available. ▪ <u>Budget</u>: Students will have $100 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 30-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 and the teacher should assist the team with their score. If the team receives a low score on any part of the design, the team should redesign if they still have time.*
IMAGINE	**Slide 17: Identify** - Explore Materials > Students will be presented with the materials needed to create a crane. The teacher or facilitator will hold up a working example of a crane mechanism. **Slide 18: Imagine** - Brainstorm > Give students one minute to individually design and draw a plan of what they think their crane 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 19: 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. > Ask students again what the design criteria are: ▪ A successfully designed crane will do the following: ▪ Lift the payload at least 8 inches off the ground ▪ Move the payload without dropping or damaging it ▪ Demonstrate stability without tipping or collapsing ▪ Place payload accurately within a marked area Bonus points will be awarded if the crane can lift a heavier payload or function effectively during high winds for 5 seconds (fan speed set to high).

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	> Students will need to select the materials to be used for the design and develop a budget for the project. Students will have $100 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 if they want to but remind them that they will lose points on their scorecard. **Slide 20: Plan –** Team Member Responsibilities Each team member must be given responsibility, such as materials manager, banker, head engineer, and quality control manager.
CREATE	**Slide 21: Create** - Design Your Crane > 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 22: Identify** – Criteria > Display the reminder slide for students to look at while working. **Slide 23-24: Create** - Test > Teachers will test students' cranes by setting up a designated testing station equipped with necessary tools and materials. Each team will have one member operate the crane to lift a payload at least 8 inches off the ground and move it horizontally to a marked area, ensuring the payload is set down accurately without damage. The crane's stability will be observed to ensure it does not tip or collapse during operation. Precision will be tested by placing the payload within the marked area without touching the borders. Additionally, for the bonus challenge, cranes will be tested for their ability to lift a heavier payload and operate effectively under simulated high winds conditions using a fan. > Students will calculate their scores when testing in front of the teacher or facilitator. 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 or facilitator 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.

IMPROVE	**Slide 25: Improve** - Redesign: Discussion > Students will reflect on their score and discuss: ▪ What worked? ▪ *Teacher's Note: Focus in on the materials being used and ask why they think those materials were helpful. Ask students what specific materials contributed to the success of their crane design and how their design choices helped achieve their goals. Ask students if they can identify any techniques or strategies that were effective.* ▪ What did not work? ▪ *Teacher's Note: Focus in on the materials being used and ask why they think those materials did not work as well. Ask students what materials or design choices proved to be less effective, and why. Ask if what challenges they faced with the stability or movement of their crane. Ask how they handled any setbacks or failures during the design process and if they could redesign their crane, what changes would they make to improve its performance.* ▪ What do you want to improve? ▪ *Teacher's Note: Focus in on engineering aspects with students. Ask students why they were designing a crane. 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 if they would design their crane 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.*