NEXT ENGINEERS

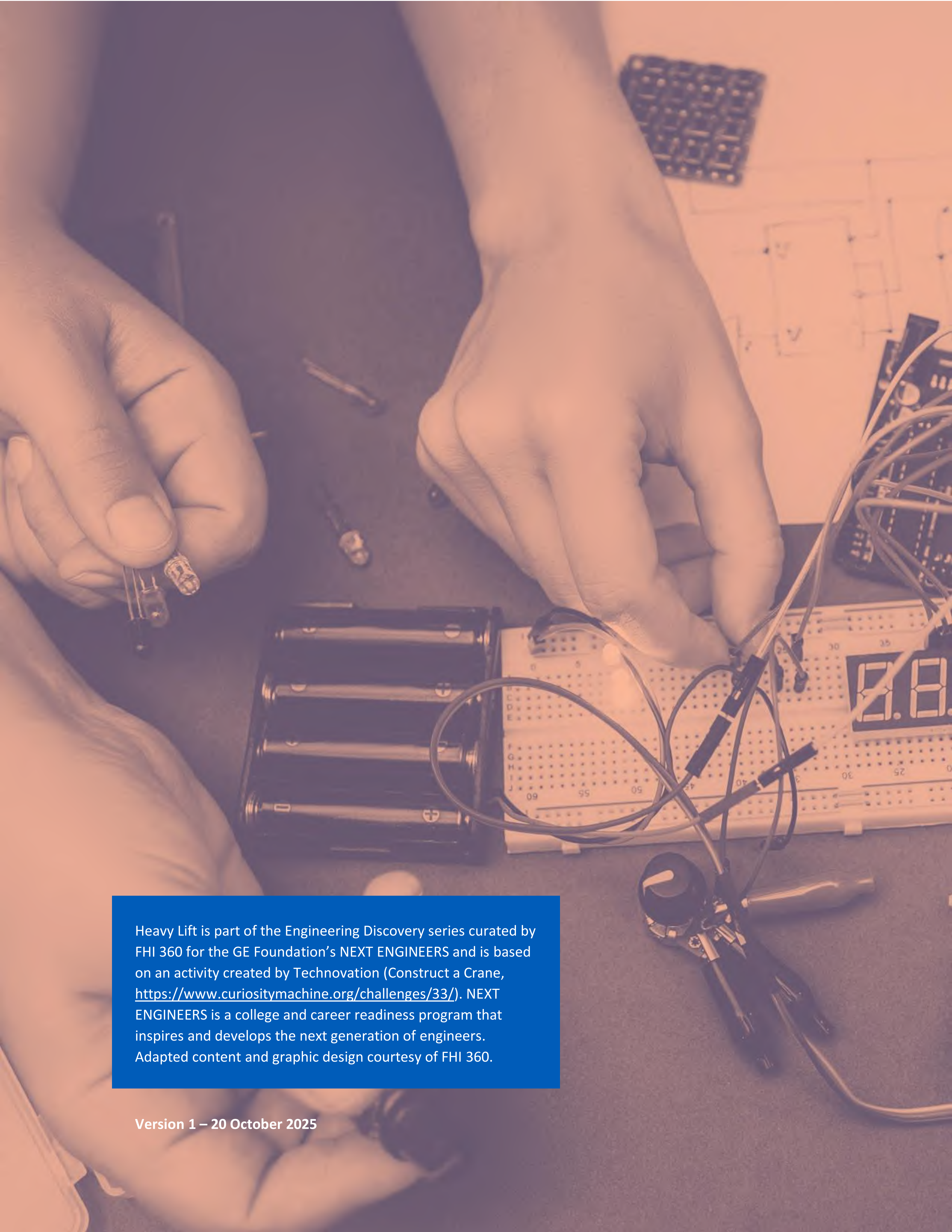
ENGINEERING DISCOVERY

Difficulty Level 1

Heavy Lift

Construction Engineering
Mechanical Engineering

NEXT ENGINEERS



Heavy Lift is part of the Engineering Discovery series curated by FHI 360 for the GE Foundation’s NEXT ENGINEERS and is based on an activity created by Technovation (Construct a Crane, https://www.curiositymachine.org/challenges/33/). NEXT ENGINEERS is a college and career readiness program that inspires and develops the next generation of engineers. Adapted content and graphic design courtesy of FHI 360.

Version 1 – 20 October 2025

Heavy Lift

HANDS-ON ACTIVITY

Time	Ages	Cost	Group size (teams)	Activity type
85 minutes	11 - 18	Low	3 - 4 students	Hands-on Activity
Engineering Areas				
• Construction Engineering • Structural Engineering		Mechanical Engineering		

Activity Introduction

Have you ever seen a giant crane lifting steel beams at a construction site (the mechanical ones, not the long-legged birds)? Or a tower crane standing tall above a new skyscraper being built? Cranes are amazing machines that help us lift and move heavy objects that would be impossible on our own. They do this using ropes, cables, pulleys, and levers. Some cranes are fixed to the ground, like those on building sites, while others are mounted on trucks or even on the decks of ships. Besides building sites, factories and docks, cranes are also sometimes used in emergency situations, to move debris, or rescue people.

Without cranes, we wouldn't be able to construct most of our buildings, assemble large structures, or transport heavy materials efficiently. They help us do jobs that are simply too big for humans to do alone. Engineers use cranes to solve big problems - literally!

In this challenge, students take on the role of construction engineers to design, build, and test a simple crane or hoist using everyday materials able to lift the greatest load possible before breaking, buckling, or toppling over.

About the Engineering Design Challenge

Students work as teams of engineers to design, build, and test a simple crane or hoist using everyday materials able to lift the maximum mass possible before it falls over or breaks. Students will explore the principles of balance, structure and strength, and mechanical advantage. The crane that lifts the most mass the requisite height will be crowned the champion.

Success Criteria

- The crane must lift the heaviest load possible before failure.
- The load must be lifted at least 20 cm (8 in) off the ground (as measured from its bottom).
- The lifting system must be operated using a winch that teams turn to lift and lower the load.

STUDENT DISCOVERIES

Students will:

- Know more about engineering and engineering careers
- Learn about the Engineering Design Process
- Participate in a team-based learning experience
- Learn about stability and structural strength
- Learn about mechanical advantage
- Have fun experiencing engineering

- The winch mechanism must be able to lock in place so the lifted load can remain suspended unaided and unsupported.

Constraints

- Teams may only use the materials provided.
- Teams must complete the activity within the time allocated.
- No part of the crane or hoist may be permanently stuck or glued to the table, floor, or walls.

Materials

Students will need blank paper and pens/pencils to design their cranes.

The following materials will be required **per team of 3 – 4 students**:

- Twelve to fourteen wooden skewers (about 30 cm (12 in) long)
- Ten craft sticks
- Six plastic or paper cups
- About four rubber bands
- 2 m (6.5 ft) of string
- Two paper clips
- Four index cards
- An empty sewing spool
- An A4 or letter sized sheet of stiff cardboard (900 gsm or more)
- Two drinking straws
- Three or four nuts or bolts (like the ones the cranes may lift)
- A roll of masking or electrical tape
- Access to a glue gun and glue sticks (optional)
- A pair of scissors

For the **Pre-Challenge Exploration,** you will need pictures of different types of cranes – a tower crane, a crawler crane, a truck-mounted crane, and a bridge crane. You can either print these images to hand to groups, or project the images using a digital projector. See the **Activity Background** for more details on each of these kinds of cranes.

The following additional materials will be required to create the **official testing station**. Feel free to have multiple testing stations as required.

- A small paper cup fashioned with a strong string handle (the cup and handle should be no more than 10 cm (4 in) tall)
- A set of small objects of equal mass (e.g., marbles, nuts, or bolts)
- A measuring tape

Note: Take note of the following when performing the official test lifts:

- Ensure the bottom of the cup is at least 20 cm (8 in) off the ground for each lift.
- Teams must lower the cup back to the ground before loading another object. This will ensure that the crane undergoes a dynamic test at each lift mass.
- The last mass successfully lifted (and suspended in place) before failure will be that team's result.

KEY WORDS

- Constraints
- Criteria
- Engineering Design Process (EDP)
- Engineering Habits of Mind (EHM)
- Engineers
- Load
- Mechanical advantage
- Iteration
- Prototype
- Stability
- Winch

TOP TIP

When testing, you can allow teams to specify how many objects they want to start testing with and how many objects they would like added for each successive test.

Facilitation Principles

Working with Youth: Facilitation Tips
(https://www.nextengineers.org/resource/working-youth-facilitation-tips) is a handy summary of the key facilitation principles that volunteers need to keep in mind when demonstrating any activity with students.

Facilitator Preparation

1. Read the step-by-step instructions.
2. Collect the materials.
3. Practice doing the activity yourself to identify where students may struggle. Bring any cranes you may have created (even the ones that failed). You can demonstrate any successful cranes.
4. Plan when and how you will share your story and career journey in a relevant and personal way. Try to integrate your story into the activity as much as possible. You can find the following volunteer resources for how to tell your story on the Next Engineers website:
   a. ***I'm an Engineer! Storytelling Worksheet*** (https://www.nextengineers.org/resource/im-engineer-storytelling-worksheet)
   b. ***I Work with Great Engineers! Storytelling Worksheet*** (https://www.nextengineers.org/resource/i-work-great-engineers-storytelling-worksheet)
5. Practice asking and answering questions students may ask. See ***Frequently Asked Student Questions*** (https://www.nextengineers.org/resource/frequently-asked-student-questions).
6. Print out copies of the **Student Worksheet** (below) for each group.
7. Set up each group's materials and your test zipline(s) before the start of the activity

Step-by-Step Instructions

Time	Instructions	Materials
5 min	**Welcome & Introductions** • Welcome students to the activity and briefly introduce yourself, noting what kind of engineer you are. • Explain briefly how and why you became an engineer. • Ask students if any of them have ever seen a working crane at a construction site, at a factory, or at a shipping port. How big was it? What did it look like? What was it lifting and moving? • If possible, play the video called *Meet Big Carl – The world's biggest crane makes its first move* (1:15) to hook students with this extreme example.	Activity Background

TIPS FOR WORKING WITH STUDENTS

- **Be prepared** by practicing the activity beforehand. Being prepared is the best start to leading confidently and having fun.
- **Facilitate like an engineer** by reflecting during and after each session. What worked? What could be improved? How could you do things differently next time?
- **Teamwork is critical** in engineering so encourage it among students. Make sure no one dominates and everyone gets to play.
- **Give one instruction at a time** to keep a large group on task and doing what you need them to do.
- **Give regular time updates** to keep students on track.

TOP TIP

If you have a little more time, play the video called Big Carl: The Mega Crane That's Changing How the World Builds (12:02) (https://www.youtube.com/watch?v=KXHKqU4jnG4) as well.

	• Use the information in the **Activity Background** to tell the group more about the different kinds of cranes, how they work, and where they are used. If possible, play some of the other videos as well.	
7 min	**Pre-Challenge Exploration** • Ask the group to explain how they think cranes lift heavy things and stay upright and balanced. Have them think about some of the cranes they have seen in real life. • One example of how cranes stay stable is the tower crane. Show an image of a *tower crane* (either one referenced in the **Activity Background** or one you have found). Explain that tower cranes often have a counter-weight on the other side of the lifting arm. This helps to keep them stable while lifting heavy objects. They also often have a strong cable connected to the lifting arm that is able to take some of the load when it lifts objects. • Show an example of a *crawler crane,* which also makes use of counter-weights (although these are positioned low down behind the crane body, but function in the same way). Often, there is also a strong cable fixed between the crane body and the top of the lifting arm. Again, this provides support to the lifting arm as it takes some of the load when heavy objects are lifted. • Now, show an example of a *truck mounted crane* in operation where the “feet” or outriggers have been deployed. These feet widen the base of support for the whole crane and make it much harder for the crane to tip over. • Finally, show an example of a *bridge crane*. In this case explain that the lifting arm is supported at both ends by strong, sturdy supports. This is an inherently stable structure. • Demonstrate how the crane you built works and what features you included to make it strong and stable. What do students like about it? What do they think could be improved.	Any crane(s) you have constructed Images of different types of cranes

3 min	**Challenge Overview**
	
	• Explain to the group that their challenge will be to design and build their own crane able to lift the heaviest load possible up to the point of failure (it either breaks or falls over). Show them the cup and the marbles, nuts, or bolts that they will be lifting.
	• Explain that the success criteria are that:
	  ○ The crane must lift the heaviest load possible before failure.
	  ○ The load must be lifted at least 20 cm (8 in) off the ground (as measured from its bottom).
	  ○ The lifting system must be operated using a winch that they will turn to lift and lower the load.
	  ○ The winch mechanism must be able to lock in place so the lifted load can remain suspended unaided and unsupported. Note that this locking mechanism does not need to be automatic. It can be as simple as a rod inserted through a disk attached to the winch.
	• Explain that the constraints are that:
	  ○ Teams may only use the materials provided.
	  ○ Teams must complete the activity within the time allocated.
	  ○ No part of the crane or hoist may be stuck or glued to the table, floor, or walls.	

60 min	**Engineering Design Challenge**
	
	• Divide the group into teams and hand each team a copy of the **Student Worksheet** and the **Engineering Design Process Summary**.
	• Tell teams that they have 60 minutes in which to design, test, and re-design their crane and test it to failure.
	• As teams work, circulate around the room encouraging them and answering any questions they might have.
	• Have teams think about:
	  ○ How they can use their materials to create a crane that is as strong as possible.
	  ○ How they can design a crane that is as stable as possible, not falling over when lifting heavy loads.
	  ○ How they can create a winch that they can turn to lift and lower the load and that can locked in place.
	  ○ How they can make sure that their crane is able to lift the load to the required height.
		Building Materials
		
		Student Worksheet
		
		Engineering Design Process Summary

TIPS FOR MAKING CONNECTIONS

- **Give constructive feedback** to help students grow and improve.
- **Ask open-ended questions** to better understand what and how students are thinking.
- **Be respectful** by listening actively and responding openly and authentically. Give students your undivided attention and the respect you want them to give you.
- **Be honest** about what you know. Say if you don't know something. Encourage students to keep trying by sharing some of your own failures and the lessons you learned.

	• Encourage teams to plan their cranes on paper first and also to test their prototypes early and often. They have enough string to use it not just for the lifting system. • As teams are ready, allow them to test their cranes.	
10 min	**Reflection and Closing** • Give teams about five minutes to discuss the reflection questions in the **Student Worksheet**. • After this time, bring the group back together to discuss their answers, paying particular attention to what students learned about engineering and the engineering design process.	Student Worksheet

Extension

This activity can be extended or modified in the following ways:

- Require that cranes be able to swivel through an angle between 45^0 and 180^0.
- Increase the minimum lift height.
- Impose a minimum load to be lifted.
- Include resources like paper towel rolls.
- Require teams to construct with paper or light cardboard

Key Words

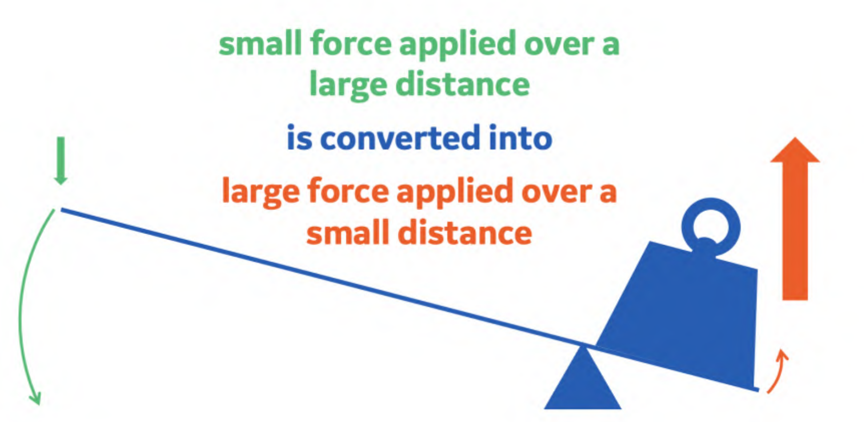
- **Load**: In terms of cranes, this is the mass or the object that the crane is designed to lift, lower, and move.
- **Mechanical advantage**: A measure of how much a machine multiplies the input force or the input distance/speed. Mechanical advantage is defined as the ratio of output force to input force.
- **Stability**: The ability of an object to maintain its balance even when lateral (sideways) or angular (twisting) forces are applied to it.
- **Winch**: A rotating drum (the spool) and a rope or cable to apply tension and pull or lift a load.

- **Constraints:** Limitations of materials, time, budget, size of team, etc.
- **Criteria:** Conditions that the design must satisfy to be considered successful.
- **Engineering Design Process (EDP):** The iterative process of researching, designing, prototyping, and testing engineers use to solve problems and design solutions.
- **Engineering Habits of Mind (EHM):** Six unique ways that engineers think.
- **Engineers:** Inventors and problem-solvers of the world. Twenty-five major specialties are recognized in engineering (have a look at the infographic at https://tryengineering.org/wp-content/uploads/18-EA-381-InfographicEngineering_R2-6.pdf).
- **Iteration:** The process of repeated design, testing, and redesign.
- **Prototype:** A working model of the solution to be tested.

Activity Background

Cranes are everywhere. They are indispensable machines. Modern cranes have revolutionized construction, manufacturing, and transportation by enabling us to lift and move some extremely heavy materials with remarkable precision and safety. These are tasks that would be impossible with human strength alone.

In essence, cranes are machines designed to lift, lower, and move heavy loads through the use of various components such as levers, pulleys, cables, and hydraulics. They work by converting a relatively small force applied quickly or over a large distance into relatively large force applied slowly or over a short distance. What you gain in force, you lose in speed or distance (or both). A simple lever is a great example.



We call these changes in force and distance **mechanical advantage** and measure it as the ratio of the output force to the input force. Machines that increase the output force have a mechanical advantage greater than 1 and are called **force multipliers**. Machines that decrease the output force have a mechanical advantage between 0 and 1 and are called **distance multipliers** (they trade a reduction in force for an increase in distance or speed).

Besides trying to achieve large mechanical advantage, cranes also need to be strong, well-balanced, and stable. Cranes often use counterweights and/or have wide bases to balance the load and prevent tipping.

Image of a crane cockpit is in the public domain https://stockcake.com/i/crane-control-room_202415_36504

Crane operators use joysticks, levers, and computerized systems to maneuver the crane with accuracy and precision. Cranes can be powered by electric motors, diesel engines, or hydraulic systems, depending on their design and application.

Cranes are vital parts of various industries including:

- **Construction** for the erection of buildings, bridges, and other essential infrastructure.
- **Manufacturing** for moving heavy materials and equipment within factories.
- **Shipping and logistics** for loading and unloading cargo at ports and stations.
- **Emergency services** for assisting in disaster relief by removing debris and rescuing trapped individuals.

There are almost as many different types of cranes as there are places where cranes are used. They come in various forms—each tailored to specific tasks and environments but can be broadly categorized into mobile and static cranes.

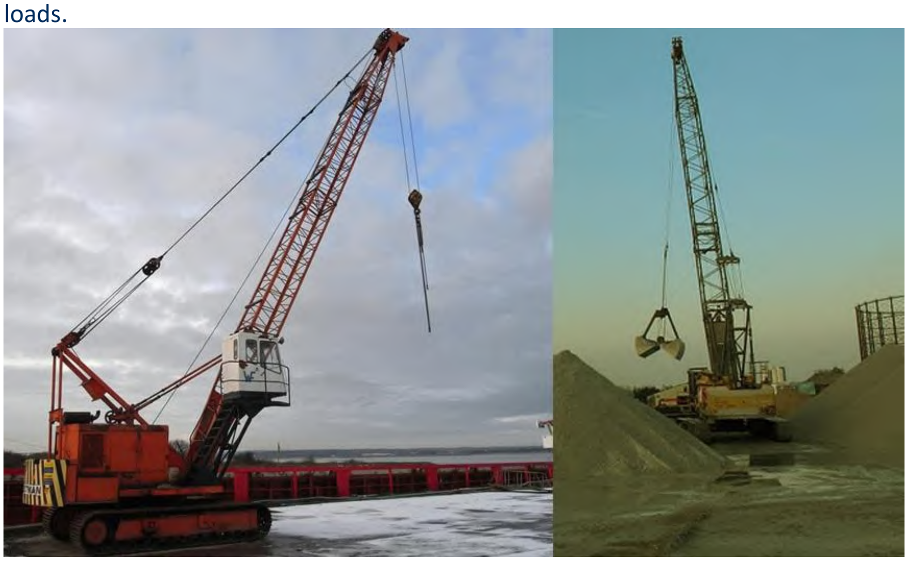
Mobile Cranes

These cranes are mounted on wheels or tracks and offer mobility and flexibility and include:

- **Truck-mounted cranes** that are easy to transport and set up, making them ideal for short-term construction projects and that increase their stability with the use of external legs or outriggers.

Truck mounted crane https://www.liebherr.com/en-us/mobile-and-crawler-cranes/mobile-cranes/ltf-truck-mounted-cranes/ltf-information-4407369

- **Crawler cranes** that are equipped with tracks (like a tank) instead of wheels offer greater stability on soft or uneven ground and can lift extremely heavy loads.



Crawler cranes https://www.mazzellacompanies.com/learning-center/what-are-the-different-types-of-cranes-used-for-construction/

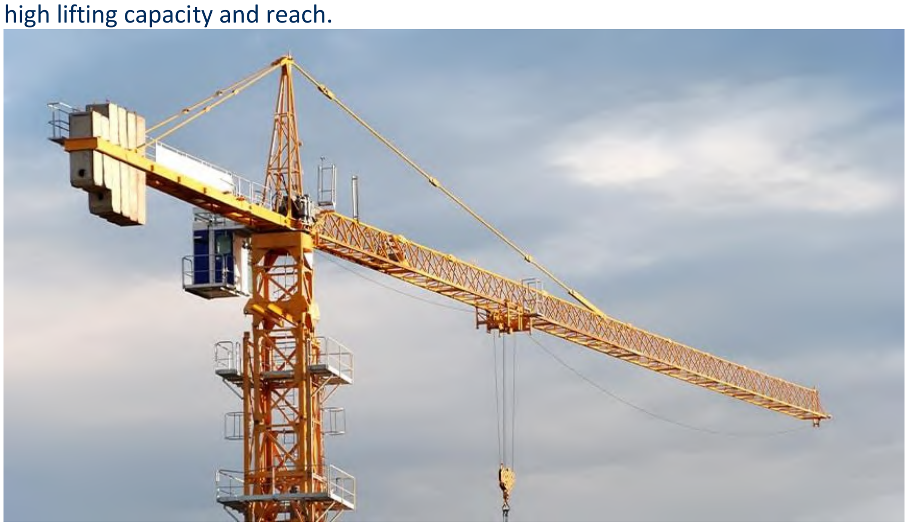
- **Rough terrain cranes** with large tires designed for off-road applications and other rugged environments.
- **Carry deck cranes** that are compact and highly maneuverable to lift and move objects in confined spaces.

If you are a nerd like me, you will enjoy watching *Inside Liebherr: Creating the Largest Mobile Cranes in the World* (52:31) (https://www.youtube.com/watch?v=fxm9NCe4anc).

Static Cranes

As the name suggests, these are installed in one place for longer periods of time, are usually used for long-term projects requiring very heavy lifting, and include:

- **Tower cranes**, commonly seen at the construction sites of tall buildings, offer high lifting capacity and reach.



Tower crane
https://www.mazzellacompanies.com/learning-center/what-are-the-different-types-of-cranes-used-for-construction/

- **Overhead or bridge cranes** installed in factories and warehouses that move along fixed tracks to transport heavy items across large areas.

Bridge crane
https://www.mazzellacompanies.com/learning-center/what-are-the-different-types-of-cranes-used-for-construction/

- **Gantry cranes** (similar to overhead cranes but supported by freestanding legs) that are often used in shipyards and outdoor manufacturing areas.
- **Floating cranes** that are mounted on barges, and used for construction projects over water, like bridge and port construction.
- **Aerial cranes** or helicopter cranes that are used to lift loads in hard-to-reach areas, such as mountain tops or dense forests.

Here are some additional resources about the different types of cranes and their specific applications:

- ***The Ultimate Guide to Understanding Different Types of Cranes*** (3:09) https://www.youtube.com/watch?v=a_aObnLgtGE)
- ***11 Types of Cranes Commonly Used in Construction*** https://www.bigrentz.com/blog/types-of-cranes
- ***What are the Different Types of Cranes Used for Construction?*** https://www.mazzellacompanies.com/learning-center/what-are-the-different-types-of-cranes-used-for-construction/

The world's biggest crane (able to lift the greatest mass) is Big Carl. It is able to lift a maximum of 5,000 t (11.2 million lbs) or about 30 Boeing 747s. More impressive is that its ton-meter rating is 250,000 ton-meters. This means that even if the load is positioned 100 m from its base, it can still lift 2,500 t. Watch *Meet Big Carl – The world's biggest crane makes its first move* (1:15) (https://www.youtube.com/watch?v=7ZalMDc9UWk)

Image of Big Carl is used under fair use https://worldsteel.org/media/steel-stories/construction-building/worlds-biggest-crane-big-carl-is-steel-built-behemoth/

While cranes may seem like modern marvels, humans have been using simple machines to lift heavy things for thousands of years. Some of the earliest known cranes were used in ancient Greece. They were human or animal powered and made of wood and were used to build the Greek temples and other large stone structures. Some of these cranes were called treadwheel cranes because the people or animals powering them walked inside giant hamster wheels.

The Romans took cranes to new heights (sorry!). Roman engineers designed larger and more sophisticated cranes that made use of compound pulleys to increase the mechanical advantage provided, and tripods to increase stability. It is estimated that some of these cranes could lift up to 6,000 kg (13,000 lbs) and were used to build aqueducts, amphitheaters (including the Colosseum), and other monuments still standing today.

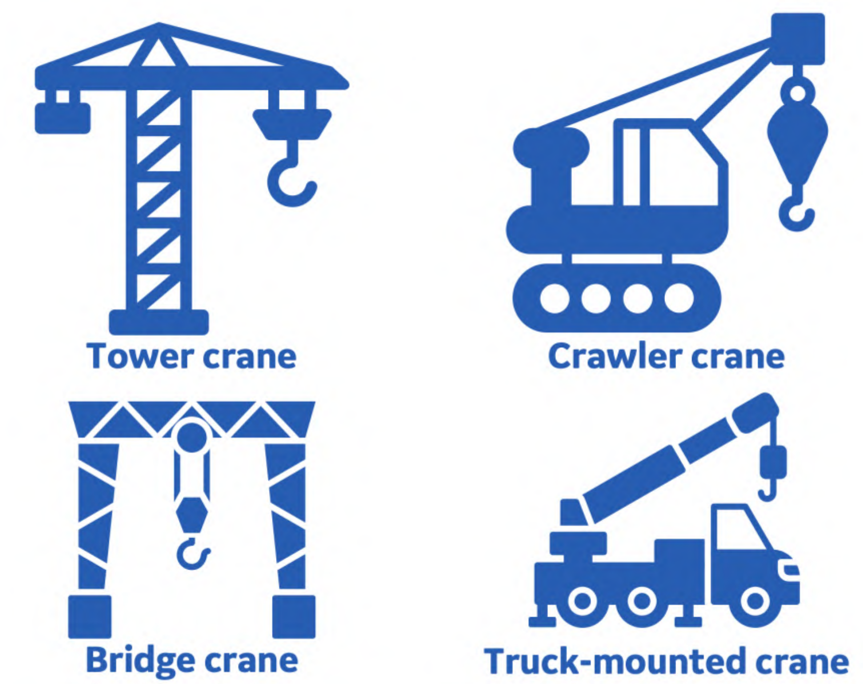
Image of a reconstructed Roman crane is used under fair use https://imperiumromanum.pl/en/curiosities/reconstructed-roman-crane/

Cranes continued to advance throughout the middle ages, but things really changed during the Industrial Revolution with the application of steam power and iron construction that allowed ever greater loads to be lifted and cranes to be operated for longer. This is also when cranes first become mobile, sometimes being mounted on rail cars.

In the 20th century, crane technology soared (sorry again!) and made the building of skyscrapers possible. Today, cranes can be extremely large, complicated and sophisticated machines packed with sensors, remote controls, and computers and able to stand taller and lift heavier loads.

In this challenge, students will not need to worry about mechanical advantage. Of course, they are welcome to design a crane with a pulley system that increases the mechanical advantage, but this is not essential to meeting the success criteria. Instead, teams will need to focus on strength and stability; building a crane that is physically strong enough to lift up a mass while also being well balanced and stable. Four basic design options are recommended as illustrated by the tower, crawler, bridge, and truck-mounted cranes.

- A tower crane design with a counterbalanced lifting arm and supporting cables
- A crawler crane design with a low, heavy center of gravity and cables supporting the lifting arm
- A bridge crane design with a lifting arm supported at both ends
- A truck-mounted crane design with outriggers that create a wider base
- Or a combination of any/all of these



Additional Resources

- ***Inside Liebherr: Creating the Largest Mobile Cranes in the World*** (52:31) https://www.youtube.com/watch?v=fxm9NCe4anc
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- ***11 Types of Cranes Commonly Used in Construction*** https://www.bigrentz.com/blog/types-of-cranes
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- ***Meet Big Carl – The world's biggest crane makes its first move*** (1:15) https://www.youtube.com/watch?v=7ZalMDc9UWk

References

This activity is based on **Construct a Crane** originally created by **Technovation Families** and available at https://www.curiositymachine.org/challenges/33/.

Visit the **Technovation Families** (https://www.curiositymachine.org) website for a host of other great engineering activities and resources.

Heavy Lift

STUDENT HANDOUT

Build a crane able to lift the greatest load possible before breaking or toppling over.

1 IDENTIFY AND DEFINE THE PROBLEM

Criteria

- Your crane must lift the greatest load possible before failing.
- It must lift the load at least 20 cm (8 in) off the ground.
- The lifting system must be operated with a winch.
- Your winch mechanism must be lockable so that you can suspend the load unaided and unsupported.

Constraints

- You can only use the materials provided.
- You must finish in the given time.
- No part of your crane can be glued to the table, floor, or walls.

2 GATHER INFORMATION

Materials

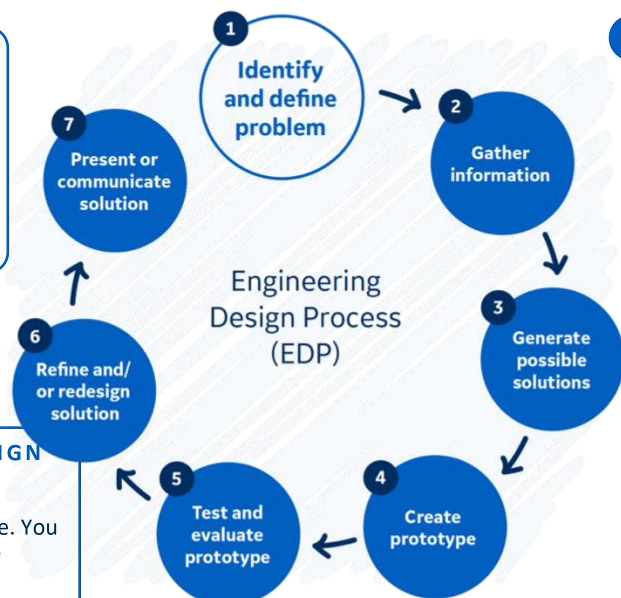
- Skewers, craft sticks, paper cups, drinking straws
- Rubber bands, string, paper clips, nuts/bolts
- Index cards, cardboard, tape, empty sewing spool
- Glue gun, scissors

? Ask yourself

- What kind of cranes have you seen before?
- How did these cranes work?
- How did they stay balanced while lifting heavy loads?

7 PRESENT OR COMMUNICATE THE SOLUTION

After 45 minutes, you must stop building and have your crane tested. What load can it lift before it breaks or topples over?



3 GENERATE POSSIBLE SOLUTIONS

Take 5 minutes to draw some possible crane designs. Share your ideas as a group, even the crazy ideas!

? Ask yourself

- What kind of crane will you design and build – tower, crawler, truck or bridge?
- Which of your materials are strong and/or stiff?
- Which of your materials could be used to help balance or support your crane?
- How big or tall does your crane need to be?
- How could you build a lockable winch to lift and lower the load?

6 5 TEST, EVALUATE AND REDESIGN YOUR PROTOTYPE

Keep testing and improving your crane. You can decide to completely change your design if you want to.

Let your facilitator know when you want to do an official load test.

? Ask yourself

- Is your crane stable without and with a load?
- Where is your crane weakest? How can you strengthen it?
- Can you lock your winch to suspend the load?
- What can you learn from other teams?

4 CREATE A PROTOTYPE

You have a total of about 40 minutes before you will need to do a final test. As you build, remember to test early and often. If an idea doesn't work, it is an opportunity to learn. Engineers learn by testing lots of different designs to see which ones work or work best.

Decide if you will build the whole crane together or if you will build different parts separately.

TEAM DISCUSSION AND REFLECTION

1. How similar was your original design to the actual crane you ended up building?
2. If you found you needed to make changes during the build phase, why did your team decide to make these changes?
3. What load was your crane able to lift before breaking or toppling over? Are there things you could have done to improve its design and performance?
4. Which crane that another team developed was the most effective or interesting to you? Why?
5. If you could have used one additional material, what would you choose and why?
6. Do you think that this activity was more rewarding to do as a team, or would you have preferred to work on it alone? Why?
7. What did you learn about engineering?
8. How do you think the activity relates to a career in engineering?

AT HOME

When you get home today, why not tell your family about the crane you designed? Tell them about how you worked in a team to design, build, and test your crane, how it worked, how well it performed and what you learned about engineering. Tell them about what you found easy and what you found most challenging or what you liked or did not like about the design challenge.

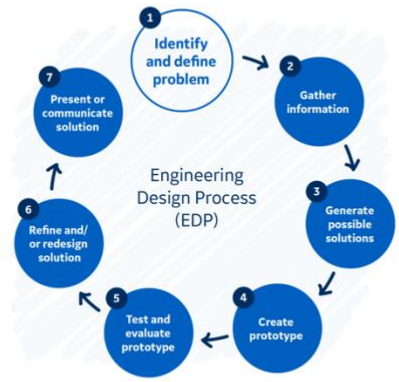
Discuss any ways you might like to change or add to the design challenge.

If you like, you can also discuss some of the reflection questions with your family.

The Engineering Design Process

STUDENT HANDOUT

The engineering design process (EDP[1]) is the key process engineers follow when they solve problems and design solutions.



1. Identify and define the problem

Engineers start by asking lots of questions. What problem must be solved? Who has the problem? What do we want to accomplish? What are the project requirements? What are the limitations? What is the goal? Through this process, engineers start to identify the **criteria** (the conditions the solution must satisfy to be considered successful) and the **constraints** (the limitations they need to design within).

2. Gather information

Engineers dig deep into the problem by collecting **information and data** about the problem and any existing solutions that might be adaptable. They talk to people from many different backgrounds and specialties to assist with this research.

3. Generate possible solutions

Now the fun really starts! Engineers start to **brainstorm** ideas and develop as many solutions as possible, sometimes even crazy ones. This is the time for wild ideas and deferred judgment. It is important to build on the ideas of others while staying focused on the core problem and keeping the criteria and constraints in mind. For example, if there is a budget, can the potential solution be developed within that budget?

4. Create a prototype

Engineers choose one or more of the most promising solutions to **prototype**. A prototype is a working model to be tested.

5. Test and evaluate the prototype

Most prototypes **fail**, but that is good. It tells engineers which ideas they should focus on. Engineers also need to decide if the design really does solve the original problem.

6. Refine and/or redesign the solution

After learning through testing, engineers **redesign and retest** until they have the best solution possible – one that balances the criteria and constraints.

7. Present or communicate the solution

Finally, engineers reach a point where they are satisfied with their solution. It does not need to be perfect, but it should '**satisfice**' - meet the criteria within the constraints. Engineers now communicate their solution to others.

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[1] Adapted from https://www.teachengineering.org/design/designprocess

Heavy Lift Volunteer Guide

This guide highlights some important information, questions, and principles to help you support teams in this challenge. Start by watching a video that explains some of the *Principles for Supporting Young Engineers* (9:40) and then *An Introduction to the Design Challenges* (6:08). You can also read about some general *facilitation tips* when working with youth.

The design challenge

Cranes are amazing machines that help us lift and transport heavy objects, construct most of our buildings, and assemble large structures that would be impossible otherwise. They do this using ropes, cables, pulleys, and levers. Some cranes are fixed to the ground, like those on building sites, while others are mounted on trucks or even on the decks of ships.

In this challenge, students take on the role of construction engineers to design, build, and test a simple crane or hoist using everyday materials able to lift the greatest load possible before breaking, buckling, or toppling over.

The criteria and constraints for this challenge are as follows:

- Success criteria
    - The crane must lift the heaviest load possible before failure.
    - The load must be lifted at least 20 cm (8 in) off the ground (as measured from its bottom).
    - The lifting system must be operated using a winch that teams turn to lift and lower the load.
    - The winch mechanism must be able to lock in place so the lifted load can remain suspended unaided and unsupported.
- Constraints
    - Teams may only use the materials provided.
    - Teams must complete the activity within the time allocated.
    - No part of the crane or hoist may be permanently stuck or glued to the table, floor, or walls.

FACILITATION NOTE

This challenge is customizable in terms of the required lift height, whether the crane needs to swivel or not, an imposed minimum load and the build resources that are available. Check with facilitator about the specific criteria and constraints.

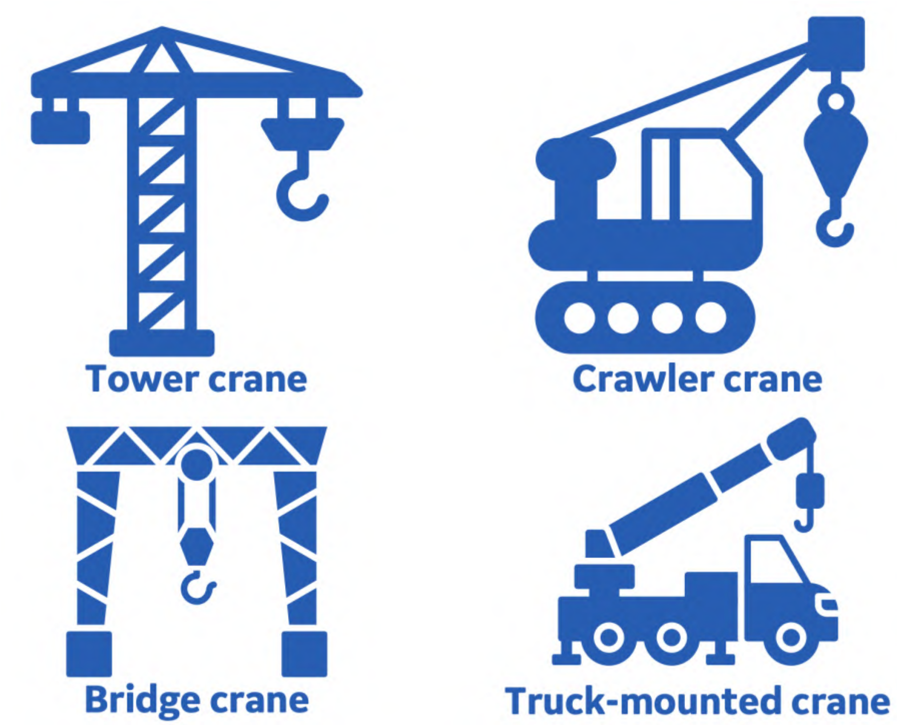
Possible design solutions

In this challenge, students don't need to worry about mechanical advantage. Of course, they are welcome to design a crane with a pulley system that increases the mechanical advantage, but this is not essential to meeting the success criteria. Instead, teams will need to focus on the strength and stability of their cranes. While introducing the challenge to students, you and the facilitator will describe four of the main types of crane design (see the main facilitator guide for examples of each type of crane).

FACILITATION NOTE

It can be a good idea to have teams think about the kinds of cranes they might have seen before, what they look like, how they work, and how they remain stable when lifting heavy loads.

- A tower crane design with a counterbalanced lifting arm and supporting cables
- A crawler crane design with a low, heavy center of gravity and cables supporting the lifting arm
- A bridge crane design with a lifting arm supported at both ends
- A truck-mounted crane design with outriggers that create a wider base



Other design tips include using the nuts and bolts to help counterbalance the lifting arm, using any extra string to help support the lifting arm, building the lifting arm as a truss, using the empty sewing spool as the basis of the winch, and using something like a paperclip or elastic band to lock the winch in place.

Key design questions

As teams start to design their cranes, encourage them to draw detailed sketches first. Drawing sketches first will help them share and think through their designs in more detail.

Some key questions to have teams think about include:

- What basic kind of crane do they want to build? What features of any or all of the basic crane designs might they use to build a crane that is strong and stable?
- How tall or big does their crane need to be to be able to lift the load 20 cm (8 in) off the ground?
- Which of their materials are stiff and strong – perfect for building a lifting arm?
- Which of their materials could be used to help counterbalance or support their lifting arm?
- How can they create a winch that allows them to lift and lower the load?
- How can they lock their winch in place so that the load can be suspended unsupported?

FACILITATION NOTE

Many teams are going to be tempted to jump straight into building. Encourage them to pause and think first and sketch and share some potential designs first, paying attention to the overall design of the crane and what materials will be used to construct each part.

As they think about the four basic crane designs and any real cranes they might have seen, have then consider what features they could borrow and combine to make the strongest and most stable crane.

Key testing questions

Encourage teams to test early and often. They don't need to wait to have a fully constructed crane before they can start subjecting it to tests. One of the first tests teams can do is hold their lifting arm at one end and test what load it can support at the other end.

It is very likely that teams will experience repeated failure. Remind them that failure is a necessary part of learning what works, and all great engineers fail all the time.

Here are some questions you can ask to steer teams through the testing and redesign phase:

- Is their crane big or tall enough to lift the load 20 cm (8 in) off the ground? How can it be made taller or the lifting arm made longer?
- Did their crane break or topple over?
  - If it broke, where did it fail? Which part, joint, or section was weakest. How can this part as well as the overall design be strengthened?
  - If it toppled over, how can it be better counter-balanced or supported when lifting heavier loads?
- Does the winch work to lift and lower the load, and does it lock in place?