

**T**he first known use of the term “robot” was by Czech playwright Karel Capek, who wrote a play in 1920 called R.U.R.: Rossum’s Universal Robots. Capek used the Czech word “robot,” which means “worker” or “laborer,” to describe the mechanical slaves portrayed in his play.

The first publicly displayed robots were “Elektro” and his trusty mechanical dog “Sparko,” who were highlighted at the 1939 World’s Fair in New York City. Elektro could dance and recite a handful of words, while Sparko would happily bark alongside him.

While robots were a mere curiosity in the late 1930s, they are an integral part of our daily lives today. Some robots are simple, such as the automatic sprinkler system in many people’s lawns. Others are more complex, such as the factory robots used to assemble cars or the robotic explorers NASA has sent to Mars.

Simple or complex, all robots obey the same principles and are designed using the same process. In this unit, students will learn what goes into a robot and the engineering design process used to create them.

## ROBOTS IN POPULAR CULTURE

Robots, and particularly intelligent robots, have long been a staple of science-fiction stories. Robots have been given a range of personalities, from the relentless destroyer of *The Terminator* to the loyal R2-D2 and C-3PO of *Star Wars*. In the 1940s and 1950s, Issac Asimov wrote the *I, Robot* series, which featured intelligent robots as main characters. Dr. Asimov created for his tales the “Three Laws of Robotics,” which all robots in his world were programmed to obey.

### Asimov’s Three Laws of Robotics

1. No robot shall ever harm a human, or through inaction allow a human to come to harm.
2. A robot shall always follow the orders of humans, unless those orders conflict with the first law.
3. A robot shall prevent itself from being harmed, unless doing so would conflict with the first two laws.

These laws conflicted in some surprisingly complex ways, which turned Asimov’s tales into wonderful

detective stories, as the protagonist tried to figure out how a robot’s seemingly bizarre behavior could be explained by the Three Laws of Robotics. These stories are still in print and would make an excellent cross-curricular introduction to the topic.



Electro and Sparko, 1939  
Image Courtesy of Michigan Humanities Council

## ROBOTS IN THE REAL WORLD

Unlike in science fiction, robots in the real world rarely resemble human beings. Walking, while learned naturally by every young child, is a surprisingly difficult skill. Robots, with their less-

than-precise sensors and motors, have a great deal more trouble mastering this task. Fortunately, robots rarely need to walk. Many robots never move from the location where they were installed!

Although research is underway to give robots artificial intelligence and “fuzzy logic” capabilities, most real robots do not have the intelligence displayed by the robots of films. In most cases, a high degree of intelligence isn’t a requirement for the task the robot must perform. Once taught the steps needed to carry out the job, the robot can simply perform those steps over and over, relying on its human controllers to step in when a problem arises.

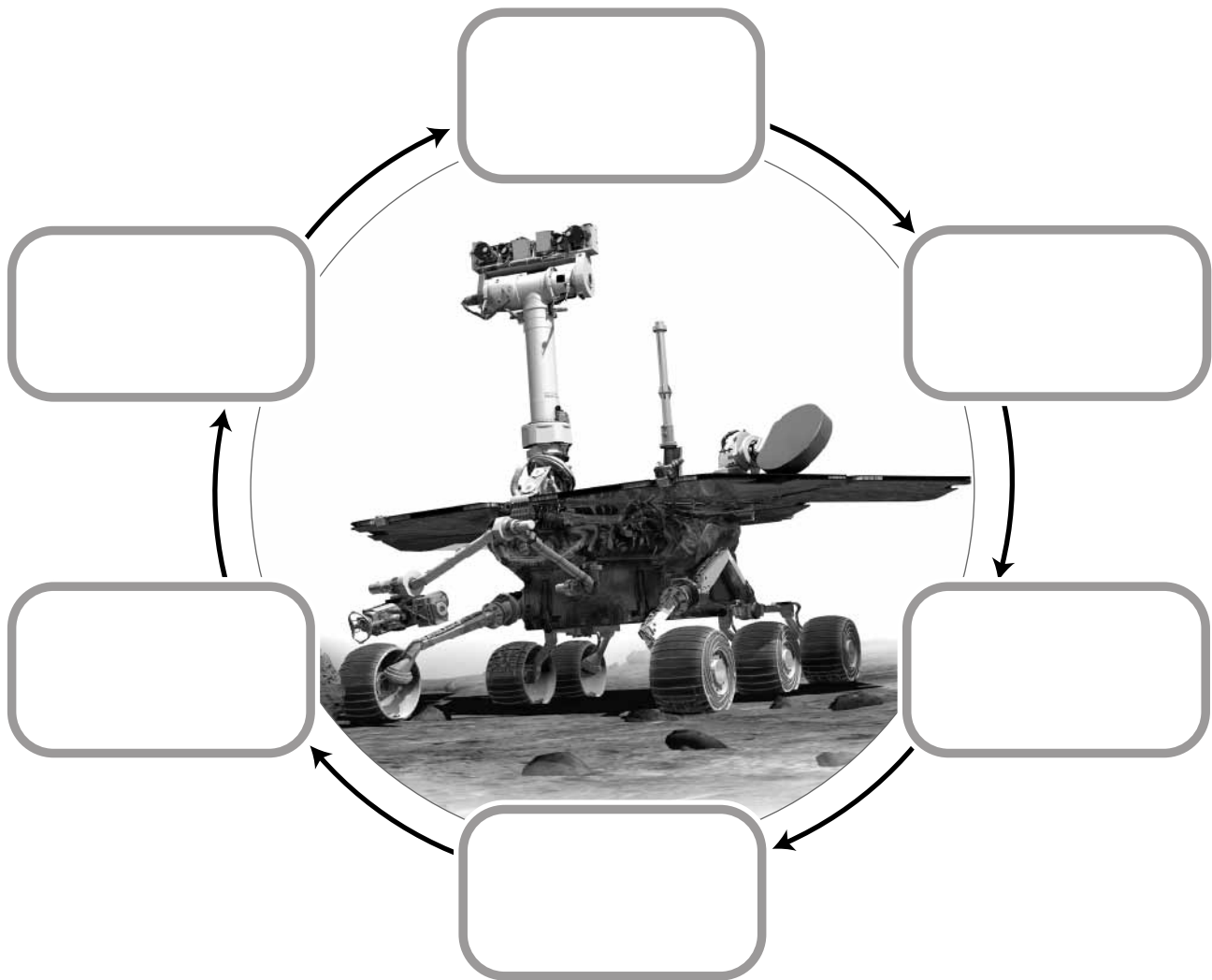
Some robots must operate in hazardous environments or in environments where humans cannot directly interact with them. In these cases, the robot must have much more decision-making power so that it can respond to its environment and to unforeseen circumstances. Classic examples of this case are NASA’s robotic explorers to Mars. Sending out a repair person simply isn’t an option when the machine is over a 100 million kilometers (~80 million miles) away!

# The Engineering Design Process



The engineering design process involves a lot more than assembling components into a final product, no matter if that product is a highway bridge, a robot-controlled assembly line, or a rover on the surface of Mars. Assembly is only a small part of the process and is

only done as the final stage. Engineers complete the design process long before they shape the first piece of steel. The design process involves the following steps, which ensure that the goals of the project are balanced with the constraints (limitations) placed on the design.



Rover image courtesy of NASA/JPL

When designing a robot, some engineers first consider the constraints that they will face. Others start with a clear statement of what the customer wants the robot to achieve. Other engineers start with an existing system and adapt or modify it to fit the current problem. No matter where the engineer begins in the design process, he or she must still address each aspect. It is very important for engineers to document every phase of the process so that when the time comes to begin construction, the engineer can be confident that the design will work to everyone's satisfaction.

In the activities that follow, students will be exposed to each phase in the design process as they design a robotic mission to the red planet. The activities have been written for students in grades 5-12, with extensions for students at each end of that range in each lesson plan. Additionally, each lesson contains extensions for teachers who have access to more "high-tech" materials such as commercial robotics kits. All of these activities have been designed to be flexible enough to fit your needs. Please feel free to modify and customize them as you see fit!



# Design For Success

The process of engineering design involves a lot more than simply building a device or a structure, which is only a small part of the overall process. The engineering design process is not a linear, step-by-step procedure; the steps repeat over and over until they converge in the “best” overall design.

**Activity #1** links your students to a fun activity called *Marsbound!*, which makes use of the popular “collectable card game” format. It allows your students to experience the engineering design process in a quick, readily accessible, but surprisingly deep way. Once they have learned to balance design goals against engineering

constraints, they will be ready to tackle an engineering problem of their own. Students should be encouraged to see the parallels in the trade-offs they made with *Marsbound!* and the trade-offs they must consider when constructing their first rudimentary robots.

**Activity #2** teaches students about the three general categories of robotic components. More importantly, they will learn to recognize these components in devices that they deal with every day. Not all robots are the intelligent automatons usually associated with the term. Your students may be surprised to realize that robots are all around them!

Get the full lesson plan at <http://mars.jpl.nasa.gov/classroom>

## ACTIVITY #1

### Marsbound!

#### Learning Goals

Students will learn the steps involved in the engineering design process by designing a robotic mission to Mars.

#### National Science Education Standards

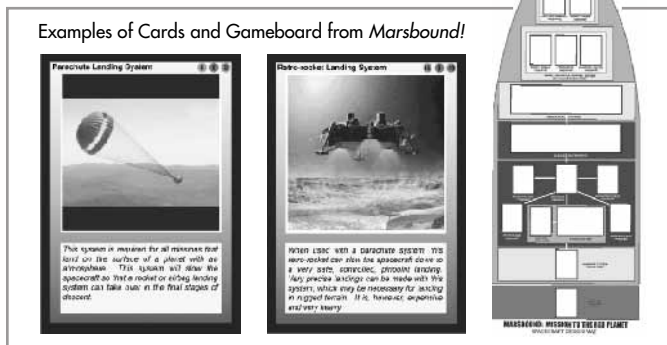
Content Standard E: Abilities of Technological Design

#### Overview

Students will use a set of “equipment cards” representing different systems that might be on a robotic mission to Mars. Each system has mass and power requirements, as well as a budget cost.

Students must ensure that their design has enough on-board power to drive all of its systems, a low-enough mass to launch with existing rocket boosters, and a low-enough cost to fit within their budget.

Examples of Cards and Gameboard from *Marsbound!*



See also the *Marsbound!* website at: <http://marsed.asu.edu>

## ACTIVITY #2

### Parts of a Robot

#### Learning Goals

Students will learn to identify the critical components that go into constructing a robot.

#### National Science Education Standards

Content Standard E: Understandings about Science and Technology

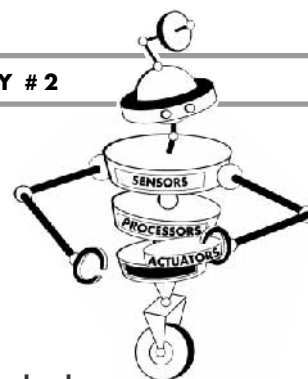
#### Overview

This activity introduces two of the three major components that go into every robot: sensors for determining its environment and actuators for affecting its environment.

Students will be presented with real-world robots and asked to identify which parts are sensors and which parts are actuators. This activity also exposes students to how robots are being used in our daily lives—they may be surprised to learn just how common robots really are!

Robots also have a third component: a processor that is able to take input from the sensors, make decisions based upon that input, and control its actuators to respond to those decisions. Some robots have processors that are not this complex—they can only perform a pre-determined set of instructions over and over. All robots, however, must have some sort of processor to control them.

Students can gain more experience with robot processors in Activity #8 (Rover Races).



# Test, Evaluation and, Revision



In the classic “egg drop” experiment, students typically construct a carrier out of various materials for their egg “passenger” with the goal (design requirement) of protecting it from harm during the drop. Students take their completed carriers to the top of a tall structure, let them drop to the ground, and hope they work. An engineer does not have the luxury of building a bridge and “hoping it works!”

In fact, before the first steel beam for a bridge has been fabricated, the engineer has done extensive tests with each subcomponent of the design and has data in hand that proves that the bridge will stand up. The real work in

the engineering design process is in performing these tests and gathering the data that will serve as proof that the design will work. The actual construction should always be somewhat assured, since the engineer is already confident in his design.

**Activity #3** introduces the concept of the test, evaluation, and revision process, while **Activity #4** allows students to put this process into practice in a variation of the “egg drop” experiment. As in real life, the “drop” is not where the real work takes place! Both of these activities, as with several other activities described on this poster, make excellent school-wide competitions!

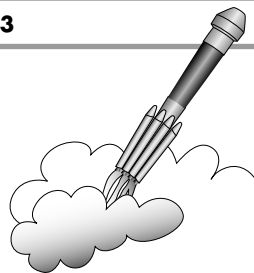
Get the full lesson plan at <http://mars.jpl.nasa.gov/classroom>

## ACTIVITY #3

### Launch: Out of This World

#### Learning Goals

Students conduct experiments to analyze the relationships between several engineering variables and extrapolate the values needed to hit a pre-determined target from their data.



#### National Science Education Standards

- Content Standard B: Motions and Forces
- Content Standard E: Abilities of Technological Design
- Content Standard E: Understandings About Science and Technology

#### Overview

Getting from Earth to Mars is not easy! Engineers must give a spacecraft enough energy to leave the Earth’s surface and the influence of Earth’s gravity. When the spacecraft arrives at Mars, more energy is needed to slow it down to land safely on the planet’s surface. They also have to make certain that the spacecraft manages to hit its target! Energy to lift the spacecraft to Mars and guidance to ensure the spacecraft arrives on target are the two biggest challenges in getting to Mars.

Students learn about the energy and guidance problems faced by NASA engineers every time they send a rocket into space. They design a rubber-band-powered launcher that propels a payload from a starting base to a pre-determined landing site. Students conduct extensive testing and revision of their launcher design to ensure the correct amount of energy for their payload and to keep it on course during its flight!

## ACTIVITY #4

### Entry, Descent, and Landing: Six Minutes of Terror

#### Learning Goals

Students apply their knowledge of the test, evaluation, and revision process to design a robot that can survive a simulated entry, descent, and landing on the martian surface.

#### National Science Education Standards

- Content Standard E: Abilities of Technological Design

#### Overview

In a variation of the classic “egg drop” experiment, students will design a rover using craft sticks and cardboard that can survive a drop of approximately ten meters (~30 feet). Glue and transparent tape are the only other construction materials that can be used—no parachutes are allowed!

It should be stressed that students get only one chance to drop their rover. It must be sufficiently sound to survive the drop the first time. The real point, of course, is not whether or not the rover survives. The real question is: did the students devise a test, evaluation, and revision program that allowed them to demonstrate with absolute confidence that their rover WILL survive?

Before the drop attempt, students will be required to present their design and the data collected from their tests to convince listeners that their rover will, indeed, survive. The success of the drop itself should be a foregone conclusion!



NASA/JPL

# ROBOTS ON THE MOVE: Getting Around on Mars



**A**ctivity #3 (Launch) required students to perform tests of their launch system in order to hit a pre-determined target. The general term for this process is calibration, and it is important to all phases of robotic development. **Activity #5** formally introduces the concept of calibration as it applies to navigating on Mars. An accurate calibration of the rover's mobility system is absolutely critical for the rover to travel safely across the martian surface.

Understanding the concept of force is fundamental to physics and engineering—and therefore to robotics! At its most basic level, a robot is just a collection of

simple machines that have been organized to do a job. These simple machines essentially apply a force to an object to change its motion in some way, be it pushing, pulling, or lifting.

**Activity #6** gives students direct experience with forces and how they can change an object's motion. This activity formally introduces the first two of Newton's Laws of Motion, giving your students a first-hand, intuitive understanding of these principles as they apply them to the real-world problem of the Opportunity rover's descent into Endurance Crater.

Get the full lesson plan at <http://mars.jpl.nasa.gov/classroom>

## ACTIVITY #5

### Command and Control: Getting From Here to There

#### Learning Goals

Students will conduct experiments to analyze the relationships between several engineering variables and extrapolate from this data the values needed to navigate to a pre-determined destination.

#### National Science Education Standards

- Content Standard B: Motions and Forces
- Content Standard E: Abilities of Technological Design
- Content Standard E: Understandings About Science and Technology

#### Overview

Spacecraft on the surface of Mars have no way of directly determining where they are on the surface. There is no Global Positioning System at Mars! Engineers must know precisely how far and in what direction the rover has traveled from its starting point. To do it, they must know how far the rover will travel at a particular power level in a particular amount of time, as well as how much the rover deviates from a straight-line course in that same amount of time.

Students will perform a simple calibration of a toy car and use that calibration to navigate to a target point on the floor. They should begin to see that every system on the robot, from the robotic arm to the mobility system, needs to be calibrated. This calibration is performed in similar ways in every case.



## ACTIVITY #6

### Endurance! Descent Into Craters

#### Learning Goals

Students learn how an object's motion can be described by its position and velocity and how forces can cause a change in the object's motion.

#### National Science Education Standards

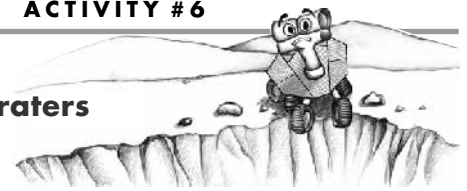
- Content Standard A: Use Mathematics in All Aspects of Scientific Inquiry
- Content Standard B: Forces and Motion

#### Overview

Working in groups, students will use small model cars to demonstrate how an object's motion can be described and how forces can change that motion.

Students will use inclined planes of varying angles to provide the initial force (gravity) to the cars. They will then use a stopwatch to measure how long the car takes to travel a distance of one meter. Dividing the distance by the time gives the straight-line velocity, also called speed. Students will compare the velocities of the cars resulting from several different angles of the inclined plane and will plot this data on a graph to make direct observation of the relationship between force and final velocity.

Because the cars begin from rest, this final velocity is related to the acceleration, leading directly to a demonstration of Newton's Second Law of Motion. Advanced students can use the data collected in this experiment to "discover" Newton's Second Law for themselves!



# A Robotic Revolution



**R**obots on Mars do not have a great deal of power available to them to use for their mission—in fact, some light fixtures in your house may use more power than a Mars rover! How, then, can a robot hope to lift heavy instruments or bring rocks into its on-board laboratories for analysis?

The robot is able to multiply the force it can apply to a task through the use of levers, pulleys, and other simple machines. These simple machines allow less force to be applied over a greater distance. **Activity #7** allows students to see that the work done is the same, but the force that must be applied is often dramatically less.

**Activity #8** introduces your students to robot programming. Getting the software (the robot's instructions) right requires test, evaluation, and revision just like the hardware of the robot does. This process is called "debugging," a term that many believe (incorrectly, as it turns out) was coined by Rear Admiral Grace Hopper early in the history of computers. In the 1940s, Admiral Hopper found a (slightly crisp) moth inside one of the huge computer mainframes at Harvard University. She removed the moth, taped it into her logbook, and jokingly penned the entry: "First actual case of bug being found." History will forever credit Admiral Hopper with the first true "debugging" of a computer system!

Get the full lesson plan at <http://mars.jpl.nasa.gov/classroom>

## ACTIVITY #7

### Robotic Arms

#### Learning Goals

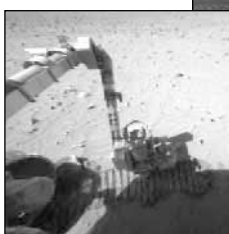
Students will learn how forces are applied in simple machines and how machines can decrease the force humans or robots must exert to perform a task.

#### National Science Education Standards

Content Standard B: Forces and Motion

#### Overview

How do engineers design robotic arms for rovers, and landers sent to Mars? How can a rover make best use of its very limited power supply to interact with the martian environment? Students will learn how machines make our lives easier by multiplying the amount of force applied to a task. Students will lift objects with a lever, using weights to measure how much force is being applied. The weight multiplied by the distance lifted is equal to the work. Students will directly experience mechanical advantage, the concept that, although the work done in moving the object is always the same, the amount of force required to move it can be drastically reduced using simple machines. This fundamental concept underlies all design principles that go into developing modern robots, both here on Earth and on Mars.



Spirit's rover arm extended towards martian soil



The 2007 Phoenix Mission will use a robotic arm to dig into the ice at the Martian north pole.

Images courtesy of NASA/JPL

## ACTIVITY #8

### Rover Races

#### Learning Goals

Students will apply their understanding of robotic programming to simulate a rover that must race other rovers across the martian surface.



#### National Science Education Standards

Content Standard E: Abilities of Technological Design

#### Overview

Teleoperation (controlling a robot from a distance) is no easy task. Rovers operating on other planets cannot be driven in a real-time "joystick mode" because the time required for a signal to travel from the Earth to another planet is so long. The Mars Exploration Rovers have quite a bit more capability to operate independently, but they still fundamentally rely on command sets that have been created on Earth and uploaded to them.

Students will program a human "rover" to navigate safely across a simulated martian landscape, retrieve a "Mars rock," and return it safely to its "lander." All commands will be pre-written on a set of index cards.

The Mars Exploration Rovers are not operating alone. Two orbiting spacecraft, Mars Global Surveyor and Mars Odyssey, are continually providing orbital surveillance and communications for the rover. Thus, student programmers will be allowed an "orbital view" of the terrain to be explored. From this view, they will write their programs and hand the stack of commands to the "processor," who will call off the commands in order. Students may soon realize that they need some way to "calibrate" their human rover!

# Mars Sample Return



**R**obots make excellent explorers in hostile environments such as Mars. But no robot, no matter how sophisticated, can make as careful and detailed an analysis of the red planet as a human can. Someday, humans will travel to Mars and will be able to study the rocks they find there. Until that time, however, scientists studying Mars would like to do the next best thing: bring a sample of Mars back to Earth for study.

In the other activities, your students have designed a mission, launched a spacecraft, and designed a system to get that spacecraft safely to the surface of Mars. In these two activities, students will investigate two important tasks necessary for any successful sample-return mission:

bringing the sample on-board the spacecraft and designing a launch platform capable of supporting the sample-return rocket and its precious cargo.

**Activity #9** introduces the concept of power as students design a machine capable of extracting maximum power from a feeble wind in order to lift a rock from the surface to the height of a spacecraft. **Activity #10** challenges students to design a structure that can support the potential energy gained from lifting as heavy a rock as possible to the greatest height possible. Both challenges can be turned into a school or district-wide competition, bringing some excitement to your students' learning experience!

Get the full lesson plan at <http://mars.jpl.nasa.gov/classroom>

## ACTIVITY # 9

### Bringing Mars Home: Get It On Board!

#### Learning Goals

Students put their knowledge of the design process into practice by designing a wind-powered robot with the maximum power output (work divided by time).

#### National Science Education Standards

- Content Standard B: Forces and Motion
- Content Standard E: Abilities of Technological Design

#### Overview

Students are presented with a straightforward, but surprisingly complex, task: create a wind-powered machine that will produce the maximum power output possible. Power is defined as the work performed divided by the time required to perform it (work, as the students have learned in previous activities, is the force applied multiplied by the distance over which it is applied). Students can approach the problem from a number of different ways: some will want to lift a small weight very quickly; others will want to move a larger weight a bit more slowly. The distance in both cases will be fixed at the height of a hypothetical Mars sample return spacecraft. In the end, it is only the final number—the power—that will determine the winner!

Materials can be as common or as exotic as desired. Remember, the only source of energy for the Mars sample lifter is a small box fan. The lifter can easily be constructed out of household materials such as wooden dowels and string, but adding pulleys and gears can make it even more of a challenge!



## ACTIVITY # 10

### Bringing Mars Home: Launch Platform

#### Learning Goals

Students learn how the test, evaluation, and revision process ensures that a finished design will meet its design goals and engineering constraints.



#### National Science Education Standards

- Content Standard E: Abilities of Technological Design

#### Overview

Students gain even more experience with the test, evaluation, and revision process critical to good engineering design. With craft sticks, students work to build a launch platform that can support the greatest weight at the greatest height—in other words, the maximum potential energy. Students are encouraged to try different forms of structural units (cross beams, suspensions, triangles or other geometric shapes, etc.), testing each type to see which can support the most weight.

It is important that students get multiple opportunities to experiment with different designs. To reinforce the idea of testing small sub-systems instead of finished designs, students should be encouraged to test only small, representative portions of a given type of structure. For example, students can explore how much weight a single triangular structural unit can support and compare that to a single structural unit of another type before constructing an entire platform for testing. The goal is for students to experience the iterative nature of the engineering design process. They should feel free to refine their design to increase its performance!





