JV InvenTeams™ - Pump It Up

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Welcome to JV InvenTeams, where students develop skills in science, technology, engineering, and math (STEM) through fun, invention-based design activities and challenges.

ABOUT LEMELSON-MIT
The Lemelson-MIT Program ([https://lemelson.mit.edu](https://lemelson.mit.edu)) is dedicated to honoring those who have helped improve our lives through invention. The Program was established in 1994 at the Massachusetts Institute of Technology (MIT), by one of the world’s most prolific inventors, Jerome Lemelson (1923-1997), and his wife, Dorothy. It is funded by The Lemelson Foundation and administered by MIT’s School of Engineering. The Lemelson-MIT Program recognizes outstanding inventors, encourages sustainable new solutions to real-world problems, and enables and inspires young people to pursue creative lives and careers through invention.

The Lemelson-MIT Program encourages great inventors through various outreach programs such as InvenTeams ([https://lemelson.mit.edu/inventeams](https://lemelson.mit.edu/inventeams)), a national grants initiative for inventive high school students who have a strong foundation in scientific and technical skills. InvenTeams are teams of high school students, teachers, and mentors that receive grants of up to $10,000 to invent technological solutions to real-world problems. The Lemelson-MIT Program developed JV InvenTeams in order to reach slightly younger high school students and provide them an introduction to inventive thinking and doing.

About JV InvenTeams
The goal of JV InvenTeams is to cultivate new ways of thinking and develop technical skills for students with limited access to hands-on STEM enrichment opportunities. Through prescribed activities, students will add to their own “toolkits” of minds-on knowledge and hands-on skills while having fun!

Students will learn how to identify a need in their lives or in the world around them and to develop their own invention after completing the main activity in each unit. They will pull from their expanding toolkit to come up with solutions.
JV INVENTEAM ACTIVITY GUIDE COMPONENTS

Each unit of JV InvenTeams activities is presented in the same format. The Educator Guide includes specific notes and segments, while the student version is more streamlined and includes working space for the students. The educator may decide how much of the information should be shared with the students and in what manner – e.g., read out loud or individually. Each meeting within the unit is estimated to take between 1.5 and 2 hours to complete.

Each group of young people will be different, so the pace of each unit is up to the educator. Know that there are numerous resources to balance the unit to meet your needs. Some may find that breaking units into a couple of sessions will allow the think-time needed for your group. Others may want to streamline items and skip some of the videos.
Each unit has the following in the first pages:

▶ Title page with summary of the unit and learning objectives
▶ Summary of each meeting within the unit
▶ Master consumable materials and tools lists

Each meeting within the unit includes the following:

▶ “Toolkit” of hands-on and minds-on skills to be learned
▶ List of tools and materials
▶ Procedure
▶ Key terms
▶ Safety message(s)
▶ Video clips
▶ Instructions with step-by-step procedural notes
▶ Pop-outs that include any of the following: historical connections, Inventor/Invention Spotlights, related patents, Extend the Learning, High School Connections, and College Connections
▶ Indicators of a successful meeting
▶ Student Self-Assessments as exit slips

**INVENTOR’S TOOLKIT**

**HANDS-ON**
- General shop safety
- Recording temperature changes

**MINDS-ON**
- Evaporation
- Thermal conductors and insulators

**KEY TERMS**

**Cold (n):** The absence of heat energy; “coldness” is a subjective term that refers to people’s perception of low temperature, or low heat energy.

**Conduction (n):** The transfer of heat within an object or between objects in contact with each other.

**Convection (n):** The transfer of heat by the circulation or movement of the heated parts of a liquid or gas.

**SAFETY**

Wear protective gloves and safety glasses for this activity. Avoid breathing in the release agent spray. Use it in a well ventilated room or outdoors.

**INVENTOR SPOTLIGHT**

In 1902, mechanical engineer Willis Carrier patented the air conditioner, a device he originally invented to solve a problem facing a paper printing plant in Brooklyn, New York. Read more about his invention—and how the invention of air conditioning helped expand Southern cities such as Houston and Atlanta.
You may ask, “Why should I invent?” Here are some of the reasons you can share during the first meeting. Invention…

▶ solves world problems like finding clean sources of energy and treating unsafe water;
▶ helps people;
▶ allows people to explore a creative process that often involves teamwork;
▶ provides fulfilling careers: inventors are often scientists and engineers who improve areas of health, energy, food and transportation;
▶ can also lead to a high-paying career with many job opportunities as an engineer or scientist; and
▶ is fun!

**Group size**

JV InvenTeams is recommended for approximately 20 students in Grades 7, 8, 9 and 10. Most activities require students to work in teams of four.

**Partnerships**

The Lemelson-MIT Program encourages participating schools to seek community partnerships to sustain JV InvenTeams. Partnership opportunities include:

▶ Science and technology museums, to provide direct mentoring;
▶ Local technology and engineering companies, to provide funding for future extension ideas, materials, or mentors;
▶ Local universities or colleges, to provide collegiate mentors; and
▶ Hardware stores, to provide tools or materials.

**Flexibility**

JV InvenTeams has built flexibility into the program to meet the needs of educators, school systems, and grants-based clubs and organizations.

Following are some examples:

▶ Each unit is designed to stand on its own. Educators can lead one unit, a few units or all of the units.
▶ The program can be held in any educational setting with a science or technology educator facilitating the activities.
▶ Each unit has approximately 6 meetings of 1.5 - 2 hours’ duration.
▶ Meetings can take place multiple times a week or once a week.


**INVENTIVE THINKING**

Both educators and students will develop an understanding of the invention process as you navigate through JV InvenTeams. This new way of thinking, part of the minds-on toolkit, may take some time to adopt since learning within the school day increasingly focuses on standardized tests of academic knowledge. Invention is a variable, non-linear process. JV InvenTeams introduces the curiosity and creativity of recognizing problems and addressing them with novel solutions. You will not need to worry about knowing the “right” answer since there are countless possibilities. Experiencing failure is part of the invention process.

Inventing is creating something new that is useful or helpful, by means of one’s own investigation, experimentation, and thinking. An invention is the product of the inventing process. It can be a device, a material, a system, and even a plant. Invention refers to a new physical thing made possible by technology for the purposes of JV InvenTeams. Inventive thinking challenges what people come to expect or anticipate. Revolutionary inventions, known as macro-inventions, make a huge impact on the way we live. Examples include the internal-combustion engine for the automobile and the integrated circuit for consumer electronics. Most inventions are micro-inventions, or adaptations that grow from larger-scale inventions. This means making an existing product faster, stronger, cheaper, easier, safer, more efficient, or more useful.

**User-Centric**

The key to inventing is to make sure the invention is user-centric. This means that students need to think about and understand problems affecting real people and their specific needs. Researching the unique characteristics and needs of the user is essential to coming up with an effective design – as is working directly with them! Students will develop empathy for the beneficiary during the process.

An example of this would be a student noticing that his or her grandmother has difficulty moving around the house in her slippers, due to slippery floors.

The student should investigate by first asking his or her grandmother:

- Do you wish your slippers had a better grip?
- What parts of the slipper do you like? What parts would you change? Why?

After learning from the user, the student can further investigate.

Questions he or she might ask include the following:

- Does the solution lie in changing the floors or the footwear?
- How can I change her slippers to make the grip better?
- Is there another product on the market that provides the ease and comfort of slippers with the safety features of shoes with more grip?

These questions will inform research and allow the student to develop meaningful solutions.
**Deciding on a Good Problem to Solve**

Identifying a good problem to solve can be challenging, but it is just like any other skill: it becomes easier with practice. Therefore, at the beginning of each unit in JV InvenTeams, students will be given a problem or scenario that requires devising an original solution. Coming up with solutions to problems can be difficult at first, but students will gain confidence in generating new ideas over time. One way to accomplish this is through transgressive thinking – applying flexible or “out of the box” thinking in one area to another. The SCAMPER technique is a good technique to start with because it provides a framework to come up with solutions.

**SCAMPER**

The SCAMPER brainstorming technique was developed by Bob Eberle and published in a book by the same title. SCAMPER is based on the notion that something new can be modified from something that already exists. Each letter in the acronym represents a different way you can mentally view the characteristics of the challenge. It's a “mash-up” of disparate things to conceive something new.

- **S** = Substitute *(playing basketball with a softball)*
- **C** = Combine *(toothbrush combined with a pencil to create a new product)*
- **A** = Adapt *(how would you eat your spaghetti without a utensil?)*
- **M** = Magnify *(how would your chair function if its legs were wider and longer?)*
- **P** = Put to Other Uses *(could your fork be used as a comb?)*
- **E** = Eliminate *(could you play tennis without a racket?)*
- **R** = Rearrange *(what if the laces of a shoe were placed on the bottom and not the top?)*

The SCAMPER technique involves the students first stating the problem they would like to solve, which defines the challenge. Then it’s a matter of asking questions, using SCAMPER to guide the students. No idea is a “good” or “bad” idea at this point.

**DOCUMENTATION**

Students should be encouraged to document their progress along the way. This includes saving sketches, designs, research data, graphs, images, and early prototypes. Most of this work, with the exception of the actual prototypes, can be compiled in the student guides. Students should routinely review their guide, adapting what they have learned and experienced to new challenges.
PATENTS
Since this program is all about invention, it is important that educators and students familiarize themselves with the United States laws that protect the intellectual property of inventors.

A patent is one type of intellectual property that can be legally protected through the U.S. Patent and Trademark Office (USPTO). The other types of intellectual property are trademarks and copyrights. A trademark includes any word, name, or symbol used to distinguish one manufacturer from another (e.g., brand name). Copyrights are recorded with the U.S. Copyright Office in the Library of Congress for original authored works like books and music.

According to the U.S. Patent and Trademark Office, patents provide legal protection to inventors’ intellectual property by excluding others from profiting from their property in the U.S. for a specific amount of time, in exchange for the inventors’ disclosure of their idea according to the criteria for granting a patent. There are three different types of patents. Utility patents are granted to inventors who discover a new and useful process, machine, article of manufacture, or a new and useful improvement. Design patents are granted to those who invent a new, original, and ornamental design for an article of manufacture. Finally, a plant patent is granted to an inventor who invents a new variety of plant. The basic components of a U.S. patent are: patent number, title, inventors, assignee (optional transfer of intellectual property to a company or other individual), abstract (short overview of invention), drawings, description (technical details), and claims (legal information). To learn more about the patent process, visit: http://uspto.gov/.

Students will be required to search patents to ensure that their idea is unique. Patent searches can be done through Google Patents and Free Patents Online. Both have easier search functions than the U.S. Patent and Trademark Office.

Jerome Lemelson, founder of The Lemelson Foundation, had a productive life as an inventor, holding more than 600 patents. He was awarded his first patent in 1953 for a toy cap, and spent the next 45 years coming up with inventions that led to products such as bar code readers, automatic teller machines, cordless phones, cassette players, fax machines, machine vision, and personal computers.

It is important to keep in mind that not all inventions are patented. Some inventors purposefully do not seek a patent with the idea that their inventions are immediately and widely available. An example is open source software, which allows anyone to use the software without paying a fee.
This openness can spur further invention since anyone can access it and make adaptations. In spite of the changes in patent law through the Innovation Act of 2013, students should adopt the habit of recording and dating their work, including early sketches and research. This practice will be useful for future science exploration and invention. To learn more, visit: https://govtrack.us/congress/bills/113/hr3309.
This unit will guide you through a series of activities that prepare you to build a water pump operated by human energy.

The unit begins with an overview of the different types of power. You will read about renewable and non-renewable sources of energy and begin to think about the potential of human energy to power a device. You will begin to think about possible uses for a water pump powered by human energy that they will construct after calculating the force, work, and power the human body can generate. You will work in teams to choose a use for your pump and sketch a prototype of it.

Upi will learn about different types of pumps and their uses. You will have the opportunity to build a simple Archimedes screw pump and a prototype of a hydraulic pump while learning about hydraulics and Pascal’s principle. You will learn about check valves and pistons after you take apart a bicycle pump. You’ll use materials like PVC pipes to build and test check valves for your pump. Ultimately, you will assemble a water pump powered by human energy and customize it for your proposed use.

You will gain both minds-on and hands-on skills in this unit to expand your toolkit. The minds-on skills include learning about hydraulics, Pascal’s principle, simple machines, and the design process—identifying a problem, brainstorming, sketching ideas, building, and testing. Hands-on skills include learning to score and cut PVC, building a simple Archimedes screw pump, assembling a check valve, and assembling a water pump.

- Design Process
- Human Energy and Human Power
- Hydraulics
- Pumps
- Uses of Pumps
MEETING SYNOPSIS

1 Invention Introduction
Do warm-up activities and discuss invention. Play “Four Corners” to determine your strengths for team assignment.

2 What Is Human Energy and Power?
Learn about the different types of energy and, specifically, how human energy can be harnessed to accomplish many different goals. Learn also the physics and mathematics behind calculating power, work, and force. Your educator will introduce the main design challenge of the unit and you’ll begin to think about possible uses for your water pump powered by human energy.

3 Pumps and Hydraulics
Learn about different types of pumps and their potential uses. Build and test a simple Archimedes screw pump and a prototype of a hydraulic pump. Also, continue discussing potential uses for your water pump.

4 Pistons and Check Valves
Take apart a bicycle pump to see firsthand how it operates, and then begin to build your own water pump. Practice cutting PVC as you learn to build check valves.

5 Building a Pump
Assemble your water pump, test it, and re-sketch a design to customize your water pump for a particular use.

6 Invention Extension
Conceptualize a new purposeful invention that uses your new minds-on and hands-on skills from the Pump It Up! unit.
JV INVENTEAMS
GENERAL SHOP SAFETY RULES

Post these safety rules at the start of Meeting 1 and keep them posted throughout the unit.

• Wear safety glasses.
• If you are in doubt about how to use a tool, ask!
• Have a plan for what you are going to do with the tool.
• Be mindful of others who might enter into your workspace accidentally.
• Secure the workpiece.
• Have a balanced stance while using a tool.
• Remove all jewelry, watches, and loose clothing before working with machinery.
• Pin up long hair and wear closed-toe footwear.
• Never work when you are tired or unfocused.
• Leave the workspace cleaner than you found it.
**Procedure**

- Get Your JV InvenTeams Guide
- Introduction to Invention and Problem Solving
- Design a Cell Phone Stand
- Think About Your Invention
- Watch Invention Videos
- Research an Invention
- Discuss Improvements to an Invention
- Investigate Real-World Improvements
- Watch Videos about the Design Process
- Set Rules and Develop Teams
- Self-Assessment

**Your Guide**

1. You will use your JV InvenTeams guide as an invention guide. This guide will be a portfolio of your work and ideas.

2. The grid paper and blank paper at the end of each meeting can be used to sketch, brainstorm, and document ideas.

**INTRODUCTION TO INVENTION AND PROBLEM SOLVING**

1. We all run into challenges on a daily basis. You will now get a taste of what being an inventor means by coming up with ideas to address some of these problems.
2. Your educator has written down some problems on strips of paper. You will work with a team to build a solution to one of these problems using everyday materials.

3. After you receive your problem, use the recycling bin to find building materials and work with your team to devise a quick invention to meet your need.

4. When you are finished, take turns sharing your simple solutions with the full group. Some questions to ask other groups include:
   - How would you change your invention if you had more time?
   - How would you change your invention if you had a bigger budget?

5. Inventors often use inexpensive, everyday materials to create prototypes of their inventions. That’s because they don’t want to waste expensive materials in the early stages of designing. Failure and mistakes are common and part of the process.

**DESIGN A CELL PHONE STAND**

1. Do you ever get annoyed by your phone not being able to stand up on its own? Inventors think outside of the box and create prototypes of their ideas using everyday materials.

2. Your challenge is to invent a low-cost cell phone stand using recycled materials like cardboard. You can also use duct tape.

3. Before you start, watch Josh Ramos’ Cardboard Videos to learn some cardboard cutting tips and tricks. Josh is a PhD candidate in Mechanical Engineering from MIT.

4. If you are having difficulty coming up with your own design, check out Josh Ramos’ Cardboard Phone Stand.
THINK ABOUT YOUR INVENTION

1. What do you like about the stand you made?

2. How would you change your design if you wanted to watch a video in the landscape format (sideways)?

3. Where are the speakers on your phone? How might you use the placement of the cardboard or other materials to improve the sound?

4. Share your design with another student. Write their feedback below:

5. How would you incorporate your and their comments in your next design? Describe this next design iteration in words or pictures.

DURING THE JV INVENTEAMS INITIATIVE, YOU WILL LEARN ABOUT NEW TOOLS AND MATERIALS THROUGH INVENTION ACTIVITIES LIKE THIS ONE. YOU WILL THINK OF ITERATIONS TO IMPROVE YOUR DESIGN AFTER SUCCESSFULLY MEETING THESE CHALLENGES.

WATCH SOME INVENTION VIDEOS

1. Each year, teams of undergraduate and graduate students apply for the Lemelson-MIT Student Prize Competition. Check out some videos from previous winners and finalists:

   • Alice Chen’s Inventions Make Our Lives Healthier (2:27)
   • Ben Peters’ Inventions Make Our Lives More Engaging (1:57)
   • Eduardo Torrealba’s Inventions Make Our Lives Easier (first 9 min)

   Watch Josh Ramos’ Cardboard Videos to learn how to safely bend and cut cardboard before doing the activity.

SAFETY

VIDEO NOTES

What are two helpful things you learned about working with cardboard from the video(s) you watched?

1. ____________________
   ____________________
   ____________________

2. ____________________
   ____________________
   ____________________

BRAINSTORM

Brainstorming ideas before you build is one way to make your final product better. Use the graph paper in the back pages of this meeting to brainstorm two different cell phone holders.
2. All good inventions, including the ones presented in these videos, stem from a real problem or need. Most inventions do not produce radical change in society, but rather build upon previous inventions to make aspects of life easier, safer, more comfortable, more engaging, and/or healthier.

INVENTION RESEARCH

1. Identify an object in the room.

2. We often take the daily products and tools in our world for granted. Each of these items has a history of evolution. Scientists, engineers, and designers made modifications over time that produced the modern object you see today.

3. You will conduct research on inventions using Google Patent Search. Google Patents list U.S. patents as well as international patents. Patents are sequentially numbered; for example, search for “student desk” and look at the images for US7571959B2.


   • How can this product continue to improve?

   • What information can you gather from the technical drawings? Why are detailed images such an important part of a patent?

INVENTION PROFILE

MIT alumna Alison Wong invented Keyprop™, a simple solution to the problem of keeping your smartphone propped up. Check out a video of her invention: Invention Profile: Keyprop.

VIDEO NOTES

Write down some thoughts you have about the videos here:

1. General thoughts:
2. How can failure turn out to be a good thing?
3. What failure have you learned the most from?

Alison Wong, Illustrator
PRODUCT NOTES

What are three things that don’t work quite right in your daily life?

1. _____________________
2. _____________________
3. _____________________

How could you improve these things?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

DISCUSS IMPROVEMENTS TO AN INVENTION

1. Think about a timeline of your daily routine. If you could improve one product or process during your typical day, what would it be?

2. In your group, discuss the following:
   • How might you go about making the improvement? Describe your process.
   • What might be some challenges to meeting this need?
   • Thinking further, do you notice anyone in your family or community who struggles to complete a certain task? What invention might improve this aspect of their life?

INVESTIGATE REAL-WORLD IMPROVEMENTS

• **Sesame Ring**: Several MIT undergraduate students were having difficulty locating their reusable train tickets upon entering the train station. Their solution is a wearable reader in the form of a customizable ring.

• **Tile™**: Do you ever have difficulty finding your keys or wallet in your home? The solution is a small piece of plastic with a chip that connects to an application on your smart phone.

• **uBeam**: Meredith Perry, a graduate of the University of Pennsylvania, was sick of long electrical wires for laptop computers. She started a company, uBeam, that is working on a wireless charger.
WATCH VIDEOS ABOUT THE DESIGN PROCESS

1. Watch the MIT Design Process Videos.

2. Draw a visual model or outline below that will help you remember the steps of the design process as you invent something.

SET RULES AND DEVELOP TEAMS

1. The JV InvenTeams initiative is all about hands-on fun. To make this possible, here are a few important rules to follow:

   • Safety is the number one priority! Watch tutorial videos before using new tools and materials.
   • Ask for help. Don’t guess, especially about how a tool works.
   • Consider all ideas. No idea is “dumb.” As an inventor, focus on the ideas with the most potential when developing a prototype.
   • Embrace failure. Failure is a part of the invention process!
   • Value your team. Everyone brings different skill sets and knowledge to the table.

2. Diverse teams are successful teams

3. Play a game called “Four Corners” to help the educator create balanced teams. Instructions are on the next page.

EXTEND THE LEARNING

You can continue exploring invention by researching well-known inventors in your community. How? Go to Free Patents Online. The login is free. Click on the SEARCH tab, then use the “Quick Search” feature to enter your location under “Inventor Fields.” You may want to search chronologically by the last 20 years.

DESIGN PROCESS NOTES

Steps of the design process are:
• identifying needs,
• brainstorming ideas,
• sketching,
• building a prototype,
• testing,
• modifying, and
• re-testing.
FOUR CORNERS GAME

Teams of inventors include people with different interests and skills. In order to organize into teams, think about your own interests and skills.

Draw lines from the items on the left to the best-matching description on the right.

Types of Team Members

Tinkerer: I like to take things apart and build things.
Talker: I like to talk to people and I enjoy public speaking.
Doodler: I like to draw things and express my thoughts through drawing.
Organizer: I like to organize people and things.

Your Interests and Skills

Sounds most like me
Sounds almost like me
Sounds a little like me
Sounds least like me

The corners of your classroom will be marked with the four types of team members. Go to your “sounds most like me” description of yourself. Your educator will make balanced teams using this information.

Name: __________________________
PUMP IT UP!
MEETING 2: WHAT IS HUMAN ENERGY AND POWER?

KEY TERMS

Acceleration (n): A change in speed or direction.

Energy (n): The property of an object that allows it to do work.

Force (n): A push or a pull on an object that causes it to accelerate.

Fossil fuel (n): Matter derived from the remains of past life; includes oil, coal, and natural gas.

Geothermal (adj): Relating to the internal heat of the earth.

Harness (v): To capture or gather.

Hydrocarbon (n): An energy-rich organic compound containing hydrogen and carbon atoms.

Mass (n): A measurement of the amount of matter something contains.

INTRODUCTION TO SHOP SAFETY

1. Shop safety is of the utmost importance so that nobody gets hurt. You will be using hand tools such as utility knives and screwdrivers and basic power tools such as drills and rotary tools. Tools should always be used in the way they were designed to be used. Watch a video: General Shop Safety.

2. Review the general shop safety rules:
   - Wear safety glasses.
   - If you are in doubt about how to use a tool, ask!
• Have a plan for what you are going to do with the tool.
• Be mindful of others who might enter into your workspace accidentally.
• Secure the workpiece.
• Have a balanced stance while using a tool.
• Remove all jewelry, watches, and loose clothing before working with machinery.
• Pin up long hair and wear closed-toe footwear.
• Never work when you are tired or not focused.
• Leave the workspace cleaner than you found it.

EXPLORING ENERGY AND POWER
1. Gather in your teams from the first meeting.
2. You are going to explore different sources of energy that can be used to generate power. Consider:
   • What things do you see in the room that require power? Lights, desktop computers, printers, cell phones, wall clocks, intercoms.
   • How are they getting that power? They may plug into the wall where they tap into the electricity in the building, or perhaps they use a battery until it is drained and needs to be recharged or replaced.
   • Where does the electricity come from to make these devices work? The power is generated by some of the sources listed below: fossil fuels, wind, sunlight, and waves.
   • Do you know of any devices that can generate power?
3. Read the following information about sources of electrical power. Then, answer the questions that follow.

   Non-renewable (adj): Any natural resource from the earth that exists in limited supply and cannot be replaced if it is used up.
   Piston (n): A cylinder that fits snugly inside a larger cylinder and moves under pressure.
   Power (n): The rate at which work is done.
   Renewable (adj): A natural resource that can be replenished.
   Watt (n): A unit of power.
   Work (n): Amount of energy involved in applying a force over a distance.

There are many different sources of energy that can be used to create power for the devices we use. Fossil fuels, like coal, gasoline and natural gas, are some. Fossil fuels are non-renewable sources of energy. They exist in finite amounts on the planet.

Fossil fuels are composed of hydrocarbons, chemical compounds made of carbon and hydrogen. The atoms of carbon and hydrogen mix with oxygen in the air during combustion, and release energy, carbon dioxide, and water.
Fossil fuels are energy-rich substances that formed from the remains of ancient organisms. For example, coal is formed from the remains of plants and is mined, or removed from deep in the ground. Oil, or petroleum, is a liquid fossil fuel. It, too, is found deep in the ground, in rocks like sandstone or limestone. The oil has to be pumped out of the ground and then processed to make it usable. The chemical energy is used to generate electric power in oil- or coal-burning power plants. The electricity can then be used to turn on our lights, cook our food, and heat or cool our homes.

Earth also has renewable sources of energy that can be used to generate power, such as wind, sunlight, tides, and waves. These renewable resources can usually be used indefinitely without reducing the supply that is available. For example, the energy we get from moving water is renewable. When it cascades over a waterfall or flows down a river, the energy of water can be harnessed to produce electricity. The water can spin a turbine—a machine consisting of a wheel or rotor—that can be used to produce continuous power.

The internal heat of the earth can also produce a renewable source of energy. This geothermal heat warms the water trapped underground. When the heated water reaches the surface, it escapes as steam or hot water. The energy from that heated water can be harnessed to heat homes or produce electricity in power plants.

- Where does electricity come from?
- What types of energy make all that electricity possible?
- What are the benefits of using renewable energy? Non-renewable energy? What about the disadvantages of each?

1. Do you know the differences between the terms “power” and “energy?” Share your thoughts. Power and energy may seem similar, but are actually very different. Energy is the ability to do work or cause change. Power is the rate at which work is done. These terms are defined in more detail under The Physics of Power below. Humans can be a source of energy to provide power for something (like a device) or to move an object.

2. Work in small teams to explore how human energy is used as a source of power and to investigate the differences between energy and power with the simple activities below. Your educator has several sets of heavy books on hand. Each member of the team should take a turn.

3. Work with your team to address the questions that follow the activities.
ENERGY

Stand up. March in place. Do some deep knee bends. Wave your hands in the air. What do you feel? Do you feel the energy moving through your body? Many inventors are looking for ways to harness that energy and put it to use.

POWER

Now, pick up several books. Walk across the room slowly. You are transferring the energy of your body to the books as you transport them. Now walk across the room again, only much faster than before. You used more energy this time. The rate at which your energy was transferred to the books was much quicker than before.

• How would you describe the difference between power and energy in your own words?
• What human-powered devices or machines are you familiar with?
• What machine would you invent that uses human energy to power it?

EXTEND THE LEARNING

Check out these videos from PBS LearningMedia to learn about the variety of ways to generate electric power!

• This short video shows how hydroelectric power is generated at the Hoover Dam: Hydroelectric Power.
• The potential of solar power for generating electricity is covered in this video: Solar Power.
• Wind power is discussed in this video: Wind Power.
• Power plants fueled by coal are the topic of this short video: Coal-Powered Electricity.
• What about humans? Do we use energy? Where does the energy we use come from?

4. Watch the video **Turning Workouts into Watts**, in which people use exercise machines to generate electricity. Then, address the following questions in your guides:
   • What did you learn from this video about harnessing human energy to power devices? What happens to all that human energy?
   • What types of activities do the people do that can be turned into electricity?
   • How many watts can be generated?
   • How can you use the movement of the human body to generate power?

View the images and a description of **Pavegen’s U.S. Patent** on their technique for energy harvesting after viewing the video. Why do you think it’s called “energy harvesting?”

**INVENTION SPOTLIGHT**

Imagine that your walk to school in the morning could power the lights that illuminate your way home in the afternoon. Do you think this would be an interesting way to use human energy? So did Laurence Kemball-Clark – he invented **Pavegen**, floor tiles that generate electrical power when people walk on them. Read the [TED blog](#) about Pavegen tiles and watch Kemball-Clark’s TED talk about them, then see a short video of Pavegen’s vision of the future of flooring [here](#).

Credit: Pavegen
THE PHYSICS OF POWER

1. Read the definitions of energy, work, and power; watch the videos; and then discuss with your team the questions that follow.

Scientists use the terms “energy,” “work,” and “power” to explain forces on objects. These terms are loosely related scientifically. However, they are often used interchangeably in everyday language. You will design a device in this unit that uses human energy to power a water pump. Below you’ll read how scientists define work and energy and their relationship to power.

**Work** is the same thing as energy expended on an object. Work is equal to the force applied on an object times the distance the object moves (work = force X distance). Let’s look at an example you might see in your classroom when you move books from one place to another. You are doing work on books when you lift a pile of books from the floor to a table. The lifting force is in the same direction of the books’ movement up towards the ceiling. However, if you walk across the floor with the books held in front of you, that would not be work on the books. Holding the books at a constant height above the floor is a force in the direction of the ceiling. That means no work is done on the books if you walk across the floor since the direction of movement is perpendicular to the force as you move across the classroom. Find out how work relates to power in this short video that uses a roller coaster as an example: [Difference Between Work and Power](#).

**Energy** refers to the ability to do work or to cause a change. Energy comes in many forms. One is the energy associated with objects in motion, and another is the energy related to the position of an object. Some energy is stored in chemical bonds between atoms, and other energy comes from the sun, wind, and other sources you read about above. Still another type of energy is the result of electrically-charged particles moving from one place to another. For a brief overview of energy, watch this short video from NOVA: [Energy Defined](#).

EXTEND THE LEARNING

Technology can now be miniaturized and easily worn on the body, giving rise to wearable devices that can monitor our health, provide us with health information, and even accessorize our clothing. You would be amazed at the innovative applications that arise when the body’s movement is coupled with technology. Check out some of these ideas by watching this video from PBS: [Wearable Technology](#). Also check out the Electronic Textiles JV activity guide.
Power is the rate at which work is done, or the rate at which one form of energy is transformed into another. For example, running up the stairs with your backpack takes more power than if you walked up the stairs with the same backpack. The amount of work done is the same, but the time required to complete the work is different. Check out this interactive that illustrates the difference, then answer the following questions:

- What is the difference between energy and power?
- How is work related to power?
- Describe the connection between energy, power, and work when you are riding your bicycle.

Pedaling a bicycle and turning a crank, like on a pencil sharpener, are ways to use the energy of the human body. There are other, less obvious, ways. Central Station in Stockholm, Sweden, captures the body heat of the commuters passing through the train station to heat water. The hot water is then used to heat a nearby building.

Read Body Heat: Sweden’s Green Energy Source about how human body heat can be harnessed and used.

Check out this interactive that visually explains how energy and power are related:

What is the Difference Between Power and Energy?

Credit: Wikimedia Commons
PEOPLE POWER

1. Do you think you can generate the power needed to operate a light bulb? This next activity will allow you to test this, using the instructions in your guides, along with a partner who is a member of your team. You will use your muscles to move a bottle of water. This will help you understand how much power a person can produce.

2. Discuss the questions below with your full team once you have completed the activity.
   - Fill a two-liter plastic bottle with water and place the cap on it. Measure the **mass** of the bottle with the scale and record the value in the “Mass of bottle” column in the data table below.
   - Tie one end of the pre-cut rope to the top of the bottle and the other end to the middle of the dowel. You may need to tape the rope to the dowel to keep it from slipping when you wind it up.
   - Use the meter stick to measure the length of the rope between the top of the bottle and the dowel, and record the value in the appropriate column in your data table.
   - Climb carefully onto a chair and hold the dowel horizontally in front of you. Make sure the bottle is suspended in the air.
   - Next, twist the dowel to wind the rope around the dowel and lift the bottle. Do not keep your arms straight (it will hurt). Have your partner use the timer to track how long it takes for the bottle to reach the dowel. Record this value in the “Time to wind up the bottle” column in your data table. You will
calculate the last three columns later.

- Reverse roles and have your partner repeat the steps above.
- Next, you should repeat the activity, but wind up the rope faster to lift the bottle. Make sure the spacing between the dowel and your body is consistent with the first trial. Your partner should keep track of time again. Record the values for your second try in the table.
- Now switch roles again and have your partner do the second trial. Each of you will end up with 2 values for time, which may be different.

**Your Data Table**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Mass of bottle (kg or kilogram)</th>
<th>Length of rope (m or meter)</th>
<th>Time to wind (sec)</th>
<th>Force = m x a (acceleration due to gravity is 9.8 m/sec², measured in N or newtons)</th>
<th>Work = F x d (measured in J or joules)</th>
<th>Power = Work/t (measured in W or watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First try</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second try</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Now, address the questions below with your full team, sharing and comparing experiences.
  - How did it feel when you rotated the dowel to lift the bottle? Was it difficult to do?
  - Did the bottle feel heavier when you rotated it a slower speed or a faster speed?
  - What could be the cause if it was harder to rotate slower?
  - How would you describe the difficulty or ease of the activity in terms of power and energy?

**THE MATHEMATICS OF POWER**

1. You are going to use simple mathematical equations to determine the values for the force, work and power, using data from one of your trials in the People Power activity. An example is provided in the table below.

2. Read through the equations and explanations that follow.

3. Use calculators, or the calculators on your cell phones, to complete the math in this section.
**Calculate the force on an object.** The force on an object (in other words, the push or pull that is exerted on it) is equal to the mass of the object (m) times the **acceleration** (a) of the object. On earth, all objects accelerate at a rate of 9.8 meters per second squared (9.8 m/sec²).

\[
\text{Force (F)} = m \times a
\]

**Calculate work.** The work done on an object is equal to the force multiplied by the distance it moved. Work is measured in joules, which combines the unit of force (newton) with a unit of distance (meters).

\[
\text{Work} = F \times d
\]

**Calculate power.** The power expended to do work is equal to the work done (W) divided by the time (t) it took to do that work. Power is measured in watts.

\[
\text{Power (P)} = \frac{\text{Work}}{t}
\]

**Sample Data Table**

<table>
<thead>
<tr>
<th>Mass of bottle (kg or kilogram)</th>
<th>Length of rope (m or meter)</th>
<th>Time to wind (sec)</th>
<th>Force = m x a (acceleration due to gravity is 9.8 m/sec², measured in N or newtons)</th>
<th>Work = F x d (measured in J or joules)</th>
<th>Power = Work/t (measured in W or watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 kg</td>
<td>0.5 m</td>
<td>8 sec</td>
<td>0.98 N or .1N</td>
<td>0.49 J or 0.5 J</td>
<td>0.06 W or .1W</td>
</tr>
</tbody>
</table>

Answer these questions:

- What does it mean if one person has a higher value for power?
- How many students would it take to generate enough power to operate a 60-watt light bulb if the power generated as a result of the work done in this activity could be harnessed and then used to operate a light bulb?

**SAFETY**

Make sure to follow these additional safety guidelines for the bottle rocket activity:

- Only do this activity outdoors.
- All spectators should stand at least an arm’s length from the student(s) using the pump. The rocket takes off very quickly and forcefully.
- Make sure the rocket is pointed away from you and all other students or teams.
- Make sure no part of your body is over the bottle.
BOTTLE ROCKETS

1. Take your understanding of human energy and power one step further. You will see how your energy can power the launch of a rocket in the following short activity.

You should only do the activity outside. Watch this short video that shows how bottle rockets work if you don’t have outside access.

2. Carefully review the safety rules before doing the activity. Wear safety glasses.

3. Work with a partner and follow the steps below:
   - Gather the 2-liter bottle, cork, water, and inflation needle, bicycle pump, and box.
   - Cut the cork in half and push the inflation needle into it. Make sure that the tip of the needle is poking through the top of the cork. If necessary, use scissors to carefully trim away some of the cork on the other side.
   - Fill the 2-liter plastic bottle about one-quarter full with water (about 3 cups) and push the cork tightly into the top of the bottle. The tip of the inflation needle should point inside the bottle.

Many measurement terms used in science are named for the scientists who worked to further our understanding of these concepts. For example, the newton (N) was named for Isaac Newton (1642–1727), an English astronomer and mathematician. Newton was the founder of modern physics and described gravity and the three laws of motion. A newton is the amount of force needed to accelerate 1 kilogram at the rate of 1 meter per second squared. See Newton’s three laws of motion in this PBS video: Newton’s Laws of Motion.
• Next, connect the bicycle pump to the inflation needle. Lock the pump into the needle with the plastic switch piece at the end of the pump hose.

Credit: Eurah Ko

• Place the bottle upside down with the cork facing down inside the small box. Cut a small hole at the side of the box to feed in the hose. Make sure the bottom of the bottle is sticking up into the air over the top of the box and is pointed away from you.

Credit: Eurah Ko
• Stand behind the pump. No one should be in front of the bottle.
• Stand back as far as the connector on the pump will allow you. Pump air into the bottle using the bicycle pump. Observe what happens to the bottle and the water in it. Have your partner help with observations, since you will be pumping.
• Address the following questions together:
  ▷ Did anyone hear any noise? Why?
  ▷ What happened when you pumped air into the bottle?
  ▷ What happened to the cork?
  ▷ Compare the movement of the bottle and the water as the water launched into the air. Specifically, describe the direction that the bottle moved and the direction that the water moved.
  ▷ Why did the bottle go up?

INVENTION SPOTLIGHT

There are many examples of devices that use human energy to power them. Some inventors have combined human energy with battery or electric power to create some useful—and fun—devices. One of the most important and useful human energy-powered machines on the globe is the bicycle. Check out this video about hybrid recumbent bicycles, which allow people to get some exercise while commuting safely to work: Power to the Pedal.

SAFETY

Make sure to wear your safety glasses!
IDENTIFY A USE FOR A HUMAN-POWERED PUMP

1. Devices that move water from one area or level to another have been used for thousands of years. These water pumps have been and continue to be vital to farming, agriculture, and industry, as well as in homes. Your team will be designing and creating a water pump powered by human energy in this unit. You will then sketch a design to meet a specific use.

2. You will work with your team to determine a use for your water pump. Inventors ask themselves and others many questions before they begin designing a product or building an early prototype. One of the questions you’ll need to answer is what your pump will do and for whom. You may want to consider where and under what conditions the pump will be used. For example, conditions may affect materials used to build the system.

3. Discuss as a class the different industries where pumps are used. Pumps are used for many different purposes. For example, they can be used in:

   **Agriculture:** Irrigation pumps are used to bring water from distant water sources to the fields.

   **Medicine:** Insulin pumps deliver a continuous source of insulin to manage the blood sugar of people with diabetes.

   **Industry:** De-watering pumps remove water from construction sites or mine shafts.

   **Recreation:** Submersible pumps are placed in ponds to create fountains.

4. There are several examples of pumps on the following pages. Discuss with your team the following questions as you look at the photographs:
   - What use or application did the inventor of each pump try to address?
   - What type of research do you think went into the design of the pump?
   - Can you think of other pump designs that could be used for the same purpose?
   - Do you use any pumps at home?
Medical Pump to Inject Insulin

**Intended use:** Releases rapid-acting insulin into the body through a tube.

**Specifications:** Helps people with diabetes to maintain a steady supply of insulin to control blood sugar.

**How the pump works:** The small pump delivers short-acting insulin 24 hours a day through a catheter, or tube-like instrument, placed under the skin of a patient. The pump, located inside a small case, can be placed near the body or attached to a pocket, waistband, or belt.

Agricultural Pump for Irrigation

**Intended use:** Moves water to where it’s needed to irrigate crops.

**Specifications:** Moves water from a lake, a stream, or a pond to agricultural fields.

**How the pump works:** Many irrigation pumps move water from a source (such as a pond) and pass it over a rotating blade that transports the water from a lower level to a higher level, where it can then be passed through a series of pipes and hoses to the fields where it is needed.

Sports/Bicycle Pump

**Intended use:** Inflates tires, sports balls, and toys.

**Specifications:** Functions as a hand-operated **piston**. A piston is a cylinder that fits snugly inside a larger cylinder and moves under pressure. There are also electrically-powered bicycle pumps.
How the pump works: The upstroke of the piston draws air from the outside through a one-way valve into the pump. On the down stroke of the piston, the air is pushed out and into the bicycle tire or toy through a needle or valve.

Fuel Injector Pump for an Engine

Intended use: Delivers fuel to an internal combustion engine.

Specifications: This is the primary fuel-delivery system used in automobile engines today.

How the pump works: This pump has two ends. One end opens into a combustion chamber, where the fuel and air in an engine is mixed. The other end houses a plunger. The plunger moves back and forth, letting fuel in on one stroke, and then forcing the fuel into the combustion chamber on another stroke. There is enough heat and pressure in the chamber to ignite the fuel, which supplies the energy to move the automobile.

Sump Pump

Intended use: Removes unwanted water from an area to keep it dry.

Specifications: These small pumps are often used in basements to prevent flooding and often have a battery backup in addition to another power supply.

How the pump works: Sump pumps are usually placed into pits or holes in a basement floor, called a sump hole. When the pit fills with water, the pump turns on automatically and pulls the water from the pit into pipes that channel it beyond the house’s foundation. Water is prevented from flowing back into the pit with the use of a one-way valve.
SKETCH A PUMP

1. Think about potential uses for a human energy-powered pump. Create a sketch and to use what you’ve learned to address the following with your team:
   • the purpose of the pump (what it will do, for whom, where, and under what conditions)
   • its size
   • its portability

2. Share your sketch with the other teams.

WRAP-UP

This meeting covered energy, work, power, and human power. It introduced some different types of human-powered devices and their uses, including pumps. You will learn more about pumps and build a few prototypes in the next meeting!

INVENTOR SPOTLIGHT

Martin Fisher won the 2008 Lemelson-MIT Award for Sustainability. He invented low-cost, human-powered irrigation pumps to help farmers in rural Africa become self-reliant entrepreneurs. With his team of designers, Fisher developed his first MoneyMaker Pump. More than 250,000 pumps have been sold, 160,000 enterprises created, and 820,000 people moved out of poverty since the low-cost irrigation pump was invented. Read more about Martin Fisher and his work here.

Credit: Lemelson-MIT Program
MY THOUGHTS

________________________________________________________________________

Student Name

________________________________________________________________________

Date
**Exploring Pumps**

1. You will be exploring simple pumps and learning how they work. Think about the following:
   - What devices are you familiar with that use pumps?
   - What do those pumps do?
   - How do you think the pump you design will work?
   - What are the components of a pump? How might these components be different for different types of pumps?

2. Read the following information about the Archimedes screw pump:
   You learned about some of the different functions of pumps in the last meeting. Pumps move substances from one place to another with some type of mechanical action. Pumps move liquids such as blood or water. They are also designed to move gases like air.
Archimedes, a Greek scientist, inventor, and mathematician who died in 212 B.C., is credited with designing one of the earliest pumps. His design was a simple one; it consisted of a screw inside a hollow pipe. The pump was designed to move water from a lower level to a higher one. In the drawing below, water is moved from the bottom of the pump to a higher elevation by turning the handle. The water moves up the coils inside the pipe and spills out the top of the pump.

The pump is powered by the energy of a person who turns a crank at the top. It was designed for irrigation purposes, enabling farmers to move water from low-lying areas to higher ground. It could also be used to move materials such as sand or ash. Today, Archimedes screw pumps are sometimes used in wastewater treatment plants, as is seen in this short video of wastewater treatment plants.

3. Discuss the following prompts with your partner:
   - How does the pump move water?
   - How does the water move? Draw an arrow that traces the movement of the water on the screw diagram.
   - Why is it easier to use a screw pump than hauling the water by hand?

Eureka! This is what every inventor wants to be able to shout. It means, literally, “I found it!” A cry of eureka is a sign that some problem has been solved or an understanding reached. Archimedes, and ancient Greek mathematician and inventor, is attributed with saying this first after a moment of inspiration. But is the story accurate? Watch a short video about Archimedes’ inventions, Archimedes, and then read an article about his “eureka moment” from Scientific American: Fact or Fiction? Perhaps the story of his eureka moment is fictional, but no one can dispute the influence Archimedes had on science and mathematics.
BUILD AN ARCHIMEDES SCREW PUMP

1. You will be working in pairs to build an Archimedes screw pump out of PVC pipe, duct tape, and vinyl tubing that can be hand-turned without a crank.

2. Review the safety rules. Then follow the steps below.
   - **Gather materials**: 1/4 x 3/8-inch clear vinyl tubing, tubing cutter, duct tape, and one 2-foot length of 1-inch-diameter PVC pipe.
   - **Cut the vinyl tubing**.
     Use the yardstick to measure and cut a 75-inch length of 1/4 x 3/8-inch clear vinyl tubing. Be careful when unlatching the handle of the tubing cutter—it opens rapidly. Place tubing into the “mouth” of the tubing cutter and gently close. Apply firm and gentle pressure until the tube is cut.

SAFETY

Make sure to follow these additional safety guidelines for this activity:
- Use caution when cutting the vinyl tubing with the tubing cutter. The handle has a latch to lock the two sides together. Lock it when not in use.
- Place newspaper on the tables or desks to absorb the water that spills.
- Use paper towels to clean up all water spills to prevent slipping.
• **Wrap the tubing around the PVC pipe.** Keep in mind that the PVC pipe and tubing is a simple Archimedes screw pump that will be hand-turned without a crank, like in the image below. Wrap the tubing around the PVC pipe’s bottom edge. Make sure to securely tape the end down. You can use several pieces of duct tape. Continue to wrap the tubing, leaving a space of about 2-3 inches between the coils. Tape each coil down as you go, using multiple pieces of tape. Make sure all of the tubing is securely fastened to the pipe.

• Leave about 2-3 inches of tubing hanging off one end and cut any excess with the tubing cutter (as shown below). Securely fasten the other end to the PVC pipe with several pieces of duct tape.
• **Fill a plastic container with water and place it on the floor.** Add about 20 drops of food coloring. You want to be able to see the colored water rise inside the clear vinyl tubing. Make sure the water covers the tubing opening on the bottom of the pipe. Place another empty bowl on a chair above the container on the floor.

• **Operate your pump and watch it work!** Turn the pump (PVC pipe) either right or left, depending on which way you wrapped the pipe. Add more water to the container as needed. Use a timer on your smart phone or stop watch to time how long it takes for the water to flow out of the top of the tubing. Continue to turn the pump until the water spills into the top container. Hold the loose end of the tubing over the higher bowl once the water gets close to the top of the tubing. This way, the water will not spill.

• Return to your team and address the following questions:
  ▷ How long did it take for the water to spill out the top?
  ▷ How do you think the diameter of the tubing might impact the movement of the water?
  ▷ Were you surprised at how well the pump worked (or did not work)?
  ▷ What is the relationship between the amount of human effort that you put into the system and the amount of water that is being moved?
  ▷ How is this an example of a using human energy to power a pump?
  ▷ How could the screw pump be a useful machine?
HYDRAULICS

1. Read the information below and watch the video on hydraulics.

2. Do the short exercise after the reading and then answer the questions that follow in your guides.

A device that relies on human energy to power it is limited by the amount of effort a human can expend. A more efficient way to pump water, rather than relying on human energy alone, is to use hydraulics. Hydraulics is the study of the properties of fluids and their movements. Engineers use hydraulics to generate and control power through liquids that are under pressure. Hydraulics are used in the brakes of a car to stop it and in hydroelectric dams to control the flow of water out of the dam. Watch a short video to see how hydraulics and moving water combine to create electricity for the Canadian province of Ontario: Hydraulics and Electricity.

Try the following short activity on your own. Take a syringe and fill a plastic cup with water. Completely compress the syringe plunger, and then place it in the water. Draw water into the syringe by slowly pulling the plunger out.

The diameter of the tubing plays a role in the success of your screw pump due to what is known as capillary action. Capillary action refers to the ability of a liquid to flow into narrow spaces, in opposition to the force of gravity. Capillary action is due, in part, to surface tension. Surface tension is where the molecules at the surface of a liquid pull toward each other. The water moves up the tube when this tension combines with the interaction between the water and the inside of the tubing. Generally, tubing with a wider diameter will move water more effectively than tubing with a very narrow diameter. The United States Geological Survey (USGS) has a very good review of capillary action.

Credit: WGBH
• Remove the syringe from the water, hold it over the cup, and push the plunger down. The water comes out.

What you are seeing is the science of hydraulics on a very simple scale. The pump you will build operates in the same way as the syringe, or the straw you use to sip beverages. These devices do not actually suck up the liquid. The syringe and the person with the straw create a **vacuum** by sucking air out of the system. The pressure in the atmosphere then pushes down on the surface of the fluid, forcing it up to fill the vacuum. This is what makes the water fill the syringe and the beverage rise in a straw.

The pump you and your team will be building is designed to take water from one place and move it to another. It is the power generated by human activity that drives the hydraulics and makes this possible. Answer the following questions in your guide:

• What happens when you put the compressed syringe into the water and try to draw water into it?
• What happens when an uncompressed syringe is placed in the water? Are you able to draw water into it?
• What do you think happens when you fill the syringe with water by pulling out the plunger and then compressing the plunger again. Why does this happen?

---

**EXTEND THE LEARNING**

**Pascal’s Principle**

Think, for a moment, about a bicycle pump. The force that you apply with a pump, as you blow up a bicycle tire, exerts a force on the inside of the tire. The air in the tire then pushes against the pump and also against the inside walls of the tire. This keeps the pressure constant throughout the tire. That idea is known as **Pascal’s principle**. Pascal’s principle says that when pressure is applied to the air inside a closed container, it is transmitted equally to the air and inside the container. Want to see more? Check out this animated video to see how this works: **Pascal’s Principle in Action**.
BUILD A PROTOTYPE HYDRAULIC PUMP

Inventors and designers often build a prototype to test their ideas. Building prototypes also allows them to work out any problems before they build the actual device. You will work with a partner to build a prototype pump using the directions below.

- **Gather your materials.** Get nine small craft sticks, five jumbo craft sticks, six quartered straws, two straws cut into eighths, syringes, two pipe cleaners, a plastic cup with water, and masking tape, paper towels, and newspaper. Cut a 30-inch length of 1/8 x 1/4-inch-diameter vinyl tubing if your educator did not pre-cut the segments.

- **Build the frame for the pump.** Bend a quartered straw piece in half and push one end of a small craft stick into the hole. Tape it down securely with the masking tape. Add another small craft stick to the other end of the bent straw and tape it down. Bend another straw quartered piece in half and add it to the end of one of the craft sticks, taping it down. Finally, bend another quartered straw piece in half and add it to the open ends of the two craft sticks. Tape each straw to the craft sticks. You now have a complete triangle.

**SAFETY**

Make sure to follow this additional safety guideline as you work:
- Use caution when cutting the vinyl tubing as the tubing cutter is sharp.
• Repeat the steps above to create a second triangle. These will be the sides of the frame.

• **Brace the frame.** Add the three remaining small craft sticks to build the braces for the frame. Tape one craft stick to the top of one side of each triangle so that the triangles are now standing upright. Tape the other two craft sticks to the bottom of each triangle on the sides. The frame should be secure and stable.
• **Build the hinge for the pump.** Get the two jumbo-sized craft sticks. Tape one of the one-eighth-size straw pieces horizontally on top of each craft stick.

![Image of a straw taped to a craft stick](Credit: WGBH)

![Image of a straw taped to a craft stick](Credit: WGBH)

• Next, tape one of the jumbo craft sticks vertically onto the side of the frame that has two horizontal supports at the top and bottom, as shown below. The straw should be facing out.

![Image of a completed hinge](Credit: WGBH)

• Thread a pipe cleaner through each of the one-eighth pieces of straw so that the straw pieces are facing each other. Secure the pipe cleaner by twisting the ends together so that the two one-eighth pieces of straw and the large craft sticks are held tightly together. Use scissors to trim off the long ends of the pipe cleaner. The craft stick that is not attached to the frame is called the **machine arm.** This is the arm of the hinge, which will do the work of pumping air or water in and out of a syringe.

![Image of a pipe cleaner threaded through straw](Credit: WGBH)

![Image of a pipe cleaner threaded through straw](Credit: WGBH)
• **Add the “pump.”** Submerge the tip of one of the syringes in a cup of water and slowly pull up the plunger. This will fill the syringe with water. Dry the end with paper towels.

• Press one end of the 30-inch piece of vinyl tubing tightly onto the tip of the syringe with the water in it to make it watertight. Tape it securely. **Make sure not to depress the syringe.** Set it aside.

![Image of syringe](Credit: WGBH)

• Twist a pipe cleaner around the top of the plunger of the other syringe.

![Image of syringe with pipe cleaner](Credit: WGBH)

• **Depress the plunger on the empty syringe so it is all the way down.** Press the open end of the tubing onto the tip of this empty syringe and tape it securely.

• Wrap another pipe cleaner around the free end of the pipe cleaner and wrap the opposite end of the second pipe cleaner to the bottom underside of the loose jumbo craft stick (machine arm) on the frame. Wrap it several times so it is securely attached, as shown.
• Tape your frame securely to your surface on both sides. Tape the tubing to the surface also. This will stabilize your pump.

• **Now, pump away!** Push down on the plunger of the syringe with the water in it and notice what happens to the water in the system. Use the machine arm to pull up the plunger with the syringe attached to it. Discuss what happens with your partner.

**INVENTION SPOTLIGHT**

We tend to think of the use of hydraulics on the big scale—large pieces of earth-moving equipment or hydroelectric dams. However, this is not always the case. One group of innovators at Oak Ridge National Laboratory is working on prosthetic fingers that use tiny hydraulic systems. Read more about it here: [Bionic Science](#).
• Rejoin your team and address the following questions:
  ▶ What happens to the water in the syringes when the machine arm is pushed up?
  ▶ What happens when the machine arm is pushed down?
  ▶ Describe the system you have created?
  ▶ Do you think this would work with air as well as water? Explain why.

This is a simple demonstration of hydraulics and the role of human energy in powering a device. The water in your pump is contained within the system. When you push down on the plunger of one of the syringes using your own energy, the water moves through the system and the plunger on the other syringe moves up, causing the machine arm to go up or down.

Address the following questions with your team:
  • What sort of applications might this pump have?
  • What could you do to make your prototype more useful or interesting?

WRAP-UP
You have now made several different types of pumps and learned about hydraulics. They are now ready to start making their own human-operated water pump in the next meeting.

HIGH SCHOOL CONNECTION
There are many different uses for hydraulics. Read how the Lynden High School InvenTeam from Lynden, Washington invented a hydraulic suspension system for a recumbent tricycle for riders with physical limitations: [Hydraulic Recumbent Tricycle](#).

Credit: Lemelson-MIT Program
MY THOUGHTS

Student Name

Date
PUMP IT UP!

MEETING 4: PISTONS AND CHECK VALVES

KEY TERMS

Actuator (n): The part of a mechanical system that causes motion.

Compression chamber (n): Device in which high-pressure air or fluid enters and pushes a piston rod, causing the air or fluid to be forced out the other end.

Check valve (n): A device for controlling the passage of fluid or gas through a pipe. Allows movement in one direction only.

Cylinder (n): Chamber in which a piston slides to move or compress a fluid or gas.

Piston (n): A disk or cylinder fitting closely within a tube that moves up and down against a liquid or gas or in a pump to start motion.

INVENTOR’S TOOLKIT

HANDS-ON
- Cut PVC pipe
- Use a drill
- Assemble a check valve

MINDS-ON
- Understand check valves
- Understand pistons

Procedure

- Pump Take-Apart
- Cut PVC
- Make a Check Valve
- Use a Drill
- Build the Check Valves
- Wrap-up

PUMP TAKE-APART

1. Now it's time for you to take apart a pump to examine the parts and how they work together. Before you examine the internal workings of the pump, you will explore the outside of it.

2. Work with a partner to examine the bicycle pump you used in Meeting 2. Move the handle up and down. Answer the following questions:
   - What happens?
   - Can you describe what it that feels like when you press the handle down?
   - What do you feel when you place your hand in front of the valve, the part at the end of the connector to the pump, while pumping?
3. The bicycle pump is essentially a **piston** inside of a **cylinder**.

4. Follow the steps below, taking turns with your partner so you both have a chance to participate. Your instructor will provide you a screwdriver for this activity.

   • Spread newspaper or cardboard on the desktop. Lay the bicycle pump on top of the paper.
   • Use the screwdriver to remove the two screws on the bottom side of the pump and the three slightly larger screws on the bottom. Keep the screws nearby so you can reassemble the pump.
   • Take off the bottom of the pump. To do this, place the pump on the floor and step on the pedal while pulling up on the cylinder. Use caution when pulling up on the cylinder to prevent hitting yourself.
• Remove the two small screws on side of the cylinder’s cap. Note that these screws are even smaller than the ones already removed. Slowly pull out the piston. It has some lubricant on it, so take care not to get this on your clothing.
• Arrange the pieces of the pump on the newspaper or cardboard.
• Look at the diagram below. How do the parts in it compare with your pump parts? Can you identify the pieces of your pump?

![Diagram of a pump]

Parts of a pump.

INVENTION SPOTLIGHT

You’ve seen bicycle pumps attached to bikes. The problem is that they can be dropped or lost, and they get so dirty that they do not function. Alexander Brown had a unique solution to these problems. Check out the following patent for a bicycle pump that is part of your seat! Have students look up the patent and view all of the technical drawings. Can they find the same parts of a pump in the invention? View A New, Improved Bicycle Pump.
• Make a sketch of the bicycle pump and its parts. You should include the following in your sketch: handle, cylinder, piston, and compression chamber.

• Now return to your team and respond to the following questions. Share your responses with the entire class:
  ▶ How easy was it to move the piston out of the pump before you disassembled it?
  ▶ Why was a lubricant used in the pump?
  ▶ How does the diameter of the piston compare with the diameter of the cylinder? Do you think the pump would work as well if the piston were much smaller? Why or why not?
  ▶ What surprised you about what you found inside the pump?
The bicycle pump you looked at is fairly simple. It consists of a handle, a cylindrical body, and a piston. The water pump you will be making has these three components as well.

Review the intended use of your water pump powered by human energy, which you determined in Meeting 2. Your pump needs to have a cylinder and a piston with a handle in order to meet the need you decided to address.

Work with your team in the activity that follows. You’ll have the opportunity to practice using the miter box. You will cut the pipe that you’ll use to make the check valve connectors for your pump.

Bicycles are used often in projects focusing on the use of human energy to power a device. But what about using a bicycle pump? The 2013 InvenTeam from the Ann Richards School for Young Women Leaders in Austin, Texas, designed and built a pressurized cooker using a bicycle pump. Find out more here: Ann Richards School for Young Women Leaders InvenTeam.

Pumps consist of a compression chamber and a plunger piston. High-pressure air or fluid enters the compression chamber and pushes the piston rod, or actuator, when you push down on the handle of the pump. This forces the air or fluid out the other end of the chamber. This short animation shows how a high-pressure pneumatic piston works: Pneumatic Pistons.

Always wear safety glasses and a dust mask when cutting PVC pipe because the process can create a lot of dust.
Gather your supplies. You will need a two-foot length of ¾-inch-diameter PVC pipe, a permanent marker, a ruler, and a miter box/saw.

4. Take turns following the steps below to practice cutting PVC. Make sure each team member gets a chance to practice at least one cut.

- Measure four 2-inch lengths on the PVC pipe, and use the marker to make marks in the right places.
- Locate a flat work surface like a tabletop or a desk. Check to make sure it doesn’t move when you are using the saw that is part of the miter box. Cover the workspace with a piece of newspaper or cardboard and place the miter box on top of it.
- Set up your miter box. You will use the miter box to cut your PVC pipe into 2-inch lengths. To do this, firmly clamp the miter box to the side of your work surface. First, place the length of PVC into the miter box. Fit the saw into the groove of the miter box. Cut through the PVC using gentle back and forth motion.
- Check your cut. Is it flat or on a slant? Was it cut to the proper length of 2 inches? There is extra PVC pipe if you need to try again.
• Have other team members repeat the steps to practice cutting PVC pipe. Two of these sections will be used as part of your pump’s check valves in the next meeting, so save them!
• Save the scrap piece of PVC pipe. You will use it shortly to practice drilling a hole.
• Respond to the following questions with your team:
  ▷ Why is PVC a good choice of material for this project?
  ▷ What potential problems do you anticipate facing as you continue to use the PVC pipes to make your water pump?

**MAKE A CHECK VALVE**

**Note: Drill and drill bits not supplied in kits**

1. Drill safety is critical. Long hair must be securely tied back. Dust masks and safety glasses must be worn. Watch this video, which shows how to use a drill: How to Use a Drill.

**HISTORY**

A scientist and inventor at B.F. Goodrich Company, Waldo Semon, experimented with synthetic rubbers to replace natural rubber in the 1920s. His experiments eventually produced polyvinyl chloride (PVC). PVC can be used in a number of ways, such as in the production of golf balls and water-resistant coatings. Production of PVC increased during World War II, when it was used to insulate wiring on military ships. Pipe made out of PVC is commonly used today to carry water and waste. Learn more about Waldo Semon here.
The 2012 InvenTeam from the Oregon Episcopal School in Portland, Oregon, developed a human-powered water-lifting system. Watch their invention at work in this short video: Water Lifting System.

2. Review the parts of a drill and the safety rules. Read through the steps of the activity and address any questions before starting.

3. Follow the steps below to practice using the drill and to build a check valve

**Practice Drilling PVC**

- You will practice using the drill on scrap pieces of PVC pipe. Get the 16-inch piece of scrap ¾-inch PVC pipe left over from cutting your check valve connectors, the 1-inch PVC pipe, newspaper, duct tape, and a marker.
- Place newspaper on your work surface.
- Use the marker to make a line of four marks about an inch apart on the top of the ¾-inch PVC pipe.
- Mark and cut an 8-inch piece off the 1-inch-diameter PVC pipe using the miter box/saw. Follow the instructions from the previous activity. The 1-inch PVC pipe will be harder to cut than the ¾-inch PVC pipe because it is wider in diameter.

Credit: Howtoons
Save this 8-inch piece of pipe. You will use it to make pump handles in Meeting 5.

- Use duct tape to very firmly tape the two pieces of 16-inch scrap PVC pipes together at the ends, making sure the four marks are facing up toward the ceiling. You’ll need a team member to firmly hold the pipes together as you tape them. **Test to make sure the PVC pipes do not move against each other by trying to move them. When you drill they will stay together if they are firmly secured. Add extra duct tape if needed.**

### Use a Drill

- You are now ready to start. First, remove the battery from the drill so no power gets to the drill. You don’t want to turn the drill on by mistake while you are adjusting it for use.

- Attach the 1/16-inch drill bit to the drill by unscrewing the chuck, the locking mechanism on the head of the drill. Usually you unscrew by turning the chuck to the left. As you turn, the open area in the center of the chuck will widen. Remove any drill bit that is already in the head by pulling it out. Place the shank (the thick end) of the 1/16-inch drill bit into the space provided, with the locking mechanism still open, and then screw the chuck to the right until it is tight around the bit. Make sure the bit is securely centered at the chuck, with the three security sides touching the bit.
• Make sure the drill is on the forward setting. There is a button at the base of the drill that changes the direction of the rotating chuck and drill bit. For example, if you were putting a screw in a wall, forward would drive a screw into the wall and reverse would remove it.

• Choose a drill setting (how fast the drill bit will spin). Use a low setting such as 2.

• Replace the battery by pushing it into the grip of the drill until it snaps in place.

• One student should lean slightly over the work surface and firmly hold the ends of the taped PVC pipes in place while the other student turns on the drill and drills a hole on the mark. Follow these steps to drill:
  ▶ Put on safety glasses.

  ▶ Place the tip of the drill bit on one of the marks on the top side of the PVC pipe at a 90-degree angle.
  ▶ Push in the trigger while applying slight downward pressure to the drill.
  ▶ Start by applying a little pressure and increase as the drill goes in deeper.
  ▶ Make sure to stop drilling once the drill bit reaches the hollow area inside of the PVC pipe. You do not want to drill into the work surface or the bottom PVC pipe.
  ▶ Make sure you both keep clothes, hair, and hands away from the spinning bit.

• Now you will move on to making your check valves. You will use the drill again in a few steps.
BUILD THE CHECK VALVES

• Gather the necessary tools and materials. Your team will need the two 2-inch pieces of PVC pipe that you cut above, four ¾-inch male PVC slip adaptors, two mini balls, two 3/8” washers, two large paper clips, PVC cement (to share as a class), epoxy or Goop® (to share as a class), a popsicle stick, the drill with the 1/16-inch bit, 2 large paper clips, pliers, a miter box/saw, duct tape, a ruler, a permanent marker, and newspaper.

• Place a washer inside wide end of the male PVC slip adaptor. Then, place the ball inside as well. Make sure the ball fits firmly in the hole, without passing through it. Take out the ball, and then use the popsicle stick to apply the adhesive the ledge within the slip adaptor, and glue the washer on.

• Test to make sure that the 2-inch length of PVC pipe fits into the adaptor and still allows the ball to slide around inside of it.

SAFETY

• Always wear plastic gloves when using PVC cement. Use PVC cement in a well-ventilated area. Open the windows, head outdoors if possible, or work under the fume hood in the chemistry classroom to avoid over-exposure to the fumes.

• Review the safety data sheet (SDS) for using PVC cement.

• The ball needs to move a little bit, but cannot fall out. You must make a mechanism to stop it. You will drill a hole into the two-inch length of PVC pipe and use a paper clip as a stop.

• Remove the 2-inch length of PVC pipe from the adaptor. Use a ruler and measure one inch from an edge of both 2-inch lengths of PVC pipe and mark these locations with the permanent marker.

Credit: Eurah Ko
• Tape the 2-inch lengths of PVC pipes to a larger scrap piece, just like you did in practice, making sure the marks are visible and facing up toward the ceiling. You can re-use one of the scrap pipes used before in Practice Drilling PVC. Just remove the tape holding it to the other PVC pipe.

• Turn on the drill. Drill a small hole through the mark you made.

• Have another team member drill a hole through the mark on the second length of 2-inch PVC pipe.

• Remove the tape from the pieces of PVC pipe. Make another mark directly across from the first mark. Tape the two-inch lengths of PVC pipe to the larger PVC pipe, then drill this second hole in each piece. Each piece of 2-inch PVC pipe should now have two holes exactly opposite of each other.

• Unbend the paper clips and slip the straightened lengths through the holes in both 2-inch lengths of PVC pipe. Use pliers to bend the paper clips over about one -quarter of an inch from the pipes. The paper clips will snap off after several bends back and forth. Bend down the short ends left sticking out and use the pliers (fully open and enclosing the pipes and the paper clips) to press the ends of the paper clips close to the PVC pipes.
The paper clip will serve as a barrier for the ball.

- Make sure the O-ring and the ball are still inside the wider end of the slip adaptor. If not, put them back.

- Put down newspaper to cover your work surface. Wear latex-free gloves and apply PVC cement to the outside of one end of the 2-inch length of PVC pipe. Then push the pipe inside the wide end of the slip adaptor. Allow the cement to dry. This should only take a few minutes.

- Apply cement inside the wider end of another PVC slip adaptor. Slide that adaptor onto the other end of the same PVC pipe and allow the cement to dry. This is one check valve!

- **Test the Check Valve.** Go to a sink and test by pouring water into both sides of the check valve. Which way does the water go through? Draw an arrow on the check valve with the permanent marker to indicate which way water moves through the check valve. This will come in handy later.
• **Make another check valve for your pump**, following the steps above. Switch roles within the team so that everyone has a chance to use the drill. Also switch roles when using the PVC cement, pliers, etc.

![Image showing check valve components](Credit: Eurah Ko)

- Address the following questions in your guides:

- What is the purpose of the paper clip in this valve?

![Image of check valve components](Credit: Eurah Ko)

**2-inch length of ¾-inch-diameter PVC pipe cemented into the male slip adaptor.**

Credit: WGBH

**Second male slip adaptor cemented to other side of the 2-inch length of PVC pipe.**

Credit: WGBH
There are many projects powered by human energy that are being developed to pump or move water in developing countries. A team of students from Temple University in Pennsylvania designed an inexpensive water pump that uses a rope and human energy to turn a bicycle wheel attached to a sand filtration system in order to make drinkable water. Find out more about their project in this short video: Human-Powered Rope Pump.

• Why is it important to know the direction that the fluid moves through the valve?

• Why do you need two check valves? Can you just use one?

WRAP-UP
This meeting covered pumps, pistons, and check valves. These are essential to building a water pump powered by human energy. You will assemble your own pump powered by human energy in the next meeting.
Procedure

▶ Make the Piston
▶ Adjust the Cylinder
▶ Attach Piston to Cylinder
▶ Make the Handle
▶ Add the Check Valves
▶ Test Your Pump
▶ Customize Your Pump
▶ Wrap-up
▶ Self-Assessment

MAKE THE PISTON

Now it’s time for you to finish building your pump. You will work with your team of four to make the piston and handle, add the check valves, and test and customize your pump. Carefully review all safety instructions, including the additional rules below, before you begin working. Then follow the steps in each of the following sections.
SAFETY RULES

- Cutting PVC pipe can produce a lot of dust. Always wear safety glasses and a dust mask when cutting PVC. Keep your safety glasses on as you complete all the steps for building your pump.
- Always keep your fingers away from the saw blade.
- All students, other than the ones using the miter box and turning the pipe, should stand at least an arm’s length from the miter box.
- Apply steady pressure on the saw handle while using the miter box. This will prevent the saw from jumping off the surface of the PVC.
- Be sure to turn the PVC pipe slowly as another student is cutting it. The cut should only go about halfway through the PVC pipe and needs to be even all around the pipe.

SET UP YOUR MITER BOX

- You will score the plunger piston in this section. First, though, you will practice scoring. Gather a 2-foot piece of 1-inch PVC pipe, the miter box with the saw, two clamps for the miter box, a ruler, a marker, and newspaper.
- Locate a flat work surface like a tabletop or a desk. Check to make sure it doesn’t move when you are using the saw that is part of the miter box. Cover the workspace with a piece of newspaper or cardboard and place the miter box on top of it.
- Set up your miter box. You will use the miter box to score—or cut shallow grooves—into the PVC pipe. To do this, firmly clamp the miter box to the side of your work surface.
PRACTICE SCORING THE PVC PIPE

Scoring PVC takes practice. You want to create even grooves around the outside of the PVC pipe that go about halfway into it. Practice the steps that follow on the 1-inch PVC pipe. Try to make sure everyone on the team gets a chance to score the PVC pipe.

- Measure and mark 1- and 2-inch measurements about one inch apart from the end of the pipe. This is where you will use the saw on the miter box to score the PVC pipe, making shallow grooves.

- Place the PVC pipe inside the miter box. Your miter box has small pegs that can be used to hold the pipe in place. Use the pegs to secure the PVC pipe close to one wall of the miter box.

- Find the slots on the miter box that form a 90-degree angle to the PVC pipe (the ones that are straight and not slanted). These are the slots you will want to use to ensure that the cut you make is straight.

EXTEND THE LEARNING

Do you need some pointers when it comes to using a miter box? Check out this article for some helpful hints and information: Miter Boxes.
• Insert the saw into these slots (they are across from one another). Make sure that the saw is lined up with the first line drawn on the PVC pipe.

Credit: WGBH

• Score the PVC pipe. It is very important that you do not cut all the way through the pipe. Have one student on your team hold and slowly rotate the pipe while you use the saw. Again, the groove on the PVC pipe should be shallow, about halfway through the pipe. Score it evenly around the entire diameter of the pipe.

• Have your educator check your work to ensure the groove is even all the way around and doesn’t cut through the pipe. Make sure each team member has a chance to practice this skill before you to move on to cutting the grooves in your actual piston. Just mark additional lines around the pipe as needed for practice.

• Get an 8-inch length of 1-inch PVC pipe, two O-rings, a marker, a ruler, petroleum jelly (to share as a class), a ¾-inch PVC plug, PVC cement (to share as a class), a hammer, and newspaper.

SAFETY

• Always wear latex-free gloves when working with PVC cement.
• Always use PVC cement in a well-ventilated area. Open the windows, go outside, or work under the fume hood in a chemistry classroom.
• Review the safety data sheet (SDS) for using PVC cement.
• Use your new skill at scoring PVC to cut grooves into the PVC pipe for your piston. Make sure your work surface is covered with newspaper or cardboard. Measure and mark 1-and 2-inch measurements from the end of the pipe. Score the grooves at those locations. The smaller pipe will ultimately fit into and slide out of a larger pipe, like the piston in the bicycle pump you disassembled in the Meeting 4.

• Clean up all of the PVC shavings and dust before continuing.

• The next step is to ensure that the piston will fit inside the cylinder with no gaps and is airtight. **This is a critical step.** Slide the O-rings into the grooves you just made on the piston, making sure they fit snugly into each groove, to create an airtight assembly. The O-ring should extend just past the edge of the groove in the pipe. This will allow the 1-inch pipe to fit securely inside the 1 ¼-inch pipe, making it airtight. If it is too high over the edge of the groove in the pipe, score it some more. You can use a hammer to lightly tap the O-ring into the score.

![Piston with O-rings attached.](Image)
Credit: WGBH

• Get the ¾-inch PVC plug (note that it has a washer on it) and PVC cement. Make sure newspaper is spread out on your work space. Put on a pair of latex-free gloves. Apply PVC cement to the end of the plug and about one inch inside the end of the PVC pipe with the grooves. Then, place the plug inside the pipe and push it in. A few gentle hits of hammer might be useful to push the plug in securely. This will seal the pipe. Let the cement dry. It only takes a few minutes. You might want to use a piece of a damp paper towel to clean up any cement that may have oozed onto the surface.

![¾-inch PVC plug on piston.](Image)
Credit: WGBH
ADJUST THE CYLINDER

• You need to adjust the width at the bottom of the cylinder so you can attach the ¾-inch close rider. This close rider will ultimately screw into and connect your cylinder with the PVC tee that holds the check valves. For now, get a 1 ¼-inch coupling, 1 ¼ x ¾-inch PVC bushing, the 1 ¼-inch PVC pipe (cylinder), and PVC cement to adjust the width at the bottom of the cylinder.

• Apply PVC cement to the inside rim of the coupling and the outside rim at the top of the cylinder. Push the cylinder all the way into the coupling. Let it dry.

• Apply cement inside the rim of the other end of the coupling and outside the male end of the PVC bushing. Insert the bushing into the coupling.

• Adjust the top of the cylinder. Get the second 1 ¼-inch coupling and the 1 ½-inch washer. Insert the washer into one end of the coupling so it sits on the ledge inside the coupling.
• Apply PVC cement to the top outer rim of the cylinder and the inner rim of the coupler. Push the cylinder into coupler. Let it dry.

• Reach into the open end of the coupling and apply a generous amount of petroleum jelly around the edge of the washer, which is under the ledge of the coupling. You should be able to see it.

**ATTACH PISTON TO CYLINDER**

• Apply a generous amount of petroleum jelly around the two O-rings on the piston.
• Insert the piston into the open end of the coupling that is sitting on top of the cylinder, twisting and gently pushing it in. Make sure the piston pokes over the top edge of the coupling. This where you will be adding the handle later.
• Slowly rotate the piston as you try to insert it into the cylinder, if the piston doesn’t fit easily into the cylinder.
• Be careful not to rotate it too much or the O-ring might rip.

![Piston poking over the top edge of the coupling. Credit: WGBH](image)

**MAKE THE HANDLE**

• Now you will make the handle for your pump. Get the 1-inch tee, two 1-inch slip caps, the 8-inch length of PVC pipe from Meeting 4, a miter box/saw, and PVC cement.
• Mark the 8-inch PVC pipe at four inches. Then, use your PVC cutting skills to cut the PVC pipe in half with the miter box/saw. You will have two 4-inch lengths of pipe.
• Put on your latex-free gloves. Apply cement inside a slip cap and push it onto the end of one of the 4-inch lengths of PVC pipe. Be sure to push it all the way inside the slip cap. Let it dry.

**INVENTION SPOTLIGHT**

Veljko Milković is a Serbian researcher, writer, and inventor. He has patented more than 100 inventions over the past several decades in Serbia. One of his more recent inventions is a water pump powered by human energy that uses a pendulum to move the water. As a result, you can pump water with just the tap of a finger! You can read about this invention and watch several videos showing how it operates here: [Finger-Powered Water Pump](#).
• Repeat the process with the second 4-inch length of PVC pipe and slip cap.

• Add cement to the inside of one of the horizontal ends of the 1-inch tee. Push into the tee one of the 4-inch lengths of PVC pipe with the slip cap attached.

• Repeat the process with the second 4-inch length of PVC pipe with the slip cap attached.
• Apply cement inside the vertical opening of the tee and the top outer rim of the piston. Hold the piston to make sure it does not slide down into the cylinder, then push the handle onto the top of the piston. Allow to dry.

ADD THE CHECK VALVES
• You are very close to completing your pump now! You have built the piston and cylinder already. You will have a complete pump once you attach the check valves you made in the last meeting.
• Get the cylinder/piston, ¾-inch PVC close riser, ¾-inch PVC tee, pipe tape, duct tape, and PVC cement (to share as a class).
• Wrap pipe tape several times around each end of the close rider. The pipe tape stretches. Pull the tape slightly as you wrap it so it attaches well.
• Tightly screw the close riser into the 1 ¼ x ¾-inch bushing on the bottom of the cylinder.
• Screw the other end of the close rider into the vertical end of the tee.

• Screw the check valves into each end of the tee. These pieces are threaded. They have male and female ends. Screw the male ends of the check valves into the female ends on the tee.
Make sure you attach the check valves in the right direction. You should have marked the direction on each valve in Meeting 4. You want to assemble the pump so that when the piston is pulled up, fluid moves in one direction, and when you push the piston down, it flows out in the other direction. You can test this using a balloon. Place a balloon on one of the control valves. Put the front of your feet on the check valves and move the piston up and down. If the valves are arranged in the correct way, pulling up on the piston will let air into the apparatus, and pushing down on the piston will push air into the balloon. Make sure this happens before you continue.

- Your water pump is complete!

Male ends are threaded here.
Credit: WGBH

Check valve screwed into one side of the ¾-inch tee.
Credit: WGBH

Check valve screwed into the other side of the ¾-inch tee.
Credit: WGBH

A complete pump!
Credit: WGBH
TEST YOUR PUMP
You have now assembled the piston, handle, and check valves for your pump that is powered by human energy. Congratulations! Now, you have to see if it works. Follow these instructions to test it:

- Use the tubing cutter to cut two 30-inch lengths of the vinyl tubing. Push a length of the tubing all the way in on each side of the check valves. Simply pushing it in will not be enough; use duct tape to secure the tubing and eliminate leaks.

[Image: 1-inch vinyl tubing pushed onto check valves and taped with duct tape. Credit: WGBH]

- Fill a bowl or bucket with water and place it on the floor. Place another empty bowl nearby to catch the water from the pump.
- Orient the pump so that the control valves are pointing in the right direction—that is, water should move from the supply bowl to the empty one.

HISTORY
Water pumps have existed since 3000 B.C. Early pumps were made with water wheels and chutes and used animals to provide the energy to turn the wheels. Visit A History of Pumps to explore the long and fascinating history of pumps.
• Take turns pushing the handle up and down, with your feet on the check valves to hold the pump to the floor. Water should leave the first bowl with each upward motion, and move into the empty bowl with each push downward. This could take a few pumps.

Check Valves
There are many different types of pumps. Sometimes we don’t think about the pumps that are in our homes until they fail. This short video from This Old House looks at what can result when a check valve fails: When Check Valves Fail.

INVENTION SPOTLIGHT
Human energy can be used to power many different things—even operate a vehicle. Check out this article, which looks at an innovative vehicle powered by human energy: Human-Powered Vehicle.
CUSTOMIZE YOUR PUMP

- You now have a pump that can move water. Look back at your original sketch. What was the intended use for your pump? Do you want to move water from a lower position to a higher position? Move it from one bucket to another? Have it travel a further distance?

- Re-sketch your design now that you understand how a water pump works. How would you adjust the pump? What additional piping, tubing, or other materials would you need?

- Work with your team to answer the questions below:
  - How much water does your pump move with each depression of the piston? How can you measure that?
  - How much water does your pump move in a minute?
  - What other designs could you come up with?
  - What can you do to change the performance of the pump?

- Compare your results with those of other teams.

- Do you want to customize your pump even further for your use? Brainstorm and draw a detailed sketch of your new idea. You might want to build a housing for your pump that holds it up straight and makes it easier to pump. Decide what other changes you want to make. Ask yourself these questions to begin brainstorming:
  - What’s your intended use for the pump?
  - Who will use it?
  - How much space do you want it to take up?
  - Do you want a housing that will store things around your pump?
  - How will the pump be held steady and in place?
  - What materials do you need?
  - What other questions do you need to address?

WRAP-UP

Take a moment to celebrate your achievement. You’ve built a pump powered by human energy!
A student named Jon Leary at the University of Sheffield (in Sheffield, England) was challenged in 2010 to make something meaningful and useful out of trash and scraps. The result was a bicycle-powered water pump. You can read more about his invention and how it is changing lives in Guatemala here: Bicycle-Powered Water Pump.
MY THOUGHTS

Student Name

Date
KEY TERMS

**Empathy (n):** The ability to understand and share the feelings of others.

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**PUMP IT UP!**

**MEETING 6: INVENTION EXTENSION**

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**INVENTOR’S TOOLKIT**

**HANDS-ON**

- Sketch invention project

**MINDS-ON**

- Research
- Conceptualize an invention
- Empathize with users

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**Procedure**

- Introduction to Invention Challenge
- Review Real-World Examples
- Brainstorm Invention Ideas
- Brainstorm Designs
- Make a Plan
- Self-Assessment

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**INTRODUCTION TO INVENTION CHALLENGE**

1. Read the following section, which gives you more information about the Invention Challenge.

Sit back and reflect on the new toolkit of skills you have acquired in this unit. You have new minds-on skills such as working in teams and understanding the design process, the prototyping process, hydraulics, the physics and mathematics of power, work, how human energy can be used to power a device, Pascal’s theory, and uses for pumps in everyday life. You have gained hands-on skills such as cutting and scoring PVC piping, assembling a check valve, taking apart a bicycle pump, and building a water pump.
Invention is centered on **empathy** and fulfilling people’s needs. **How could you use your new skills to solve a real problem? Your challenge is to select a person or group of people with a need and apply your skills to invent a solution.**

You will conceptualize a project. Your ideas have the possibility of becoming InvenTeams projects in future years!

Before you decide WHAT to invent, you must research a real need and determine WHO you will be helping. You can think locally, regionally, nationally, or even internationally. If you choose to look internationally, you can research the needs of a particular country or region to develop a product that may be useful. Perhaps your school already has a partnership with a “sister city” in another country.

For additional information on problems/needs in other countries, explore the [World Bank](https://www.worldbank.org) website.

### REVIEW REAL WORLD EXAMPLES

Review as a class the examples of purposeful inventions on the following pages.

**Example 1**

Many farmers in Africa are finding it difficult to grow their crops. Drought conditions prevail during some months of the year, while during other times, there is too much rain to support plant life. A group of students from Penn State University have developed a portable and affordable greenhouse that uses easily-obtained materials. The greenhouse is made of PVC piping and rice bags. It can be expanded and easily moved from place to place. Students developed this product as part of an exhibition called Open Minds sponsored by the National Collegiate Inventors and Innovators Alliance. Learn more about their [innovative greenhouse](https://worldbank.org).

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**EXTEND THE LEARNING**

Explore the book *Design for the Other 90%*, by Cynthia E. Smith, to read about projects that help the 5.8 billion people in the world who have little or no access to the products and services many of us take for granted.
Discuss as a Class
What are some of the problems with the greenhouse as presented? Can you think of any other low-cost solutions that might improve the durability of the greenhouse? How would it meet a user’s needs? Who might benefit from this solution?

Example 2
The Northeast High School InvenTeam from Oakland Park, Florida designed and built a generator system powered by human energy that they used to filter drinking water. They built a portable, lightweight, and affordable system with a battery powered by bicycle power that then runs a series of pumps and ozone generators to filter and sanitize drinking water. Student representatives from the team were even invited to showcase their invention at the 2013 White House Science Fair! Read more about their invention: Northeast High School InvenTeam.

Discuss as a Class
What are some of the “screw ups” the team encountered along the way? What approach did the team take to overcome those stumbling blocks? What parts of the design make the pump easy to use and transport? In what ways could you use their ideas to improve upon your water pump powered by human energy?
Example 3
Rural farming communities face unique challenges. Lack of water resources, lack of electricity, and lack of technology are all things that farmers struggle with. Dr. Bernard Omodei sought to bring a new type of irrigation pump to rural communities in South Australia—one that relied on rain and solar power. Read more about his invention here: New Irrigation System.

Discuss as a Class
What makes this irrigation system unique? What other applications for solar power can you think of? What are potential pitfalls of this technology? How would you work to avoid those types of problems? Can you think of other renewable resources you could integrate to power the pump now that you know how to build a pump?

BRAINSTORM INVENTION IDEAS
1. You’re going to brainstorm invention ideas, but remember that you need to think first about WHO your invention will help.

2. The most successful brainstorms are the ones in which all ideas, even wacky ones, are proposed, and all ideas are accepted. You never know when a wacky idea will inspire a great invention!

Take a few minutes to brainstorm invention ideas using the blank pages in your Student Guide. Rejoin your team and share after you’ve come up with ideas. Brainstorm new ideas together. Remember to think of ways to apply the new minds-on and hands-on skills you have learned, such as cutting PVC and understanding how to capture human power. Think of specific users and their needs. For example, could you build a system that charges a battery using human power? Could you create a pump that could be used to pump water and move air across distances?
BRAINSTORM SOLUTIONS

1. SCAMPER is a process for coming up with solutions. It is based on the notion that many new things are modifications of something that already exists. Each letter in the acronym represents a different way to arrange the characteristics of what is challenging you to come up with new ideas:

   S = Substitute
   (Playing basketball with a softball.)

   C = Combine
   (Toothbrush combined with a pencil to create a new product.)

   A = Adapt
   (How would you eat your spaghetti without a utensil?)

   M = Magnify
   (How would your chair function if its legs were wider and longer?)

   P = Put to other uses
   (Could your fork be used as a comb?)

   E = Eliminate
   (Could you play tennis without a racket?)

   R = Rearrange or Reverse
   (What if shoelaces were placed on the bottom and not the top?)

2. To use the SCAMPER technique, you should first state the problem you would like to solve. Then, ask questions about it using the SCAMPER checklist.

3. Do some personal brainstorming in your guide using the SCAMPER technique.

4. Come back together as a team after brainstorming to discuss ideas and streamline them. Select one idea to take to the next step.
MAKE A PLAN

1. Remember that all ideas are good ideas. You should record all ideas in your guide.

2. Ask yourself and your teammates the following questions to make sure you are on target:
   - Is the product offering something useful and unique?
   - Are you excited and motivated to develop your idea?
   - What new tool and/or material skills would you need to learn?
   - If the product meets a local need, would a community group, municipality, university, or company want to get involved with the project?
   - Who will benefit from the invention? Is a user clearly identified?

3. Use the invention worksheet in your guide to document and sketch your team’s idea. This is a version of what high school InvenTeams use in their project proposals.

4. Your team and the others can share their ideas with the class in a culminating celebration of your work. You should apply for InvenTeams grants if they want to continue this work!
INVENTION CHALLENGE BRAINSTORM

For this brainstorm, it’s important that you get ALL of your ideas down, especially the wacky ones! You never know when a wacky idea will turn into a great invention.

WHO will you help?

WHAT will you invent?
DRAW IT!

Student Name

Date
INVENTION WORKSHEET

Our JV InvenTeam members are:

The product we are inventing is: ___________________________ to

______________________________________________________

(short description of what it does)

______________________________________________________

It is useful for __________ because __________________________.

(the user) (description of the need or problem)

______________________________________________________

It is unique because __________________________

(description of how it’s different from other solutions)

______________________________________________________

It functions by _______________________________________

(description of how it works)

______________________________________________________

The tools we need are:

______________________________________________________

______________________________________________________

The materials we need are: __________ __________ __________ __________

______________________________________________________

______________________________________________________

The estimated total cost of our invention will be: $ ________________
What problem do you want to solve?


\[
\text{S} = \text{Substitute} \\
\text{(Playing basketball with a softball.)}
\]

\[
\text{C} = \text{Combine} \\
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