LEMELSON-MIT JVInvenTeams™

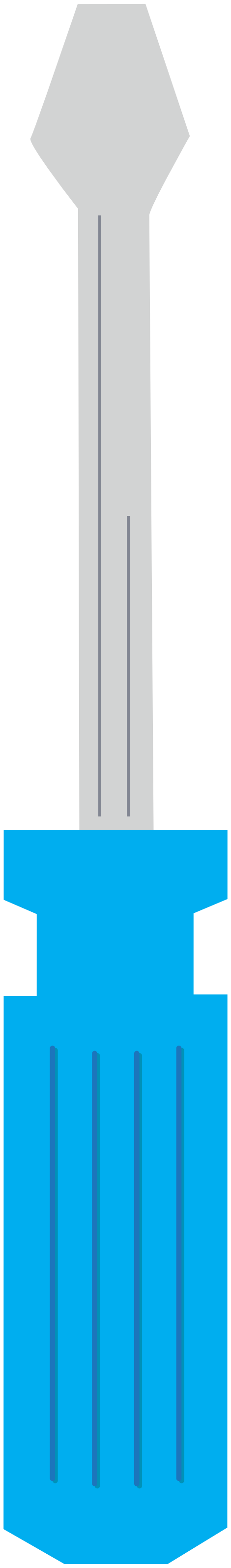
EDUCATOR GUIDE

ACTIVITY OVERVIEW

MEETINGS

APPENDIX

INTRODUCTION TO JV INVENTEAMS



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**) 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**), 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 students and provide them an introduction to inventive thinking and doing.

About JV InvenTeams

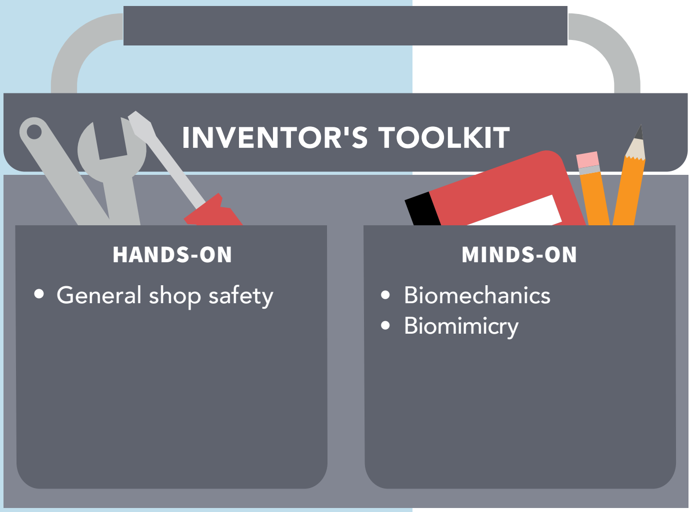
The goal of JV InvenTeams is to cultivate new ways of thinking and develop technical skills for students with limited access to hands-on STEM enrichment opportunities. Through prescribed activities, students will add to their own "toolkits" of minds-on knowledge and hands-on skills while having fun!

Students will learn how to identify a need in their lives or in the world around them and 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 InvenTeams 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 read 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 meetings 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
- Agenda
- 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 and Invention Spotlights, Related Patents, Extend the Learning, High School Connections and College Connections
- Student Self-Assessments that serve as exit slips
- Indicators of a successful meeting

KEY TERM(S)

Insole (n): The fixed inner layer of a shoe.

Isometric Drawing (n): Visually representing a 3D object in two dimensions on paper.

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.

Students may ask, "Why should I invent?" Here are some of the reasons you can share during the first meeting. Invention…

- solves world problems;
- 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 7-10. 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

The 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. 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)*

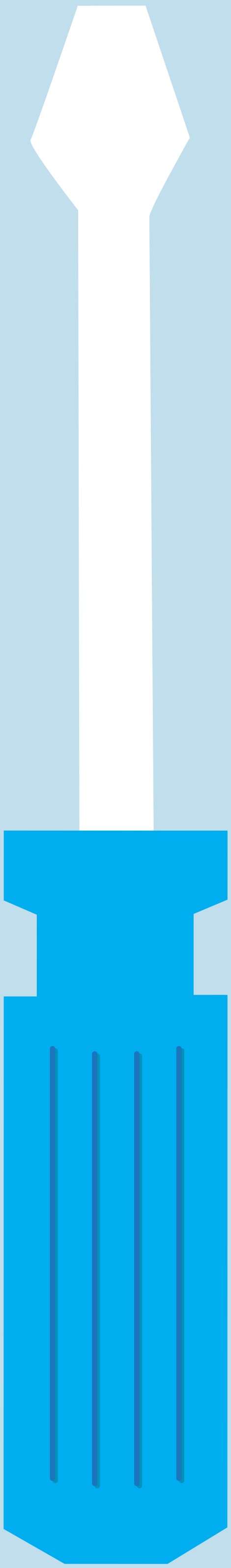
A = **Adapt** *(how would you eat your spaghetti without a utensil?)*

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. There can certainly be good ideas!

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://www.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**.

UNIT SUMMARY

Students will create a mechanical door opener in U Control. They will learn about simple machines and how engineers integrate them into mechanical systems in new, inventive ways. Students will think about existing mechanical and automatic door opener designs and consider the users and needs these designs meet. Students will consider new users and new designs to fit their needs. Students will cut and assemble a door out of foam insulation board. They will then learn about motors and motor control in Meetings 4 and 5. They will understand what a circuit is, and how to create a circuit using a breadboard to control a motor's motion. Finally, they will construct their mechanical door opener by attaching the motor, the breadboard, and the control arms to the door to make the door opener. They will consider improvements on the design as part of the prototyping process.

Students will gain both minds-on and hands-on skills in U Control to expand their toolkit. Minds-on skills include understanding machines and mechanical systems, general motor science, electricity and circuits, and the prototyping process. Hands-on skills include general carpentry skills, using a utility knife to cut foam insulation board, cutting and stripping wire, and breadboarding to create circuits. Students will learn what it means to be inventive thinkers and will practice inventive thinking as they progress through the unit.

LEARNING PRINCIPLES

- Mechanical Systems
- Motor Science
- Electricity and Circuits
- Prototyping

MEETING SYNOPSES

1 Invention Introduction

Students do warm-up activities and discuss invention. Students play “Four Corners” to help the educator assign diverse teams.

2 Introduction to Simple Machines

Students learn about the three main types of mechanized door openers and how they work to fill users’ needs. Students complete problem/ solution charts to develop an understanding of the design process in invention.

3 Build a Door

Students demonstrate an understanding of screws as simple machines and what foam insulation board is. Students learn how to use a utility knife to safely cut foam insulation board.

4 Motors 101

Students demonstrate an understanding of the basic types of motors. They can identify the basic parts of a DC motor and explain how they operate. Students know how to read and interpret a motor specification sheet.

5 Controlling a Motor

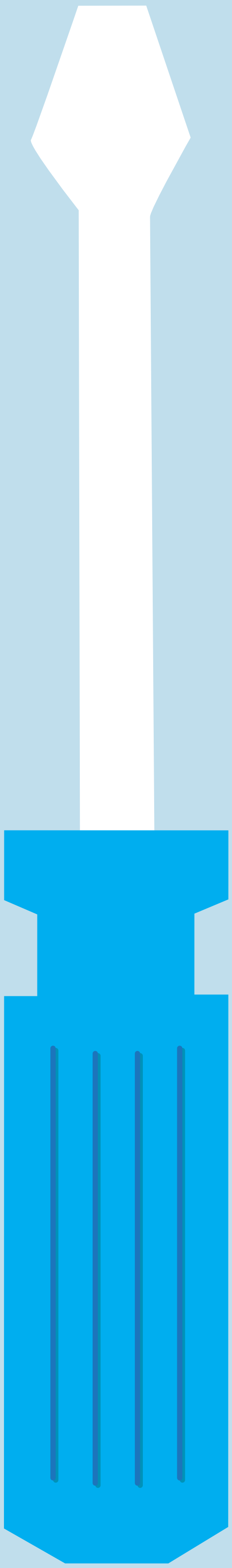
Students demonstrate an understanding of the devices used to control the motion of a motor, including H bridge motor drivers, switches, and breadboards. Students successfully breadboard a servo motor to a switch to control the motor’s motion.

6 Final Build

Students use their knowledge of materials, building, and mechanical systems to brainstorm ideas for a prototype.

7 Invention Extension

Students conceptualize a purposeful invention that uses their new minds-on and hands-on skills from U Control.



FACILITATION TIPS

Word Wall

Consider using the Key Terms to construct a Word Wall. Use the Word Wall to help young inventors review what was covered in the previous session, reinforce concepts that may need some review, and reinforce the use of new words to promote vocabulary growth.

Idea Board

Consider creating an Idea Board out of poster board that serves as a repository for new ideas and questions. Students can post new invention ideas here, which can be referenced for the development of their inventions at the end of the unit.

Teamwork

Students will be working in teams throughout this program. Consider inviting a coach from one of your school's sports programs to talk about how important teamwork is on and off the field.

Facilitating Redesign

Teams test their first lens prototypes and think about ways to improve them. You may find that your students would like to design a second prototype and test again. If you have the time and resources to facilitate a second round of designing and testing, follow these tips to help you engage your students in engineering practices as they work:

Encourage students to improve only what needs to be improved. It is a natural impulse to want to throw away an entire design idea because one element of it needs improvement. Encourage students to think hard about what elements of their design work well and what elements do not. Help them narrow their focus so they are truly improving specific elements of their original design, as opposed to starting from scratch.

Have students link their improvement ideas to particular results from their first test and from peer feedback they received. Make sure students use evidence from their test results and specific ideas from peers to justify each improvement. This helps students stay grounded in their actual design.

Encourage students to learn from the work of others before implementing improvements. Engineers and inventors always learn from the work other people have done! Have students do some more research on lenses before deciding on their improvements. Encourage students to link their improvement ideas to specific information they learned in their research.

Have students predict how their results might change based on the improvements they made before testing. Students will likely have lots of ideas about how their second prototype will perform, as compared to their first prototype. Allow students to explain what they think will happen and why. Encourage students to apply their understanding of lens properties and focal length to the design process.

Have students reflect on the strengths and weaknesses of their second prototype after testing. Encourage students to identify what worked well and what did not in their second design. Have students brainstorm further improvements and justify their ideas with evidence from their previous tests. Tell students that inventors often repeat this process of prototyping and testing many, many times before releasing a final design!

JV INVENTEAMS SELF-ASSESSMENT: U CONTROL

Inventors need to be confident and know their own strengths and weaknesses. Use this table to think about how likely you are to complete these skills with confidence. Check the response that best describes your confidence right now.

I CAN...	PROBABLY	MAYBE WITH HELP	PROBABLY NOT
make something useful out of material like cardboard, wood, fabric, or foam insulation board.			
safely cut foam insulation board with a utility knife.			
safely use tools like wire cutters/strippers and screwdrivers.			
work as part of a team.			
breadboard an electrical circuit.			
build a mechanical door opener.			
identify a real-world problem to solve.			
apply my skills to solve a real-world need.			

TODAY

Which skill was the most challenging?

____

Which skill was the most enjoyable?

____

IN THE FUTURE

What will YOU invent?

____

How is it unique?

____

How is it useful?

____

PROBLEM STRIPS (INVENTION INTRODUCTION)

Copy and cut out these Problem Strips prior to leading the Invention Introduction with students.

You want to eat soup but you don’t have a spoon.

You need to walk across a hot concrete parking lot after going to the beach, but you don’t have any shoes.

You hit a baseball over a barbed-wire fence and need to get it back.

A fly is buzzing in your room and the noise it makes is bothering you.

You lost an item under your heavy dresser and want to get it back.

JV INVENTEAMS
GENERAL SHOP SAFETY RULES

Discussing shop safety helps set the tone to introduce inventing with electronics in the classroom. It introduces safe practices and helps students understand why these practices are used. Asking your students to help develop the rules may help with the ownership and understanding of the lab safety rules. You may also choose to set the rules. Either way, make sure students understand these rules and why they are necessary. You may ask students to create posters for display in the room throughout the year to emphasize safety and remind students of the specific safety rules. Keep these safety rules posted throughout the unit.

SAFETY

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

U CONTROL
MEETING 1: INVENTION INTRODUCTION

KEY TERMS

Engineering (n): Using science and technology to design and improve objects and systems to solve a problem or meet a need.

Invention (n): A unique and useful device or process.

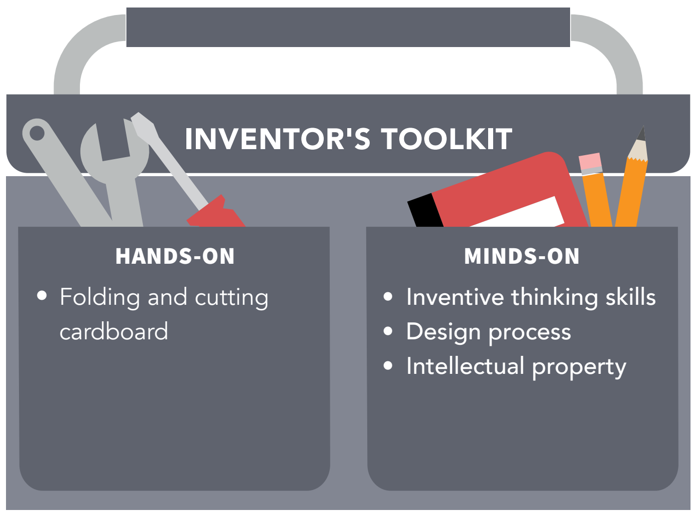
Iteration (n): A version of a design in a series of designs.

Modification (n): The act of making small or partial changes.

Patent (n): An intellectual property right issued by the U.S. **Patent** and Trademark Office, excluding others from making or selling the **invention** in the U.S. for a specified period of time in exchange for disclosing the **invention**.

PhD (n): A postgraduate academic degree awarded by universities.

Prototype (n): A model of something built to test a concept. Many **iterations** are created before the final design is determined.



Tools & Electronics

- Writing utensils
- Utility knives or sharp scissors
- Projector and computer to show video

Materials & Shop Supplies

- Student guide
- Shipping tape
- Cardstock
- Cardboard and scrap materials from the recycling bin
- Problem strips
- Self-Assessment

Procedure

- Distribute Guides and Introduce JV InvenTeams
- Introduction to **Invention** and Problem Solving
- Design a Cell Phone Stand
- Watch Some **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

DISTRIBUTE GUIDES AND INTRODUCE JV INVENTEAMS

1. Let students know that today they will learn about the basics of **invention**. Get everyone thinking about **invention** by asking:
   - How would you define "**invention**?"
   - Why do you think people invent things?

2. Distribute one JV InvenTeams guide to each student. Tell students that their **invention** guides will be a portfolio of their work. Explain that the grid paper and blank paper at the end of each meeting can be used to sketch, brainstorm, and document ideas.

3. Explain that items written in **bold underline** represent links to be clicked.

INTRODUCTION TO INVENTION AND PROBLEM SOLVING

1. Tell students that we all run into challenges on a daily basis. They will now get a taste of what being an inventor means by coming up with ideas to address some of these problems.

2. Divide the class into teams of 3 or 4 and give each team one of the Problem Strips you prepared.

Early prototypes of the Polaroid camera from the MIT Museum collection

3. Have teams devise a quick **invention** that solves their problem by using materials from the recycle bin.

4. Bring everyone back together and have teams take turns sharing their solutions. To facilitate sharing, students can ask the following:
   - What else would you do if you had more time?
   - What would you add or change if you had more expensive supplies?

5. Explain that 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.

MEETING 1

EDUCATOR NOTE

Consider constructing a Word Wall with these Key Terms to help young inventors review what was covered in the previous session, reinforce concepts that may need some review, and reinforce the use of new words to promote vocabulary growth.

EDUCATOR NOTE

The cell phone activity could take even longer if students get invested. Consider breaking this meeting into two sessions if you want to take your time.

Hands-On and Minds-On

MIT's motto is Mens et Manus, which translates to Mind and Hand. Inventors are resourceful and use many tools. Some "tools" are based on learned knowledge stored in our minds from science and math classes. Other "tools" are practiced – hands-on skills like drawing and building things.

EDUCATOR NOTE

After Cell Phone Stand

It is beneficial for students to conduct some peer evaluation if you have extra time. Have students leave their finished cell phone holders on their table tops. Leave a blank piece of paper and pen next to each stand. Students can walk around the room and anonymously leave some constructive feedback. A few students can share their feedback and explain how they would improve their project.

DESIGN A CELL PHONE STAND

1. Ask students if they ever get annoyed by phones not being able to stand up on their own. Explain that inventors think outside of the box and often create **prototypes** of their ideas using everyday materials.

2. Tell students that their challenge is to invent a low- cost cell phone stand using recycled materials like cardboard and tape.

3. Before students start, have them watch **Josh Ramos' Cardboard Videos** to learn some cardboard cutting tips and tricks. Josh earned his **PhD** in Mechanical **Engineering** from MIT in 2018.

4. If students are having difficulty coming up with their own design, they can check out **Josh Ramos' Cardboard Phone Stand.**

5. When finished, have students respond to the follow-up questions (below) in their guides.
   a. What do you like about the stand you made?
   b. How would you change your design if you wanted to watch a video in the landscape format (sideways)?
   c. Where are the speakers on your phone? How might you use the placement of the cardboard or other materials to improve the sound?

6. Have students share their design with another student.

7. Ask students how they would incorporate their peer's comments and their own in their next design? Tell them to describe this next design **iteration** in words or pictures in their Student Guide.

8. Tell students that during the JV InvenTeams initiative, they will learn about new tools and materials through **invention** activities like this one. They will think of **iterations** to improve or change their designs, after successfully meeting challenges these activities present.

Cellphone stand example

Students folding cardboard

WATCH SOME INVENTION VIDEOS

1. Explain that each year, teams of undergraduate and graduate students apply for the Lemelson-MIT Student Prize. Have students check out some cool videos from previous winners and finalists on the **Lemelson-MIT Program's** website.

- **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)

2. Explain that 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.

PATENT PROFILE

MIT alumna Alison Wong invented **Keyprop**, a simple solution to the problem of keeping your smartphone propped up.

EDUCATOR NOTE

After Videos: Debrief

Engage students in a discussion about the videos. Students should be asked to think and converse about the common themes, the inventors' approach, and why failure during the process is okay.

EDUCATOR NOTE

Extend the Learning

An additional resource that may inspire **invention** research is a video called **Extend the Learning: InvenTeams**. Produced by the Museum of Science in Boston.

EDUCATOR NOTE

Before Product Discussion

Ask students in small teams or as a class to devise a list of problems or things that don't work quite right in their daily lives. Give them a few examples to help them get started, such as a grandparent slips walking in socks, their laptop computer wires get tangled up, and they can't wake up to an alarm.

EDUCATOR NOTE

Before Real-World Examples

Explain to the students that **invention** follows a process of identifying needs, brainstorming ideas, sketching, building a **prototype**, testing, modifying, and re-testing. Potential users are consulted for feedback throughout the process.

LEMELSON-MIT JV InvenTeams

RESEARCH AN INVENTION

1. Have students identify an object in the room. Ideas include a specific type of desk, piece of technology, chair, tool, writing utensil, or article of clothing.

2. Explain that 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 product you see today.

3. Tell students that they will conduct research on **inventions** using **Google Patent Search**. Explain that 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.

4. Give students a few minutes to conduct research on the product they identified.

   - 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**?

DISCUSS IMPROVEMENTS TO AN INVENTION

1. Tell students they will learn to carefully observe the world around them in search of problems that can be addressed with a technological solution.

2. Have students work in small groups to brainstorm how they could improve one product or process they use during a typical day. Students will respond to the following prompts in their guides:

   - 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 app on your smartphone.

- **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. Have students watch the **MIT Design Process Videos**. The videos cover: Design Introduction, Observation, Brainstorming, Idea Selection, and Prototyping.

2. Give students time to outline the design process in their guides.

SET RULES AND DEVELOP TEAMS

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

Allison Wong, Illustrator

- 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. Explain that most of the projects require working in small teams. Diverse teams are successful teams.

3. Use the directions on the next page to play "Four Corners." This game will help you place students into diverse teams.

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.

EDUCATOR NOTE

After Design Process Videos

Ask a volunteer to recap the steps of the design process. Have them draw a visual outline to include on the Idea Board. Survey the students to see if they have any questions before proceeding.

Steps of the design process are:

- identifying needs,
- brainstorming ideas,
- sketching,
- building a **prototype**,
- testing,
- modifying, and
- re-testing.

EDUCATOR NOTE

Before Setting Rules

You can create a bold list of these rules to place on the Idea Board or somewhere else that is visible in the classroom.

SELF-ASSESSMENT

Collect the completed self-assessments as exit slips when students leave.

INDICATORS OF A SUCCESSFUL MEETING

Students can build a cardboard cell phone stand. They can demonstrate how to think like an inventor, and they understand how the design process works.

FOUR CORNERS GAME

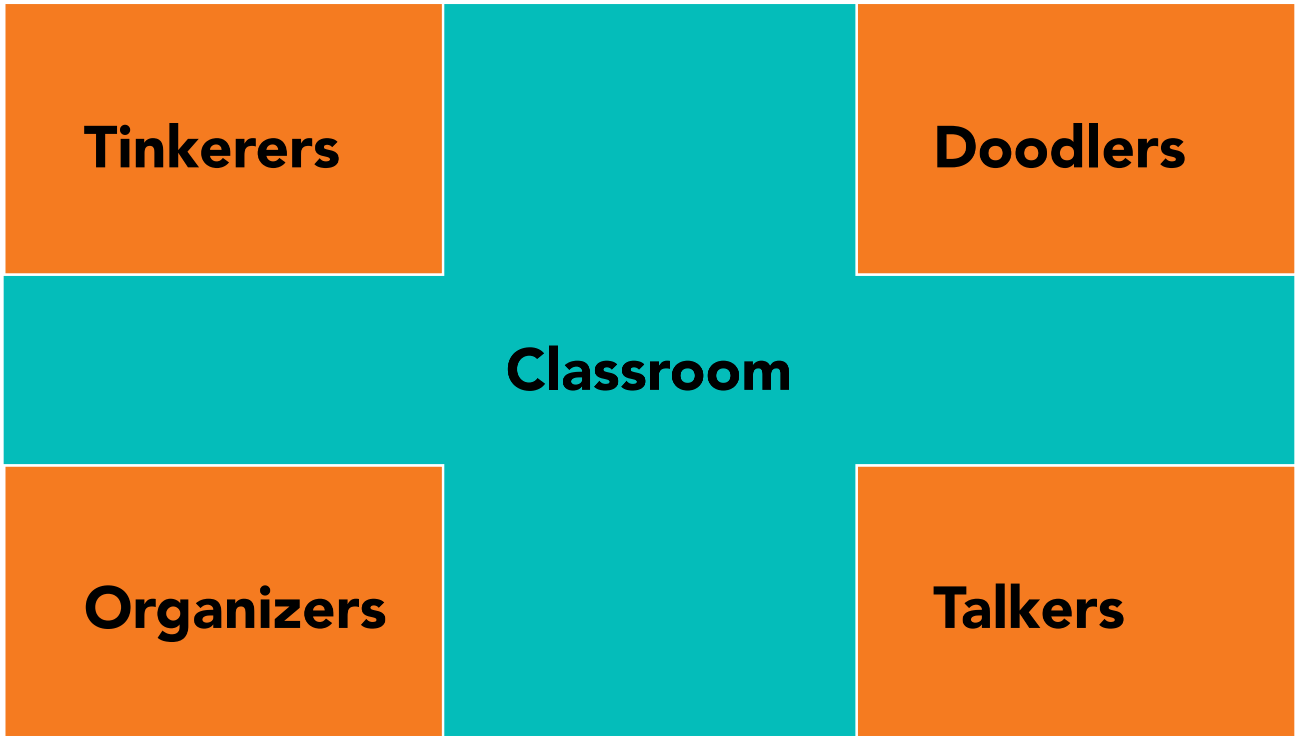
Teams of inventors include people with different interests and skills. Ask students to think about their own interests and skills to help you organize the class into diverse teams. Have students draw a line from each type of team member on the left to the best-matching description on the right.

The corners of your classroom will be marked with the four types of team members. Students will decide which corner best matches their interests and skills.

Ask students to go to their respective corners based on their “sounds most like me” description. The corners will have an equal number of students in an ideal world. If they don’t, mention to the students that equal numbers are needed in order to make well-balanced teams. Have students in the larger group(s) look at their “sounds almost like me” description and compare with the corners needing students. Ask students to consider rearranging.

Types of Team Members	**Your Interests and Skills**
Tinkerer: I like to take things apart and build things.	Sounds most like me
Talker: I like to talk to people and I enjoy public speaking.	Sounds almost like me
Doodler: I like to draw things and express my thoughts through drawing.	Sounds a little like me
Organizer: I like to organize people and things.	Sounds least like me

Have students count off within their corners once each has a nearly equal number of students. Finally, have all 1s, 2s, 3s, and 4s come together to form their **invention** teams. Write down the names and teams in your notes. These teams will come into action when students start designing.



MY NOTES

U CONTROL
MEETING 2: INTRODUCTION TO SIMPLE MACHINES

KEY TERMS

CAD (n): Computer aided design.

Energy efficiency (n): The goal of achieving maximum productivity with minimum energy.

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

Inclined plane (n): A flat plane tilted on an angle that provides a mechanical advantage when used to raise the height of an object.

Input effort (n): The effort or force exerted on an object.

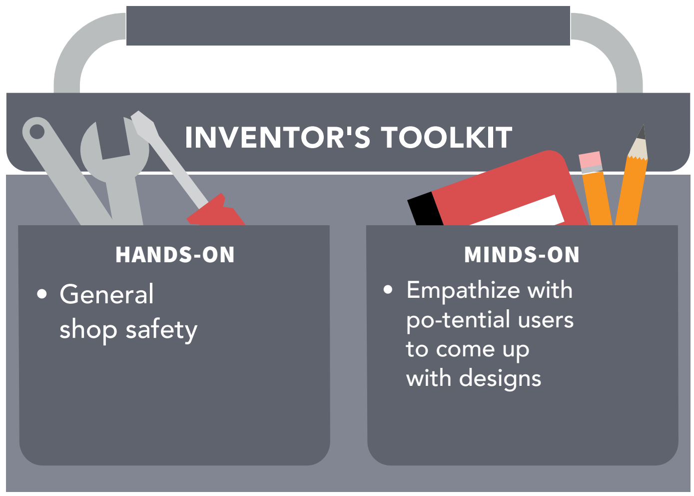
Lever (n): A rigid object used with a pivot point, or fulcrum, to move a load.

Machine (n): Any mechanical or electrical device that uses energy or force to perform or help perform work.

Motor (n): A mechanical or electrical device that uses an external power source to create motion.

Mechanical advantage (n): The amount by which a machine can multiply a force.

Mechanical system (n): A system that accomplishes work by using forces and movement.



Tools

- Writing utensils
- Computer and projector to show videos

Materials

- Student Guides
- Shop safety rules
- Self-Assessments

Procedure

- Introduction to Shop Safety
- Introduction to Machines
- Watch a Video About Simple Machines
- Six Simple Machines
- Systems in Engineering
- Investigate Mechanical Door Openers
- Identify Users and Their Needs
- Taking a Closer Look: **CAD** Drawings (optional)
- Self-Assessment

INTRODUCTION TO SHOP SAFETY

1. Tell students that shop safety is of the utmost importance so that nobody gets hurt. They will be using hand tools such as utility knives. Tools should always be used in the way they were designed to be used. Have students watch a general **shop safety** video (10 min).

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 working space 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.

INTRODUCTION TO MACHINES

1. Ask students to gather in the teams you created in the first meeting.

2. Let students know they are going to design a mechanical door that will open with a switch. Ask students:

- What do you think it takes to make a door opener?
- What parts will the opener need?
- How might learning about control arms and motors help you build a door opener?

3. Have students read independently the following information about machines and how they work.

KEY TERMS (CONT'D)

Output effort (n): The effort or force produced by an object.

Pulley (n): A wheel with a groove in it that allows for a rope, a chain or another device to move over it.

Screw (n): A simple machine used to translate rotation into linear motion.

System (n): Something that is made up of a lot of parts to do a job.

Torque (n): A measure of the tendency of a force to rotate an object about an axis, fulcrum, or pivot point.

Wedge (n): A triangular-shaped inclined plane used to separate two objects, hold them in place, or lift them.

Wheel and axle (n): A wheel is locked to an axle, which moves the wheel.

Work (n): The amount of energy involved in applying force over a distance.

4. Review the definitions for **machine**, **work**, and **mechanical advantage** with students after reading. Everywhere around you are **machines** that help make your life easier. Inventors and engineers are always at work thinking about how to integrate **machines** into new inventions or use them in new ways.

   A **machine** is any device that helps you do work. Work is defined in mechanics as the amount of energy involved in applying a **force** over a distance. It is calculated as:

   Work = Force x Distance

Hammers help you do work by making your swing longer and amplifying **force**.
Credit: Malene Thyssen, Wikimedia Commons

   Think of a hammer. A hammer helps you do work by making your arm longer. The **force** you exert on the nail when using the hammer is multiplied by the increase in distance from your arm to the nail. The amount of work by which a machine can multiply a **force** is called the machine's **mechanical advantage**. All **machines** use **mechanical advantage** to multiply **force**.

   A **machine** may multiply the **force** exerted on an object, but ultimately the amount of **force** going into the **machine** (**input effort**) and the amount of **force** produced by the **machine** (**output effort**) always balance out. All of the amplified **force**, or **output effort**, produced by the **machine** comes at a price: To get more **force** or **output effort**, you have to sacrifice some distance. Think of a seesaw: If two objects of unequal weight are placed at either end, the lighter object will have to move farther away from middle of the seesaw to balance the weight of heavier object. The **force** exerted by the lighter object (**output effort**) increases as the distance increases. You have to decide whether you want to save **force** and apply a smaller **force** over a longer distance, or to save distance and apply a larger **force** over a smaller distance.

WATCH A VIDEO ABOUT SIMPLE MACHINES

1. Have students read the following introduction to simple machines:

There are six simple **machines** that create a **mechanical advantage** allowing humans to do more work. They are the **lever**, the **wheel and axle**, the **pulley**, the **inclined plane**, the **wedge**, and the **screw**. These can be thought of as the "building blocks" from which all **machines** are

MEETING 2

composed. Your mechanical door opener will use a few of these simple **machines** to do the work of opening a door.

2. Have students watch the **Simple Machines video**, in which the six simple **machines** are shown and discussed.

3. Have students share with a partner what they learned from the video using the discussion questions as a guide.

DISCUSSION

Have students discuss the following questions with a partner:

- How does a **lever** make life easier?
- How are **levers** used to open doors?
- Do you think a doorknob is a simple **machine**? Discuss why or why not.

SIX SIMPLE MACHINES

1. Have students read the following information on simple **machines**. Tell them that they will learn how engineers combine simple **machines** into **systems** that work together to meet a specific need. Explain that the mechanical door opener they will build involves both **mechanical** and electrical **systems**.

Six Simple Machines

Lever: Many **tools** used for moving things are **levers** that provide the user with a **mechanical advantage** – they can make work easier. There are three classes of **levers** based on how the rigid **tool** moves a load around a pivot point, called a fulcrum, while exerting **force**. Examples: crowbar and scissors (Class 1), nutcracker (Class 2), and tongs and tweezers (Class 3). The arms on your mechanical door opener will be **levers**.

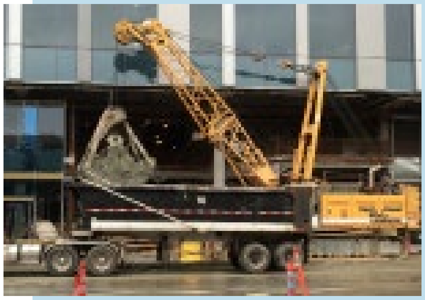
Pulley: A wheel with a groove in it that allows a rope or a chain to slide over it; the wheel helps create a **mechanical advantage** to lift the weight more easily. Examples: flagpole and construction cranes.

Wheel and axle: A **wheel** is locked to an **axle** so they both move together as an assembly. Examples: steering wheel, the wheel of a bicycle and the rear-wheel sprocket.

A car steering wheel is an example of a wheel locked to an axle. Credit: Wikimedia Commons

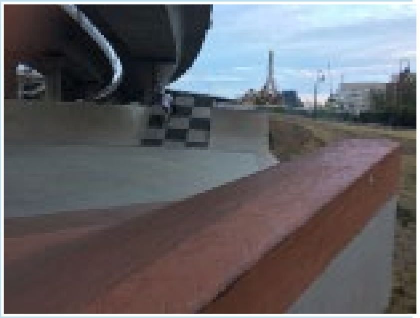
Tongs are an example of a **lever**. Credit: Wikimedia Commons

Pulleys used to lift loads on a ship. Credit: Wikimedia Commons



Construction cranes use **pulleys** to lift heavy loads. Credit: Leigh Estabrooks

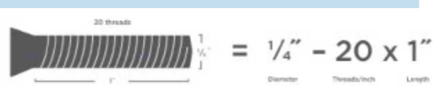
A wheel of a bicycle and the rear-wheel sprocket is another example of a wheel locked to an axle. Credit: Leigh Estabrooks



Skateboard park ramps are examples of **inclined plane**s. Credit: Leigh Estabrooks

Moving truck ramps with access ramps are examples of **inclined plane**s.
Credit: Leigh Estabrooks

Wheelchair or access ramps are examples of **inclined plane**s. Credit: Leigh Estabrooks



Inclined plane: A flat plane lengthens the distance you lift or move something, which increases **mechanical advantage** and lessens effort. Examples: wheelchair or access ramps, moving truck ramps, skateboard park ramps.

Wedge: A triangular-shaped **inclined plane** used to separate objects, hold them in place, or lift them. Examples: **wedge** used to split wood, door stop.

A **wedge** is used to help split logs.
Credit: Benjamin Estabrooks

A doorstop is a **wedge**.
Credit: By Strait

A modern Archimedes **screw** at a pumping station in the Netherlands
Credit: M.A. Wijngaarden

Screws: Screws are used to convert one type of motion into another. They convert rotational or turning motion into linear motion. There are **screw** mechanisms and objects that are commonly called "**screws**." A famous **screw** mechanism was invent-ed by Archimedes in the 3rd century BC. Called a water **screw**, it has been used to move water for irrigation or drainage and many types are still used today. **Screws** made of threads on shafts are used for fastening parts together. **Screws** use their **mechanical advantage** to press two or more pieces of material together like the **screws** that attach hinges and brackets to your door.

EXTEND THE LEARNING

Screws are fasteners. They have heads with eternal, ridged threads on shafts. They are used to hold things like wood and metal objects together. Screw heads are shaped to be used with specific types of screwdrivers like Philips head and flat drivers. Most screws are tightened with a driver when turned to the right.

Screws have characteristics that include length, diameter, and pitch – the distance between threads – that determine how they are labeled and used. For example, a screw labeled "20 tpi x ¼ inch x 1 inch" means the screw has a 20 threads per inch (tpi), a ¼-inch diameter shaft, and a 1-inch length. Learn all about fasteners from this poster developed by MIT's D-Lab.

Gears: Sometimes gears are used with simple **machines**. Gears are used to magnify or reduce **force**, change the direction of the axis of rotation, or increase or decrease speed.

Engineers use their knowledge of the six simple **machines** when they conceptualize, design, and build **mechanical systems** such as the mechanical door opener you will make. You can use your knowledge of how the **machines** work to anticipate and troubleshoot the problems that come up when you build your **mechanical system**. You can even use your knowledge to be creative and exchange one **machine** for another!

2. Have students fill in the chart with examples of simple **machines** they use in their everyday life.

Look at the chart below. Fill in the columns with examples of simple **machines** you have seen in your everyday life.

6 SIMPLE MACHINES	What is it?	Where is it?
Lever		
Wheel and axle		
Pulley		
Inclined plane		
Wedge		
Screw		

SYSTEMS IN ENGINEERING

1. Ask students to read independently the following background on engineering **systems**. Have them underline the important parts in their guides.

A **system** is made up of lots of parts that are put together to do **work**. Inventors often create a **mechanical system** when they put together several simple **machines**. A **mechanical system** accomplishes **work** by using **forces** and movement. You will be constructing a mechanical and electronic **system** in this unit: a mechanical door opener that operates using a switch. Let's break that down.

Mechanical systems are complex assemblies of **machines** that help complete a task. You will be putting together several simple **machines** in your door opener, to create the structure of the door and the basic parts to make it move.

You'll also be creating an electronic **system**. There are three main parts in an electronic **system**: the input, the process, and the output. You'll be learning more about these parts in Meetings 4 and 5. Your electronic **system** will be controlled by a switch and powered by a **motor**.

2. Have students discuss the question below within their teams. Some examples of mechanical/ electrical **systems** are **motor** vehicles, electric bicycles, and air conditioners. Have students try to explain what makes these **systems** mechanical and electrical **systems**.

Amos Winter (PhD, MIT, 2010), now Associate Professor of Mechanical Engineering at MIT, and Tish Scolnik (BS, MIT, 2010) developed the Leveraged Freedom Chair, a wheelchair that uses a lever to push, making it easier for riders to travel over rough terrain. Riders, depending on where they grab the lever, can gain more speed and torque than a regular wheelchair on a flat surface. Read more about how Winter and Scolnik's innovative integration of the lever into an existing mechanical system has helped people gain more mobility in developing countries: Leveraged Freedom Chair.

INVENTION SPOTLIGHT

A "Leveraged Freedom" wheelchair in use. Credit: Prof. Amos Winter

MEETING 2

DISCUSSION

- What are some other examples of mechanical/ electrical systems that you have encountered in your daily life?

INVESTIGATE MECHANICAL DOOR OPENERS

1. Have students read independently the following information on different types of mechanical doors.

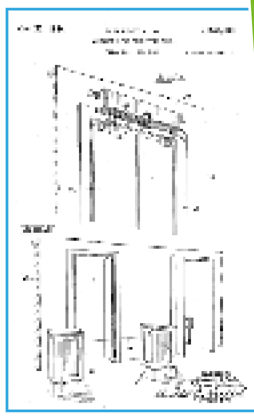
You've probably walked through an automatic door if you've stepped foot inside a commercial or public building. An automatic door is a mechanical door-opening system designed to allow users to pass through with little or no effort. There are many different types of automatically opening doors, and there are several methods to activate them. Some factors engineers consider when designing automatic door styles—and builders use when choosing one—are space, **energy efficiency**, and the nature of the pedestrian traffic that will be coming through the doors.

SENSOR-OPERATED DOORS (A.K.A. "AUTOMATIC DOORS")

- **How they work:** The doors operate by detecting movement via a sensor and then opening automatically. Sensor-operated doors usually have both activation sensors that detect approaching pedestrians, and safety sensors that detect departing pedestrians so that the moving door does not collide with them.
- **How they are powered:** Electricity (motors).
- **Where they are found:** Grocery stores and other commercial buildings.
- **Useful for:** High-volume traffic (energy saving), people with disabilities.

HIGH SCHOOL CONNECTION

Automatically opening doors were the invention (U.S. Patent # 1978093) of Horace H. Raymond and Sheldon S. Roby, engineers at Stanley Works. Raymond developed a pneumatic (air pressure) operator for his kitchen cabinet doors and showed it to his coworkers, who realized the value of his invention. His patent combines a pneumatic operator with photoelectric, or light beam, control to open the door. MIT was one of the first institutions to install Raymond's doors, which became known as "Magic Eye" doors because of the eye-shaped light sensors posted in front of the doors.



The patent was titled "Apparatus for Operating Doors."

The "Magic Eye" doors of MIT's Building 7. Credit: Eurah Ko

HIGH SCHOOL CONNECTION

The 2016 Norwood High School InvenTeam from Norwood, Massachusetts, invented a retractable awning to prevent and clear snow buildup on school roofs. Snow clearing is accomplished with retractable legs and an ejection method that pushes snow off the awning. Read more about this invention here: [Norwood High School InvenTeam]

Credit: lemelson.mit.edu

SWITCH-OPERATED DOORS

- **How they work:** The switch to open the door is operated manually, via a push button or a swipe card.
- **How they are powered:** Electricity (motors).
- **Where they are found:** Airports, train stations, commercial buildings.
- **Useful for:** Security checkpoints and access doors that require more control over the open/close cycle.

A swipe card triggers a switch to rotate these train station turnstiles and lock them after one turn. Credit: Wikimedia Commons

LOW-ENERGY POWER ASSIST DOORS

- **How they work:** Operated by a switch and a door closer. Low-energy power assist doors reduce the **force** or effort it takes to open a door while you push or pull on it.
- **How they are powered:** Electricity (motors), hydraulics, springs.
- **Where they are found:** Libraries, schools, health care facilities.
- **Useful for:** Ease of opening, avoiding "slamming."

A push button activates a switch inside this door opener. Credit: Wikimedia Commons

This low-energy power assist door is operated by a switch. It has a motor-ized door closer (the metal box at the top) that opens and closes the door. Credit: Wikimedia Commons

Have students discuss the following prompts with team members:

DISCUSSION

- Who are the possible users for each door design?
- How is each design adapted to users' needs?
- What are likely drawbacks or problems with each door design? How could the designs be improved?

MEETING 2

IDENTIFY USERS AND THEIR NEEDS

1. Have students read the information in their guides about door users and their needs. Have them **work** in their teams to complete the problem/solution chart.

2. Tell them they have completed the first few steps of the design process, a process that inventors follow in pursuit of new products. This process starts with identifying a problem or need, researching, brainstorming, and formulating ideas. The problem here is that a person in a wheelchair can't push open a door. Solution ideas include an automatic door opener.

IDENTIFY USERS AND THEIR NEEDS

Inventors first identify a need or problem they would like to solve before they begin their designs.

Inventors and designers often examine products already on the market before creating a new product.

Think about manually opening a door. It seems like a simple task, but there are many circumstances in which it's difficult or impossible. Brain-storm users, situations, and locations in which an automatic door would be useful or even vital. Some ideas include:

- People with disabilities
- Indoor/outdoor pets
- Farm animals that need to be "cooped"
- Sanitary reasons (e.g., the doors on public bathroom stalls)
- "Hands full" situations (carrying objects or loading)
- Assisted living residences

INVENTOR SPOTLIGHT

Klemens Torggler, a kinetic artist, creates mechanical art using large rotating squares. He invented a flip-panel door made of two large squares that opens and closes at the touch of a finger. Find out more about Torggler and his invention here: Torggler's doors

Example of Torggler's art.
Credit: Klemens Torggler, Wikimedia Commons

LEMELSON-MIT InvenTeams

Narrow the focus by briefly discussing and researching the various needs of your audience. For example, what disabilities and conditions might affect a person's ability to open and close a standard door? How might a door system designed for a blind person be different from one for some-one with advanced arthritis?

Use the problem/solution graphic organizer here to organize your brainstorm. List the problems and needs of the various users you've identified and potential door design solutions. Think of the automatic door designs you've observed and their features.

User	Problem	Solution

Now you will move from thinking about the problem to doing something that solves the problem. You will learn more about how automatic doors operate (swing arms and motors) as you work with a small team to design and build a prototype of a mechanical door opener system in this unit.

TAKING A CLOSER LOOK: CAD DRAWINGS (OPTIONAL)

1. Explain that inventors and engineers often use **CAD** (computer -aided design) to make detailed precision technical drawings of their designs. **CAD** software allows engineers to "speak" to each other using these technical drawings as a common technical language. These drawings are often used to analyze designs and look for improvements and modifications to make. Read the following material out loud to students:

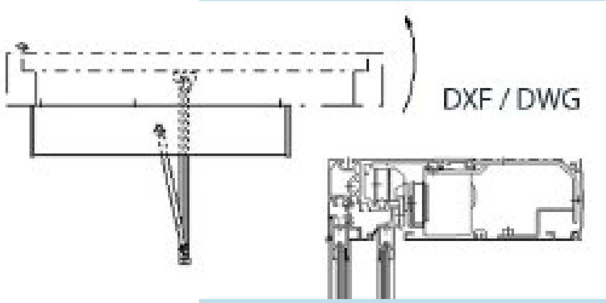
Let's take a closer look at automatic door construction. The **CAD** (com-puter-aided drafting) computer program is used for making detailed precision drawings of the components or elements in a 2-D or 3-D model. There is a **CAD** drawing in your guide and a photo of something called a door closer, which is a mechanical device used to control the rate at which a door opens and closes so that it does not slam. Some-

INVENTOR SPOTLIGHT

Not all door openers adequately meet the needs of people with disabilities. Regina Pontes suffers from several mobility restraints that limit use of both her right and left hands. She asked MIT's Hacking Medicine participants to help build her a door that she can use. The Hacking Medicine program brings together teams of college students, engineers, physicians, and other pro-fessionals to solve some of health care's biggest challenges. Read more about Regina and why people with disabilities still need better-en-gineered automatic doors: Hacking Medicine times door closers are motorized by connecting them to electric motors, either inside or outside the box. You will be using a similar construction for your mechanical door-opening system.

2. Have students take a look at the photo and the **CAD** drawing below and answer the prompts that accompany each one as a team.

- Label the parts of the door closer on both the **CAD** drawing and the photo: control box, control arms, fasteners.
- What simple machines do you notice in the construction of the door closer?
- How are the parts of the closer fastened together?
- How are the control arms attached to the door?
- How are the control arms constructed? What materials are they made of?
- Where should the motor be attached, if it had one—on the door or the wall?
- Why do you think the engineer chose this design? What problem is the door opener or closer solving?



CAD drawing of a door closer.

Credit: Wikimedia Commons

INVENTOR SPOTLIGHT

A team of graduate students at MIT analyzed door use in a building on campus that was equipped with both revolving and swinging doors. They found that the swinging door allowed as much as eight times more air to pass through the building than the revolving door, causing a significant loss of energy in heating and cooling the building. They found that just 23 percent of visitors used revolving doors, although they are more energy-efficient. Read more about the study here: Revolving Doors

SELF-ASSESSMENT

Collect the completed self-assessments as exit slips when students leave.

INDICATORS OF A SUCCESSFUL MEETING

Students demonstrate an understanding of simple machines. Students also understand the three main types of mechanized door openers and how they work. Students complete problem/solution charts and develop an understanding of the design process.

U CONTROL
MEETING 3: BUILD A DOOR

KEY TERMS

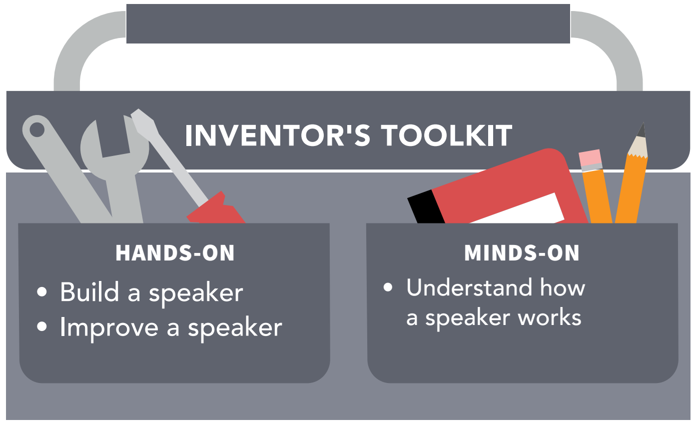
Foam insulation board (n): A stiff, lightweight material that can be easily cut.

Nut (n): A type of hardware, usually made of metal, used to hold together objects that have been connected by a screw.

Pilot hole (n): A small hole drilled or tapped into material before a screw is installed that creates an easy path for the screw to follow and prevents it from splitting the material.

Screw (n): A cylindrical pin or rod with a head on one end, used as a fastener.

Washer (n): A flat ring used with a screw to tighten a joint and redistribute the pressure.



Tools

- Safety glasses
- Writing utensils
- Computer and projector to show videos
- Dust masks

Per Team

- Utility knife
- Yardstick
- Screwdriver set
- Marker

Materials

Whole Group

- Student Guides
- Clear packing tape
- Self-Assessments

Per Team

- 2 pieces of 2-foot x 2-foot x 1-inch foam insulation
- Cardboard to protect tabletops when cutting
- 2 door hinges (2-inch x 1 3/16-inch)
- 4 L-brackets (2 1⁄2-inch)
- 20 **screws** (8-32 tpi x 1 1/2-inch)
- 10 **nuts** (#8-32)
- **Washers** (#8)

Procedure

- Construct a Door (may be divided into two meetings)
- Review the Process
- Self-Assessment

CONSTRUCT A DOOR

1. Tell students that they will be using the steps in their guides to build a door for their mechanical door opener. Explain that inventors create a prototype as the early version of a product idea. The prototype is created with rough, inexpensive or improvised materials to make sure an invention will function as planned. It can also be larger or smaller in scale than the finished product. Ask:

    - What is a prototype in your own words?
    - Have you ever built one?

2. Have students join their teams. Tell them they will be measuring and cutting foam insulation, screwing in **nuts** and bolts, and completing other tasks to build the door.

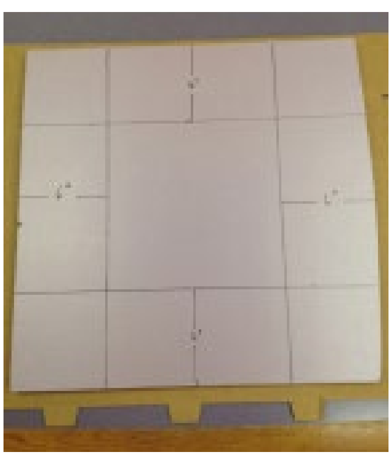
3. Tell students that each person should have specific roles in the building process. Have them revisit their strengths to determine which group members should be in charge of each step. Suggest that they consider having one person read the directions while others work, and switch roles halfway through.

4. Have students begin. Tell them to carefully review the instructions for each step as a team before they start. Use the troubleshooting tips provided to assist them if they run into problems.

5. Collect and store the leftover foam insulation. It will be used later to make mounts for the doors in Meeting 6.

CONSTRUCT A DOOR

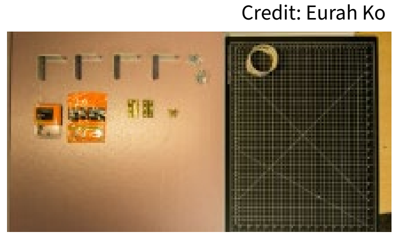
Step One: Measure and mark the foam insulation



Credit: WGBH

- Place the foam insulation on a table with cardboard under it. Use a yardstick to measure 6 inches in from all four sides and mark with tick marks at 1-inch intervals. Draw lines with a marker to connect the tick marks.

Credit: Eurah Ko



MEETING 3

EDUCATOR NOTE

Building the door out of **foam insulation board** may take longer than one meeting to complete. Decide where a good breaking point may be before you begin this meeting with students. Some teams have divided measuring and cutting of the foam insulation from the assembly of the door. Meeting 4 is a minds-on meeting about motors. The important lessons about motors may be balanced with completing the hands-on assembly of the door out of foam insulation that students start in this meeting.

EDUCATOR NOTE

Organize the materials for this meeting ahead of time. Set aside the **screws** that came with the door hinges. The students will be using different **screws**. Do not hand out materials until the last minute, as students will be distracted by them while you are giving instructions. Make sure all students have their safety glasses on before they start.

- Turn the foam insulation over and repeat the process, making sure your measurements are accurate so they align with the other side.

Myco Board produced from mycelium, the vegetative growth stage of fungi. Credit: Ecovative

HISTORY

Foam core is a light, sturdy material that is stiff and easy to use. The company, Monsanto, invented foam insulation in 1957 in 1/8-inch and 3/16-inch sizes for the graphic design industry. It has now become popular in architecture, where it is often used for prototyping small objects, and in the framing industry, for backing paintings. Students often use foam core to mount science fair projects.

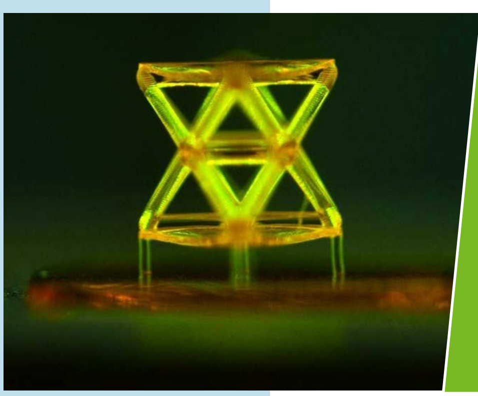
SUSTAINABLE SOLUTIONS

Eben Bayer and Gavin McIntyre created an environmentally friendly insulation called Greensulate™ made primarily of mushrooms, water, and agricultural waste. Bayer says his flash of inspiration came when he realized that you could take a living organism, like fungi (mushrooms), and use its explosive and explorative growth (mycelium) to hold insulating particles together. This thought was inspired by seeing logs, leaves, and other brush being held together in the woods by living networks of fungi mycelium. Bayer was awarded the Lemelson-Rensselaer Student Prize in 2007 for his work. Read more about Bayer and McIntyre's work: Greensulate

Step Two: Make cuts using a utility knife

- Now you're ready to make cuts in the **foam insulation board**. Foam insulation is a stiff yet very workable material that is ideal for prototyping. Watch this video from MIT's Design Online about **cutting foam core safely**, then read the safety tips on the following page.

- Your door will be made from a type of foam insulation, so it's thicker than the foam core board you'll see in the video. The same cutting and safety tips apply.



Microscopic image showing a single unit of the structure. Credit: MIT News

HISTORY

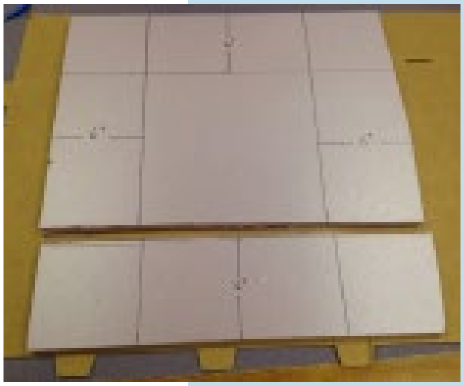
Engineers are always thinking of ways to build lighter, stronger materials. Often, the tradeoff in creating stiff materials is that they are dense and heavy. Engineers at MIT and Lawrence Livermore National Laboratory developed an ultrastiff, ultralight, nanostructured material that is based on repeating patterns, the same principle that makes the Eiffel Tower so strong, yet so airy. Read more here: New Material

SAFETY TIPS

SAFETY

1. **Wear safety glasses.**
2. **Wear dust masks.**
3. **Utility knifes have really sharp blades! Be very careful.**
4. **Always keep the utility knife retracted when not in use.**
5. **Make sure your fingers or other body parts are NEVER in the cutting path.**
6. **Angle the blade straight down, with a low cutting angle.**
7. **Use multiple passes and light strokes.**

- Open a utility knife and cut along the bottom line. Use steady strokes and multiple passes. **Remember to angle the blade straight down or perpendicular to the foam insulation to get the best cut. Use the rigid measuring stick as a guide to keep your fingers out of the way of the blade and to make straight cuts.**
- Your goal is to cut as deeply as you can. If the pieces do not separate, make deeper cuts. You can also gently snap the two pieces apart. Be careful not to force the pieces apart; it may create very uneven edges.



Credit: WGBH

- Turn the foam insulation over and repeat on the other side to make sure you cut completely through the foam insulation.
- Cut the middle square. This will be your "door." You will now have three shapes: an upside down U-shape which will be the door frame, a smaller square shape which will be the door, and a rectangular shape which will be the base. The door frame and base are shown to the right.

Credit: WGBH

EDUCATOR NOTE

Make sure all students are wearing safety glasses and dust masks. Have students practice making cuts a few times on the spare foam insulation before beginning to cut the door.

EDUCATOR NOTE

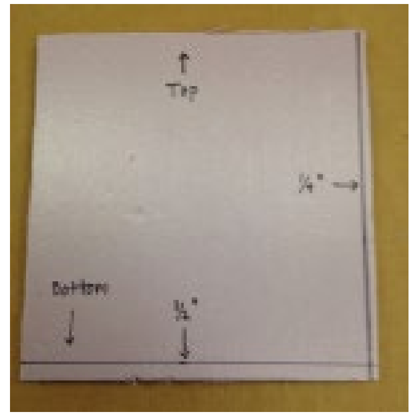
Troubleshooting Tips: The door does not open smoothly and catches against the frame.

The door may not open smoothly if the foam insulation edges are ragged. Test to make sure the door will open. Use the utility knife to shave away the excess to make a smooth edge if it does not open well. Make sure to cut slowly to avoid the knife slipping and to avoid tearing the foam insula-tion. Always cut away from yourself and make sure no one is within an arm's length of the person who is cutting.

EDUCATOR NOTE

Have students practice making **pilot holes** and screwing in **screws** on the spare foam insulation before working on their doors.

- Take the extra piece of foam insulation and measure and cut a 6-inch piece across the bottom only, using the same process as above. This will be a second "base" (rectangular piece).
- Measure and mark a line ½ inch up from the bottom and another line ¼ inch from the right side of the door. This will ensure that the door doesn't get stuck in the frame. Cut along these lines.



Credit: WGBH

Step Three: Attach the door hinges

- Remove the hinges from the packaging and set aside any **screws**. You will be using larger **screws** to attach the hinges to the door.
- Place the door and the frame face up on a flat surface.
- Place a hinge 1½ inches below the top left edge of the door and the inner left corner of the frame. Make sure the raised centers of the hinges are facing up. The hinge should straddle the door and frame.
- Mark inside the top and bottom holes of the hinge with a pencil.
- Place the other hinge 1½ inches from the bottom left edge of the door. Remember to make sure the raised center of the hinge is facing up. Mark inside the top and bottom holes of the hinge with a pencil.
- Remove the hinges. Press a **screw** into all marked areas, making slight indentations in the foam insulation.

Demonstrate where to place the hinges, the first 1½ inches from the top left edge of the door and the inner left corner of the frame, and the second 1½ inches from the bottom left edge of the door. Make sure the students place the raised center of the hinge facing up. The hinges should straddle the door and frame.

Show students how to mark the top and bottom holes of each hinge with a pencil, then use a **screw** tip to make an indentation on the marks.

- Mark the top and bottom holes on either side of each hinge with a pencil. Remember to make sure the raised center of the hinge is facing up.
- Remove the hinges. Press a **screw** into all the marked areas, making a slight indentation in the foam insulation.

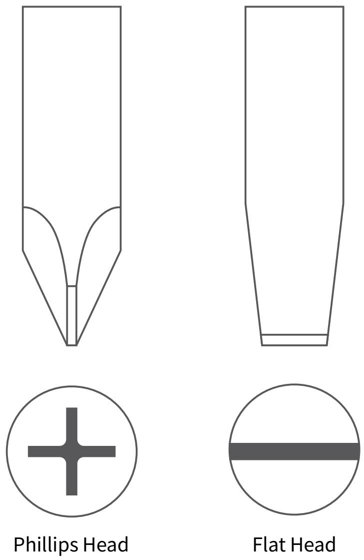
PILOT HOLES

The process of pressing a **screw** into foam insulation is similar to drilling "**pilot holes**" in wood construction. Builders drill a small hole into a piece of wood before installing a **screw**. The **pilot hole** creates a path for the **screw**, to help ensure it goes in straight and doesn't split the material.

- Use a Phillips head screwdriver to screw in the **screws**, pushing them slightly as you go. Foam insulation is sturdy but is still easy to split.
- You can help to avoid splitting by having one team member hold the foam insulation in place while another drives in the **screws**. Do not screw hardware too tightly or too forcefully.

PHILLIPS HEAD AND FLAT HEAD

You may have heard the terms "Phillips head" and "flat head" to describe **screws** and screwdrivers. The term "Phillips head" refers to a type of beveled **screw** head invented by a man named Henry F. Phillips. One must use a Phillips head screwdriver to drive this type of **screw**. A flat head screwdriver is a screwdriver with a flat blade. It's used to drive slot head **screws** and other **screws** without a beveled **screw** head.



- Place a **washer** over the exit end of each **screw** and twist a **nut** over the **washer** until secure.
- Test to make sure your door opens and closes easily. Smooth the rough edges with the utility knife if it does not.

EDUCATOR NOTE

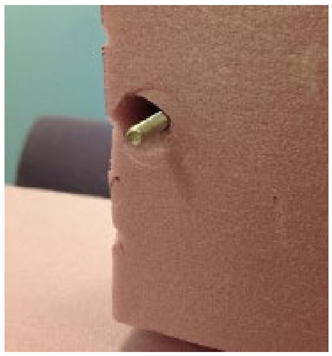
The instructions in Step Four are definitely a four-person job. Have students take turns holding the frame and brackets, and so on. Encourage them to discuss roles and how to make the process easier as they work.

Some students may still take over the building process while others sit back. Make sure each person has a role and is actively participating.

TROUBLESHOOTING TIPS:

A screw split the foam insulation near the edge: Try to screw straight down and not at an angle. Reinsert the **screw** at an angle if the **screw** is too close to the edge of the foam insulation.

A screw creates a hole in the foam insulation that's too big: Remember to be gentle when screwing the hardware in place—foam can "tear" easily. Do not push too hard. Use a **washer** to stabilize the area if you make too big a hole where the **screw** exits. Make sure you don't tighten the **nuts** so much that they dig into the foam insulation.

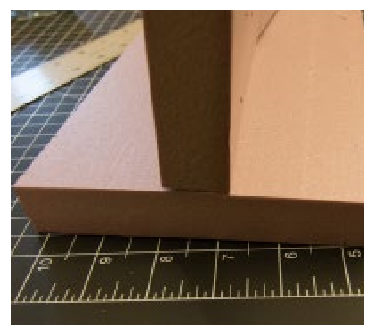


The foam insulation may split or develop holes that are too large if you screw in the hardware too forcefully or too close to the edge.
Credit: WGBH

Step Four: Attach L-brackets to the frame

NOTE: Throughout these steps, handle the materials gently to make sure they aren't damaged.

- Position the frame with its attached door vertically on top of the base. Make sure that the frame is centered and its edges match the short edges of the base.
- Have a team member hold the frame in place while another positions one L-bracket on either side of the frame, about 11⁄2 inches from the edge of the base. Make sure the brackets do not hang over the edge of the base. Do not attach them yet.
- Position the other two brackets 11⁄2 inches from the bottom inner edge of the frame. The structure will not be as stable if you don't place them appropriately.



Make sure to stagger the L-brackets.
Credit: Eurah Ko

LEMELSON-MIT JV InvenTeams

- Have a team member mark the holes in the L-brackets with a pencil to show where the **screws** will go. Remove the door frame, keeping the brackets in place.

- Press a **screw** into all marked areas, making a slight indentation.

- Place the frame back onto the base and begin to screw the L-brackets into the base and the frame. Do one side at a time.

- Use a screwdriver to screw the machine **screws** through the foam insulation, pushing gently as you go. Place a **washer** over the **screw** and twist a **nut** over the **washer** until secure.

- Periodically check to make sure the L-brackets are tight enough against the frame to hold it stable.

An L-bracket attached to the inner edge of the door frame.
Credit: WGBH

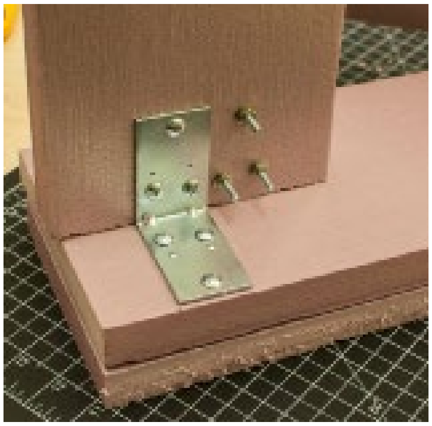
Machine screws secured with **nuts** and **washers**.
Credit: WGBH

Step Five: Attach the extra base

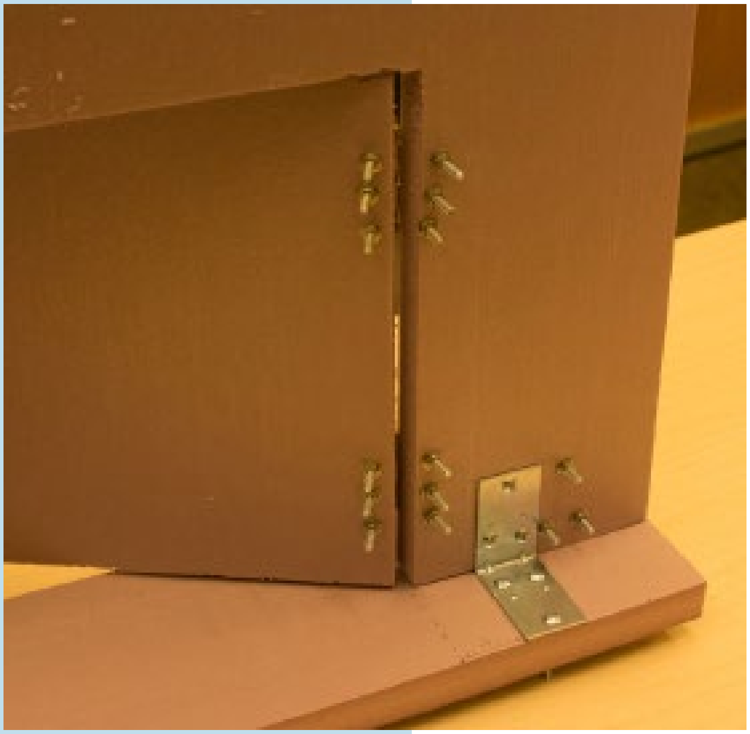
Attach the extra base (sub-base) beneath the base of the assembled door. This will help prevent the **screws** at the bottom from catching and scratching surfaces.

- Place the sub-base under the base, matching the edges. Gently push down on each side of the base to press the ends of the **screws** into the top of the sub-base.

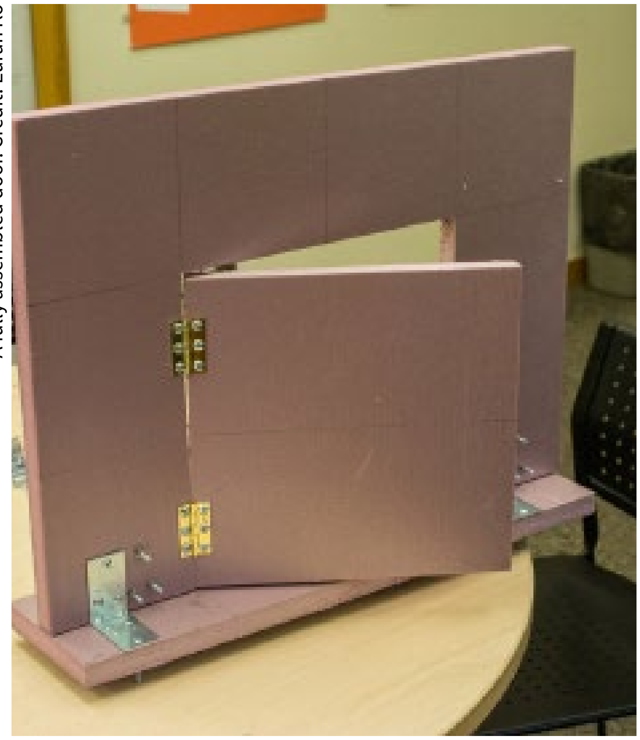
- Tape the sub-base to the base.



Tape the sub-base to the base.
Credit: Eurah Ko



Credit: Eurah Ko



A fully assembled door. Credit: Eurah Ko

HIGH SCHOOL CONNECTION

The 2018 Dayton High School InvenTeam from Dayton, Oregon, invented a system to monitor and automate home chicken coops. The system includes a live feed camera view into the coop, a door opener with a programmable timer, and temperature monitor with a fan to automatically cool the coop when temperatures go above a programmed threshold value. Learn more here: [InvenTeam]

Credit: lemelson.mit.edu

REVIEW THE PROCESS

Tell students they have just built the base, or skeleton, of their mechanical system! Most mechanical systems have a central structure to which other parts are added. They'll be attaching and constructing the other parts (the control arms and the motor) of their mechanical door-opening system in Meeting 6. Have students discuss the following prompts with their teams, and then have them share their thoughts with the whole group:

- Think about any problems you had putting together the door. What do you think caused the problems? What would you do differently next time to avoid the problems?
- Think about the materials used—what are the pros and cons of each material? Can you imagine different and/or better materials to use for prototyping? What are the pros and cons of these materials?
- What improvements would your team make to the design of the door? What would you do differently?

SELF-ASSESSMENT

Collect the completed self-assessments as exit slips when students leave.

INDICATORS OF A SUCCESSFUL MEETING

Students construct a door and a door frame. Students demonstrate an understanding of **screws** as simple machines and what foam insulation is. Students acquire hands-on skills by using a utility knife to safely cut foam insulation.

U CONTROL
MEETING 4: MOTORS 101

KEY TERMS

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

Hydraulics (n): The branch of science concerned with the flow of liquids through pipes and channels.

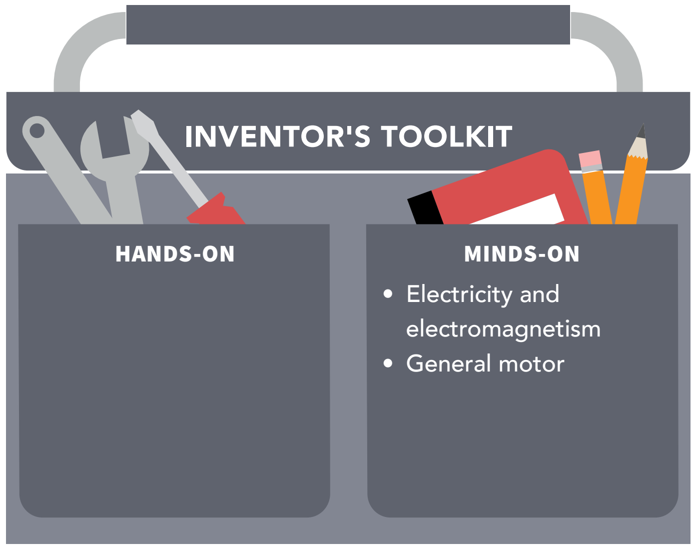
Load (n): A weight or source of pressure on something.

Lorentz force (n): The force exerted on a charged particle moving through an electric and magnetic field.

Magnetic field (n): The force field that fills the space around a magnet or a wire carrying an electric current.

Millinewton meters (mN*m) (n): A unit of torque often used in motor specification sheets.

Motor (n): A mechanical device that generates motion.



Tools

- Computer and projector to show videos
- Writing utensils

Materials

Whole Group

- Student Guides
- Motors
- Self-Assessments

Procedure

- The Science of Motors
- Watch a Video: Electrons in Motion
- Investigate Motors
- Reading Motor Spec Sheets (optional)
- Self-Assessment

THE SCIENCE OF MOTORS

1. Remind students that they have investigated door openers and users' needs, learned how simple machines operate, and built their doors and door frames. They will now explore **motors**—the devices that will make their doors open and close. Tell them they'll read some information about **motor** science, watch a video about how **motors** work called Electrons in Motion. Ask the group:

- What everyday devices are you familiar with that operate using **motors**?
- How does the **motor** make the device work?
- How do you think a **motor** will make your door opener work?

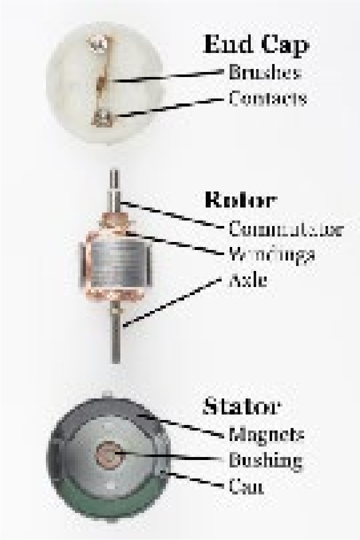
2. Read the following information on how **motors** work out loud to students, or have them read it independently.

You have just completed several steps in the design process. You have investigated door openers and users' needs, learned about how simple machines operate, and built the base of your door.

But, how are you going to make your mechanical door opener . . . open? The **actuator** is the most important component in any mechanical system. The **actuator** is the thing causing the movement. A **motor** will be the **actuator** in your door opener, causing the control arms and the door to move. It's helpful to know how a **motor** works so you know how it will open and close your door and how to attach it to the door.

The typical **motor** used today has two basic parts: a **stator** and a **rotor**. The **stator** is a stationary magnet inside the **motor**. There is a coil of wire inside the **stator** mounted on an axle that spins. This is the **rotor**. When electricity flows through wires, it creates a **magnetic field**, which will either repel or attract a magnet. Devices called brushes carry the current to a commutator, which reverses the electric current so that the magnet is constantly repelled, attracted, repelled, attracted, and so on. This constant repelling and attracting serves to keep the **motor's** shaft spinning. The shaft is a metal piece attached to the end of an axle. It is the part of the **motor** to which a **load** or gears are attached.

DC motor.
Credit: Wikimedia Commons



Inside a DC motor.

MEETING 4

KEY TERMS (CONT'D)

Nominal voltage (n): The voltage at which a device operates best.

Ohm's law (n): A law that states that voltage is equal to current times resistance.

Resistance (n): A material's tendency to resist the flow of charge (current).

Revolutions per minute (rpm): The measure of the frequency of rotation.

Rotor (n): The part of a motor that turns; the shaft is attached to it.

Stator (n): The stationary part within which a rotor turns.

Torque (n): A measure of the tendency of a force to rotate an object about a fixed point.

Voltage (n): The relative difference between any high-energy and low-energy point; it is measured in volts (V).

Velocity (n): The speed of something in a given direction.

EDUCATOR NOTE

Building the door out of foam insulation may take longer than one meeting to complete. This meeting is a minds-on meeting about motors. The important lessons about motors may be aided by completing the hands-on assembly of the foam insulation door that students started in the last meeting.

3. Review the prompts below and have students share what they learned with a partner. Point out the **motor** diagrams, which they should reference for the prompts.

- What causes a **motor's** shaft to spin?
- How would you attach the control arms to the **motor** based on the door opener pictures you viewed in the last meeting? Circle the location of the **motor** in the first picture.
- The second picture shows the inside parts of a **motor**. Can you still identify where you would attach the control arms on the **motor**? Circle the location on the **motor** diagram (picture 2).

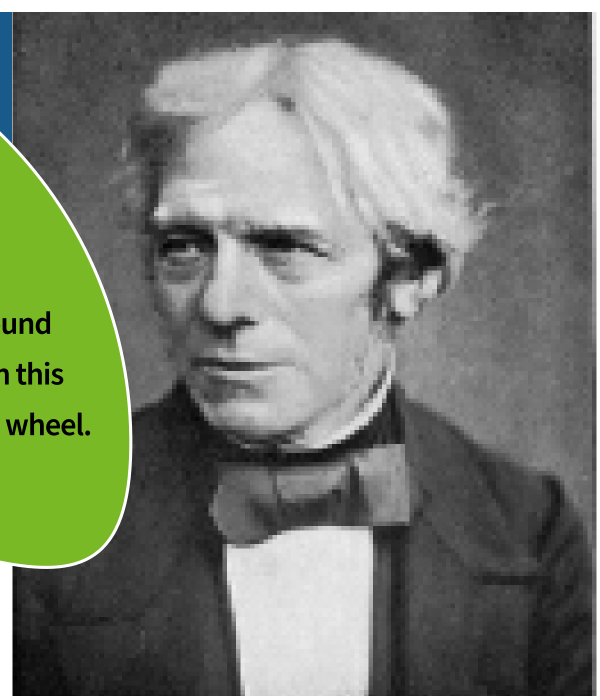
First electric model car.
Credit: Wikimedia Commons

HISTORY

The first rotating device driven by electromagnetism was built by Peter Barlow in England in 1822. Moritz von Jacobi created the first rotating electric motor in 1834. Two Dutchmen, Sibrandus Stratingh and Christopher Becker, took the electric motor a step further by using it to power a small model car in 1835, which became the first known practical application of an electric motor.

INVENTOR SPOTLIGHT

Michael Faraday is one of the most important inventors in history. He was one of the first to understand that an electric current flowing through a wire produces a magnetic field around that wire. He invented many rotating devices based on this principle, including the Faraday rotator and the Faraday wheel.



Michael Faraday.
Credit: Wikimedia Commons

WATCH A VIDEO: ELECTRONS IN MOTION

1. Play the video about how motors work, Electrons in Motion, which gives an overview of the basic principles behind motor science.

2. Have students respond to these questions in their guides:

- What did you learn from the video about the science behind how motors work? Describe in your own words how the **rotor**, **stator**, and shaft work together to make a motor work.

- What motion does the motor generate to do work? How is this motion useful in opening a door?

3. Ask for volunteers to share their responses with the whole group.

EXTEND THE LEARNING

Inventions that revolutionize fields—like the integrated circuit—are called macro inventions. Macro inventions change the way we live and do business. The light bulb and the steam engine are examples of macro inventions. Micro inventions demonstrate improvements and advancements in current inventions. The separator condenser for the steam engine is an example of a micro invention. It improved upon the steam engine's design. Such inventions are very important but do not have the same scale or breadth of impact on our lives as macro inventions. Often, macro inventions precede micro inventions. Micro inventions are evidence that one can always invent improvements!

EXTEND THE LEARNING

The force behind the movement of the wire in an electric motor is referred to as the Lorentz force. When an electric charge moves through an electric field, the force moves in the same direction as the electric field. When an electric charge moves through a magnetic field, the force moves in a direction perpendicular to the magnetic field and the direction the charge moves in. This is what makes the wire in an electric motor rotate over the magnet. Consider the direction of the electric current, where the magnetic field might be, and the direction of the motion of the wire.

INVESTIGATE MOTORS

1. Summarize the two main categories of motors and the three different types of DC motors using the content below. Have students read the short guide to motors and underline the important parts as they read.

INVESTIGATE MOTORS

Motors generally fall into two main categories: DC and AC. DC motors use the constant flow of electricity from batteries. AC motors use the AC current from a typical wall socket to drive them.

There are three main types of motors within the DC motor family: standard brushed DC motors, gearhead motors, and servo motors. The standard brushed DC motors are the simplest and have coils of wire, shafts, magnets, commutators, and brushes enclosed in a case. The gearhead motors and servo motors are more complex. Gearhead motors have gears attached to the shaft, and servo motors contain control systems along with gears to allow for precise position control.

Standard brushed DC motor.
Credit: Wikimedia Commons

Standard brushed DC motor: This is one of the main types of motors. It has four main components—coils of wire, shaft, magnet, commutator, and brushes—enclosed in a case.

- Uses: Toys, simple tools, appliances
- Pros: Inexpensive, lightweight
- Cons: Can be noisy, less control over speed and motion

Gearhead motor.
Credit: Wikimedia Commons

Gearhead motor: A motor with a gearhead on it. A gearhead is a box of gears that attach-es to the shaft of a motor. Adding a gearhead to any motor will reduce the speed while simultaneously increasing the **torque**. **Torque** is the measure of the tendency of a force to rotate an object about a fulcrum, or pivot point. More **torque** means more power to make something rotate. Gearing can be add-ed to any type of motor, not just DC motors.

- Uses: Robotics, radio-controlled cars
- Pros: Speed reduction, increased **torque**
- Cons: Less precise motion control, friction causes balky movement

Servo motor: A motor that has a control system in that allows for precise speed and/or positioning.

- Uses: Robotics, radio-controlled cars
- Pros: Low cost, precise motion control
- Cons: Limited range of motion

Servo motor.
Credit: Wikimedia Commons

2. Give each team the motor they'll be using for their mechanical door opener. Give students time to examine the motors and then have them respond to these questions in their guides:

- Which motor, of the three motors described above, do you think is the one you will be using on your door opener?
- Identify the parts of the motor and their functions.
- How do you think the parts work together?

EXTEND THE LEARNING

It can be harder to pedal, but you go farther with each pedal, when you ride a bike with gears and shift to a lower gear. It is easier to pedal, but you do not travel as far with each pedal, when you shift to a higher gear. This is torque at work. Torque is the measure of the tendency, or ability, of a force to rotate around a fulcrum, or pivot point; velocity is the speed of something in a given direction. You reduce the speed of the shaft, but gain torque, when you add gears to a motor. In other words, the motor goes slower, but is stronger and has more ability to move a load about its shaft. If you want to open a full-size door, you would want a powerful motor that comes with gears or to which you can add gears. For more information, visit: Drives and Gears

EDUCATOR NOTE

Motor *specification* sheets are commonly referred to as spec sheets. This may need to be communicated to the students.

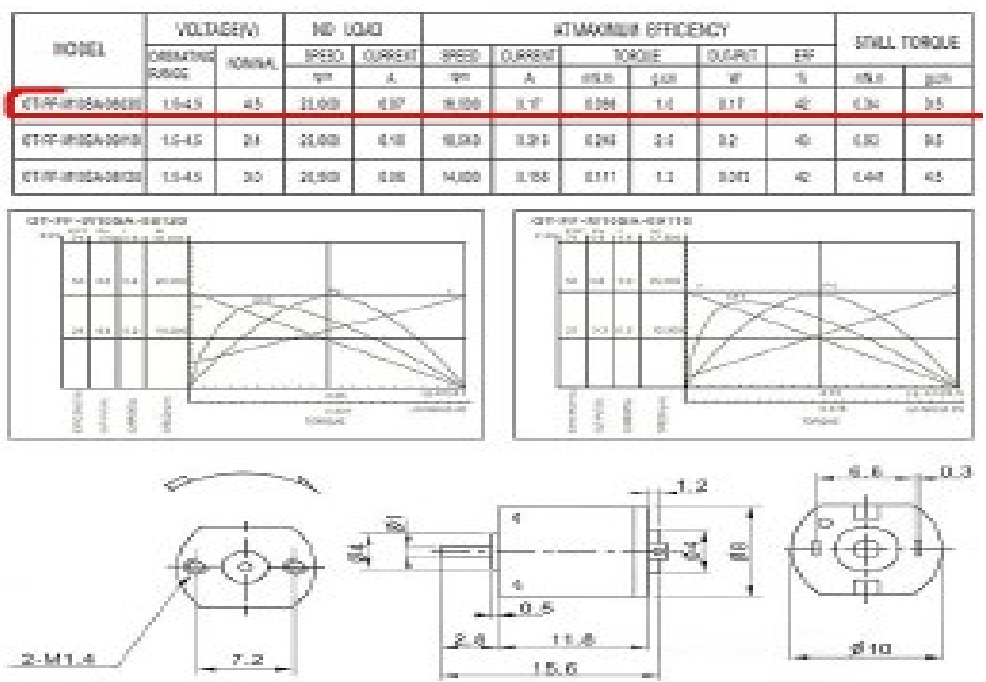
READING MOTOR SPEC SHEETS (OPTIONAL)

1. Do the following activity with students if time permits and if your students will benefit from some math exercises. Have them read independently and then discuss the information in their teams. Tell students that the following reading will help them choose a motor for other projects that may involve motors.

READING MOTOR SPEC SHEETS

You'll make a prototype of a door opener using foam insulation board and simple hardware in this U Control unit, but what if you wanted to make a full-sized door opener? How would you determine which motor to use?

One of the first questions you will want to answer when choosing a motor for a project is: How powerful does the motor need to be? Motors usually have specification or "spec" sheets that give the specifications for a particular motor. These spec sheets usually tell you how much **voltage**, or power, the motor needs to operate, how fast the motor spins, and how much weight or pressure it can handle before it stops spinning. Let's explore a typical spec sheet for a DC motor:



Credit: SparkFun

Look at the headings: **Voltage**, No **Load**, At Maximum Efficiency, and Stall **Torque**. These are typical pieces of information you will find on a motor spec sheet. But what do they mean? Here's a short guide to decoding each piece of information:

Voltage: This tells you how much **voltage** the motor will need to spin. **Voltage** is the relative difference between any high-energy and low-energy point; it is measured in volts (V). The motor will operate when you give it between 1.5V–4.5V in this case. However, the motor will work best when given the **voltage** at the top end of the range, the value under the "Nominal" heading.

No Load: Load refers to the object or weight that will be applied to the motor's shaft. "No **Load**" tells you how many **revolutions per minute (rpm)** the motor will spin without a **load** attached to it ("Speed" is how fast, and "Current" is at what amperage).

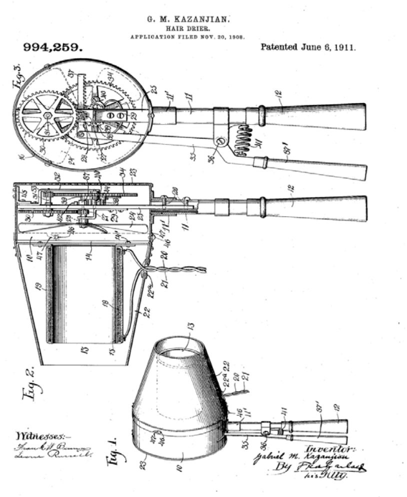
At Maximum Efficiency: These values tell you how fast the motor will spin with the **load** attached. They tell how the motor performs at "maximum efficiency," in other words, with the least amount of input power being wasted.

Stall Torque: This tells you when the motor has reached its limit of **resistance** and will stop spinning. In other words, it's the maximum strength of the motor. It is usually measured in **millinewton meters (mN*m)**, which is force times distance. Check the online source **www.onlineconversion.com/torque** to change mN*m into U.S. standard units (e.g., oz-in.) to get a clearer sense of how much force, or weight per unit of distance, your motor can handle.

For more information about selecting the right motor, check out: **Motor Selection**.

EXTEND THE LEARNING

Inventions for hair dryers go back to the 19th century, but it wasn't until the mid-20th-century that the first hand-held blow dryer was invented. The patent for the first hand-held hair dryer was held by an Armenian-American named Gabriel Kazanjian in 1911. His hair dryer boasted a compact design that made it portable and easier to use than larger versions. The hair dryer was operated by a crank that would turn a system of gears inside the device. A heater inside heated air as it passed through and out the barrel. See Kazanjian's patent here: Hair Dryer



Patent diagram of the first hand-held hair dryer.

CALCULATE

You may want to find out how fast a motor will spin when you add a **load** to it before choosing a motor. You first need to multiply the **torque load** (the **load** you are putting on the motor) by the quotient of the speed at which the motor runs without a **load**, and the motor's stall **torque load**. Then you subtract the result from the motor's no-**load** speed:

Step 1: Torque load x (No-**load** speed/ Stall **torque**) = Speed Loss with **load**

Step 2: Motor no-**load** speed – Speed Loss with **load** = Motor speed with the **load**

Here is an example of the calculation:

The motor's no-**load** speed is 23,000 **revolutions per minute (rpm)** and the stall **torque** is 0.34 **millinewton meters (mN*m)**. Suppose you placed a **torque load** of 0.2 oz-in. onto the motor's shaft. How fast would the motor spin?

INVENTION SPOTLIGHT

The Vehicle Assembly Building at NASA's Kennedy Space Center in Florida is home to the production of giant rockets and space shuttles and has the world's tallest doors. Four doors rise 456 feet high and weigh 888 tons. How do you power open the world's largest, heaviest doors? The answer is via hydraulics. Hydraulics use pressurized liquids to produce and transmit power in a system. Extremely large, heavy doors are often driven by hydraulic power sources, which make them better able to resist compression and more efficient at lifting heavy loads. Read more about the doors here: Hydraulic Doors

Step 1: 0.03 mN*m. x (23,000 rpm/0.34 mN*m) = 2,029 rpm (Speed Loss with **Load**)

Step 2: 23,000 rpm – 2,029 rpm = 20,971 rpm (Motor Speed with New **Load**)

The motor's shaft will turn at a rate of 20,971 rpm with a **torque load** of 0.03 mN*m.

Complete the calculation with a 0.5 mN*m **torque load** added to motor shaft. Now that you know how to calculate the speed of a motor with a particular **load**, you're well equipped to select motors for a variety of applications.

SELF-ASSESSMENT

Collect the completed self-assessments as exit slips when students leave.

INDICATORS OF A SUCCESSFUL MEETING

Students can summarize the basic science concepts behind how motors work. Students demonstrate an understanding of the basic types of motors. They can identify the basic parts of a DC motor and explain how they operate. Optional activity: Students know how to read and interpret a motor spec sheet.

U CONTROL

MEETING 5: CONTROLLING A MOTOR

KEY TERMS

Breadboard (n): A board for making an experimental model of an electric circuit.

Circuit (n): A closed loop that allows electric charges to move within the loop.

Conductor (n): A substance, body, or device that easily lets electricity pass through.

Electric current (n): The rate at which electric charges are flowing.

Ground (n): The process of excess charges moving away from a charged object to a much bigger neutral conductor.

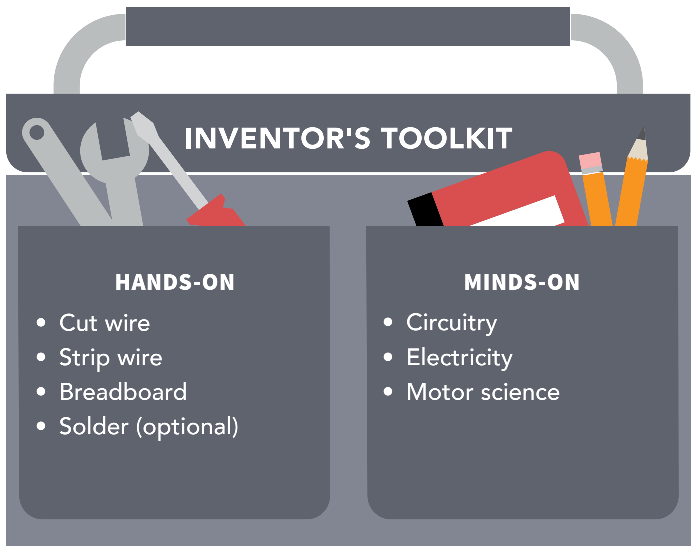
H bridge (n): A type of integrated circuit chip that allows voltage to be applied across a load in either direction.

Polarity (n): The positive or negative state in which a body or system reacts to a magnetic or electric field.

Relay (n): A device used to transmit a signal to open or close a circuit.

Resistance (n): A material's tendency to resist the flow of charge.

Resistor (n): A device designed to introduce resistance into an electric circuit.



Tools

Whole Group

- Writing utensils
- Computer and projector to show videos
- Safety glasses
- Dust masks
- Soldering iron and lead-free solder (optional)

Per Team

- Jewelry pliers
- Small screwdriver set
- Wire cutter/stripper

Materials

Whole Group

- Student Guides
- Red and black solid core wire
- Painter's tape
- Self-Assessments

Per Team

- Servo motor
- DC motor
- 1 9V battery
- 8 AA batteries
- 2 battery holders (each holds four AA batteries)
- 1 9V battery snap holder
- 1 breadboard
- 1 jumper wire set
- 1 SPDT switch (on-off-on toggle)
- 1 H-bridge motor driver chip

Procedure

- Build a Simple Circuit
- Controlling the Motion of a Motor
- Build a Circuit to Control a Motor
- Self-Assessment

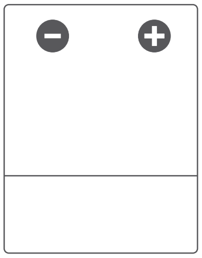
BUILD A SIMPLE CIRCUIT

1. Review with students what they've learned so far. They've learned that a motor converts electrical energy into mechanical energy using wires and magnets. Electricity flows through wires, which creates a magnetic field that either repels or attracts a magnet that is near it. The wires are connected to a shaft, which spins from the constant repelling and attracting of the magnet. Tell students that in this meeting they will learn how to control the motion of a motor.

2. Read and review the background information on **circuits** with students, and then have them do the activity that follows with their teams:

A **circuit** is a closed loop that allows an electric charge to move in the loop. You are making the loop, or closed **circuit**, when you touch the wire. You cause **electric current** to flow the other way when you reverse the battery connections. In other words, you reverse the **polarity** of the battery. This causes the shaft to spin in the opposite direction.

Polarity is the positive or negative state in which an object reacts to a magnetic, electric or other field. It tells whether electrons are moving to ward or away from an object. Batteries are an example of a **polarized** component. Usually batteries will indicate positive and negative terminals with "+" and "-" symbols. Red and black wires correspond to **polarity** as well: Red wires are usually used to connect to the positive terminal of a battery, and black wires are usually used to connect to the negative side. **Polarity** is very important in electronics, so you want to connect **polarized** components in the correct direction. Otherwise, you may either "short out" your components, or they just won't work.


A battery has a positive and a negative terminal.

SAFETY

"Shorting out" electric components can be unsafe. It can cause smoke, sparks, or damage to components. Always wear safety glasses when making circuits in case you connect the parts incorrectly.

MEETING 5

KEY TERMS (CONT'D)

Short circuit (n): A circuit with low resistance resulting in a high electric current.

SPDT (n): Single pole, double throw switch.

SPST (n): Single pole, single throw switch.

Solder (v): The process of joining metal objects with a fusible metal called solder, solder can be used as both a verb and a noun.

Switch (n): A device for opening or closing an electric circuit.

Transistor (n): A device used to amplify and switch electronic signals.

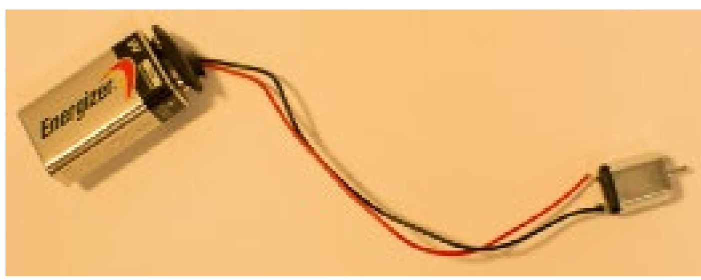
EDUCATOR NOTE

Students, after reading, will work in teams to build a simple circuit. Each team will need a DC motor with leads, a 9V battery, a battery snap holder, and painter's tape. Gather these materials ahead of time.

Work in your teams to do the following:

- Get a DC motor with the wire leads on it, a 9V battery, and a battery snap holder.
- Snap the battery holder onto the 9V battery. The battery is your power source.
- Take a small piece of painter's tape and wrap it around the shaft of the DC motor.
- Touch the black wire from the motor to the black wire of the battery.
- Touch the red wire from the motor to the red wire from the battery. What happens?
- Reverse the connections by touching the red wire of the motor to the black wire of the battery. What happens now? Repeat by touching the black wire of the motor to the red wire of the battery.

3. Tell students they have just created a simple circuit to operate a motor and to change the direction of a motor's rotation.



Example of a simple circuit.
Credit: Eurah Ko

EXTEND THE LEARNING

Electrical currents like to flow from a higher voltage to a lower voltage. You divert the electrical charge and do something useful, like make a light bulb light or a motor move, when you put a load in the path of an electrical current. There isn't anything to slow down the current when there is no load, so the current flows freely and can overload the circuit, causing a "short circuit." This can cause wires to burn up, batteries to drain, or other damage to occur to the power supply. Always be aware of how you connect polarized components. Never directly connect the pos-itive side to the negative side of a polarized power supply (such as a battery) or you will create a short circuit.

MEETING 5

CONTROLLING THE MOTION OF A MOTOR

1. Have students independently read the following information and underline the important parts as they read.

You've seen that all you need to switch the direction of a motor is to switch the polarity of the current. But how do you make your motor go in different directions without having to disconnect and reconnect wires each time?

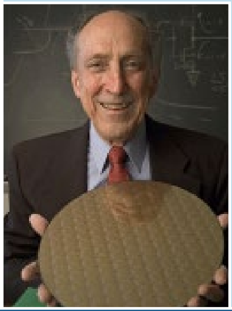
What you need to do is integrate circuits with all of these functions in one system. Luckily, inventors and engineers have identified this need and have designed devices such as SPDT (single pole, double throw) switches, H bridges (a type of integrated circuit chip), and breadboards to streamline the process. You can control the motion of the motor for your mechanical door opener without manually switching the wires with these devices. Read on to learn more about each device.

SWITCHES

A switch is a device that controls the flow of a current in a circuit by determining the "open-ness" or "closed-ness" of the current. Two metal pieces inside the switch touch, allowing current to flow, when the switch is at the "on" position. The metal pieces are pushed apart, stopping the flow of current, when the switch is at the "off" position. Think of a light switch: The path of the electric current flows, and the light turns on, when you turn it on. The path of the current is stopped, and the light turns off, when you turn it off.

An SPST (single pole, single throw) switch has two positions—on and off. Pole refers to the number of circuits a switch can control, and throw refers to the number of wiring path choices a switch can provide. The SPST switch can only control one circuit in one wiring path. An SPDT (single pole, double throw) switch is a type of switch that has three positions—on, off, and on. It also controls one circuit, but the circuit has two configurations. It has two types of "on" positions, accommodating two paths for the electric current.

Inside a light switch.
Credit: Wikimedia Commons

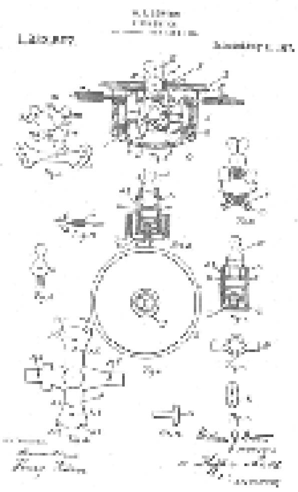


Robert Dennard.
Credit: Alan Orling, IBM
(Lemelson-MIT site)

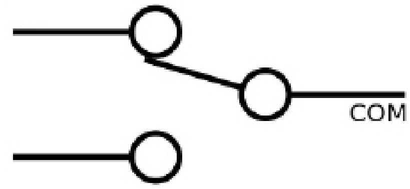
INVENTOR SPOTLIGHT

Robert Dennard grew up in rural Texas. He was always looking for better, faster ways to do things—especially laborious chores like chop-ping wood. He and his colleagues at IBM conceived the scaling theory, a concept that led to denser, less expensive, and faster integrated circuits. These developments then led to the computer industry's "miniaturization," the concept that drives the production of portable computing devices such as laptops and cell phones. He won the $100,000 Lemelson-MIT Lifetime Achievement Award in 2005 for this and other contributions to the microelectronics field. Watch this video of Dennard discussing his life as an inventor:

Robert Dennard



SPST Switch
Credit: Wikimedia Commons



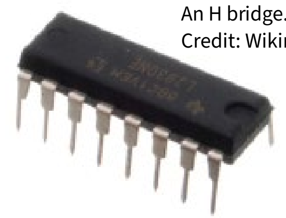
SPDT Switch
Credit: Wikimedia Commons

Above is an SPST switch and below is an SPDT switch. Note that two con-tacts are being made (open/closed, off/on) in the SPST switch, and three contacts are involved (open/closed/open, on/off/on) in the SPDT switch.

PATENT SPOTLIGHT

William J. Newton was the inven-tor of the first toggle switch under U.S. Patent # 1233597 A. His "flush switch" allowed a single lever, or toggle, to control multiple circuits in a light switch.

H BRIDGES



An H bridge.
Credit: Wikimedia Commons

Integrated **circuit** chips are chips that connect **circuits** using transistors and relays and other components. A transistor is a device used to amplify and switch electronic signals, and a relay is a device used to transmit a signal to open or close a **circuit**. These allow users to combine **circuits** in one device.

H bridges are a special type of integrated **circuit** chip. An **H bridge** works by allowing current to flow across a load in either direction through a series of gates, or switches, that exist inside the device. There are four gates inside an **H bridge** that control the flow of current. The **H bridge** in the photo has 16 pins, or metal legs. They are numbered from 1 to 8 down one side of the bridge, and from 9 to 16 up the other side of the bridge. Each pin on the **H bridge** has a unique position and function in conducting the **polarity** of a **circuit**, which is why it is critical that each wire is connected to one of the slots on the row next to the correct pin in the **breadboard**.

EXTEND THE LEARNING

Marie Van Brittan Brown, a nurse, invented and patented a device for closed-circuit television security. Brown was concerned about home safety and developed a security system using a motorized camera, a monitor, and peepholes. The camera was set up to take images through four peepholes in a door, and would send the images to the monitor. The door could also be unlocked remotely using an electric switch. Brown's invention was patented in 1969 as number 3,482,037. This became the predecessor of the modern closed-circuit television (CCTV) system used today for surveillance and crime prevention. Learn more: Marie Van Brittan Brown

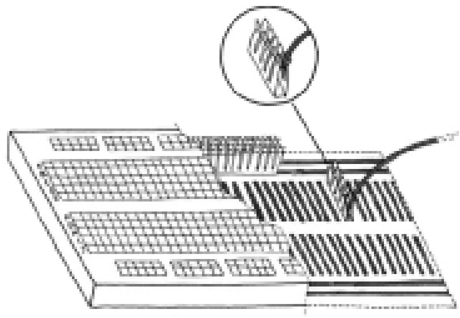
Marie Van Brittan Brown
Credit: Wikimedia Commons

BREADBOARDS

Creating **circuits** can be a burdensome process. **Soldering** all of those connections can be time-consuming, and if you make a mistake, you have to make those connections all over again. **Breadboards** are devices used to connect wires quickly, temporarily and, most importantly, without **soldering**.

Breadboards consist of a network of connected rows of metal links covered by a plastic shell. The metal links connect to create one continuous **circuit**. The rows are numbered to help you keep track of the connections. You create electrical **circuits** by inserting the wires and pins of electrical devices into the holes on the top of the board. The wire conducts electricity through the metal links in that row.

Metal links are inside the **breadboard**. A wire inserted into a metal link is electrically connected to other wires or pins inserted into the same metal link.



Credit: Wikimedia Commons

There are power rails on both sides of the board. They have a power column (+) and a ground column (-). Usually, batteries are hooked up to them to provide power to the rows on that specific side of the **breadboard**.

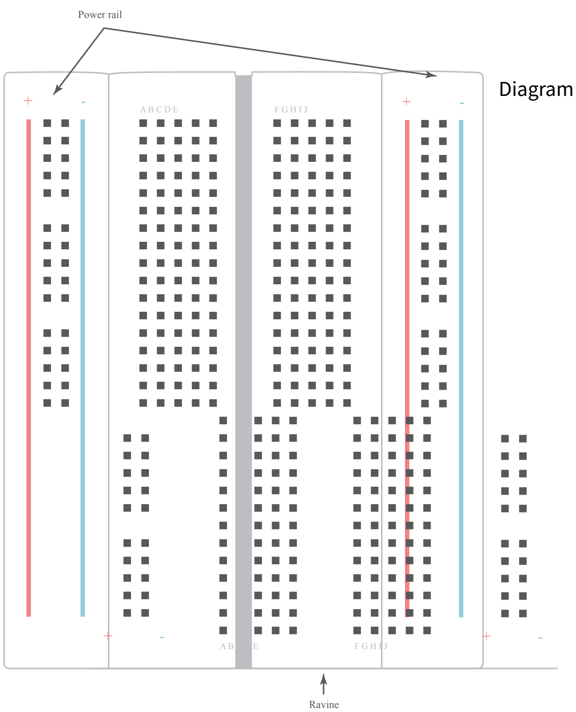


Diagram of a breadboard.

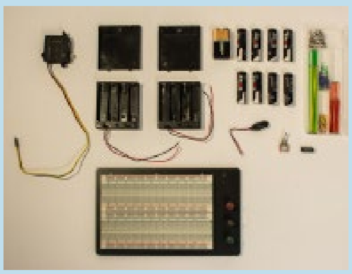
Credit: Mahjongg | Raspberry Pi Forum

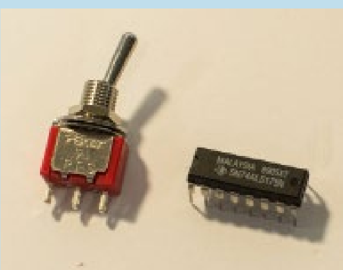
PATENT SPOTLIGHT

Breadboards get their name from—you guessed it—boards used to bake bread! People would use a breadboard and some nails or thumbtacks to connect the wires on the breadboard's wide flat surface when electronic components were big and bulky. Originally, a "breadboard" was just that, a plank of wood used to cut bread on. Nails or brass push pins were inserted, then the leads of various electronic components were soldered to these pins. This practice evolved into today's "breadboards."

EDUCATOR NOTE

Pack, group, and gather materials ahead of time to save time in the meeting. Reference the materials/tools list at the beginning of the meeting to determine what each team needs. Do not hand out materials until you are ready to have the students start working. Students may become distracted playing with the materials.





Credit: Eurah Ko

BUILD A CIRCUIT TO CONTROL A MOTOR

1. Have students work in their teams to complete the breadboarding activity that follows. They will create an integrated circuit to make their motors move forward and reverse using a switch instead of switching wires, as they did in the simple circuit activity. <u>**You can lead the class by reading each step aloud, or you can have teams read and follow the directions on their own.**</u>

2. Consider breaking the meeting into two meetings if you have time constraints. You can save time by preparing the materials (see STEP ONE) for students beforehand.

SAFETY

Wear safety goggles throughout the entire activity.

Step One: Prepare the materials

- **Attach wire leads to the switch.**

  The SPDT switch has three connections ("legs") for each of the circuits (on/off/on). Cut and strip both ends of two pieces of red stranded wire and one piece of black stranded wire using the wire cutters/strippers. The wire should be 3 - 5 inches long. Attach the red wire to the two outer legs ("on"), and the black to the middle leg ("off") to help keep track of the polarity of the legs.

SPDT switch. Note the legs to which you will attach wires.

Watch this video tutorial for best practices on cutting and splitting wire: **Wire Tips**.

SUSTAINABLE SOLUTIONS

Wire for electronics projects comes in two styles: solid core and strand-ed. Stranded wire is made up of bunches of tiny thin wires, and solid wire is one solid piece of wire. Solid core is best for use with breadboards because it is stiff and easier to get into the small entry holes in the breadboard. Stranded wire is best for use with jobs that require more flexible wire.

Credit: Sparkfun.com

- **Attach the battery snap holder to the 9V battery.**

  Make sure not to jam the snap holder into the battery to avoid damaging the connection.

- **Insert the four AA batteries into the battery holder.**

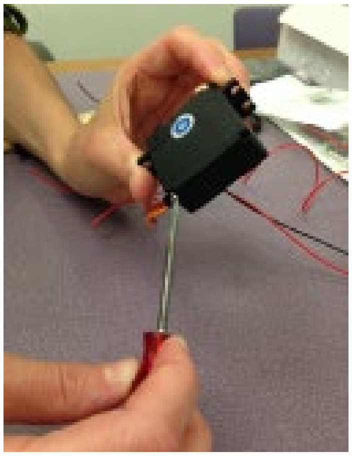
- **Prepare your motor.**

  Read below for detailed instructions. You'll be using a servo motor for your door opener. A servo motor has the correct gears to open your door. Your servo motor, however, needs to be adapted for the purposes of your door opener. Servo motors, as you have learned, are like gearhead motors with electronics inside them that allow for precise position control. You won't need this feature for your mechanical door opener. You will disconnect these electronics to adapt your servo motor. Follow these instructions:

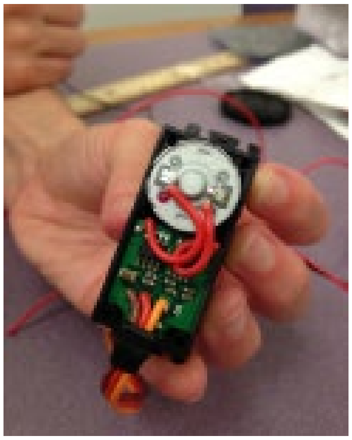
- Use a screwdriver to remove the screws from the top of the servo motor and remove the top plate. Keep the screws and the plate together and put them aside.

- Locate the green circuit board, the small silver DC motor inside, and the wires connecting them.

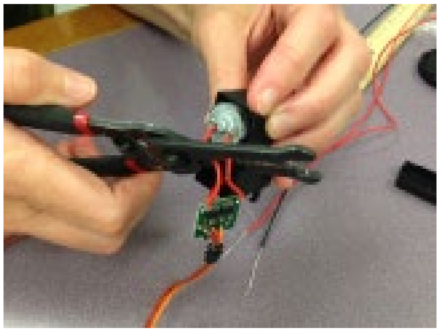
- Use wire cutters to cut the two red wires connecting the circuit board to the DC motor, and the three red wires connecting the circuit board to the body of the motor. Don't cut too much of the red jumper wire. It could interfere with the electricity exchange. Remove the circuit board completely.



Remove the screws.
Credit: WGBH



Credit: WGBH



Credit: WGBH

EDUCATOR NOTE

You may want to have students solder the leads to ensure they remain securely attached. This will require extra materials and time to practice. Consider making it a separate session beforehand. Refer to this link for more information on soldering: [**Soldering Tips**]

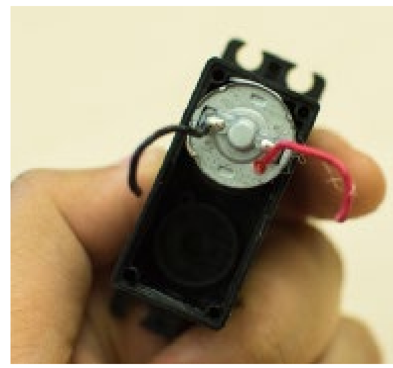
A soldering iron.
Credit: Wikimedia Commons

EXTEND THE LEARNING

A technique called soldering is used to make permanent circuit connections (wire to wire, wire to mo-tor). Soldering is the process of joining metal objects with solder, a type of metal. Desoldering is the process of melting the solder to undo the soldered connection. Learn more about soldering here: [Soldering Info]

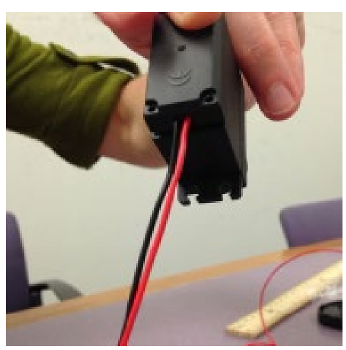
- Remove the wire leads left on the motor. You will be rewiring the motor.
- Cut a two-foot piece of red solid core wire and a two-foot piece of black solid core wire. Strip both ends of each using the wire cutters/strippers. ***NOTE: The length of the wire is important. It will allow you to connect the motor to the breadboard later.***
- Use the jewelry pliers to twist the stripped end of the red wire around one of the motor's posts. Do the same with the black wire around the other post.

Credit: WGBH



Credit: WGBH

- Hold the wires together and carefully place the plate over the wires to put the top plate back onto the motor. There is a small gap in the plate that allows the wires to go through. Reattach the plate to the motor using the screws and a screwdriver.



Credit: WGBH

Place the top plate back onto the motor.

- Finally, attach the four-arm motor attachment that came with the servo motor by gently pressing it over the servo spur (the tiny, circular knob with many teeth). Press one of the gold screws into the hole on the top of the attachment.

Credit: WGBH

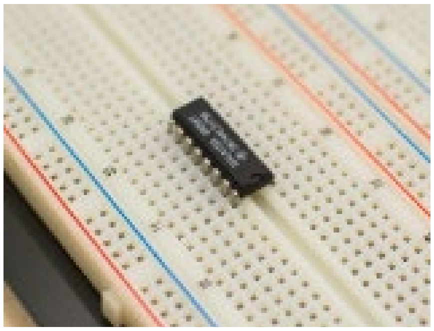
NOTE: The arm you just attached to the motor is a gear. Gears are enormously effective machines when used with motors, as they reduce or magnify force. Gears also can change the direction of axis or rotation, or increase or decrease speed. The arm was attached to another gear, called a spur gear (the tiny, circular knob with many teeth). Energy is transferred and changed as it moves to the spur gear and the arm(s), creating the rotational torque of the motor, which will later be used to move the control arms of your door.

Step Two: Set up the breadboard

Follow these steps to set up the breadboard. You can also use the picture of the fully assembled breadboard (on the separate full page) as a visual guide.

- **Place the H bridge in the middle of the breadboard.**

  Insert the pins (silver pegs) of the H bridge into the holes on either side of the ravine (the deep channel in the middle of board). Make sure the little gap is facing up.

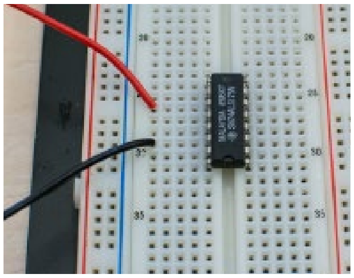


Credit: Eurah Ko

Tip
Never jam or push the wires into the **breadboard**. Jamming the wires can damage the **breadboard**.

- **Attach the motor to the breadboard.**

  Take the two motor wire leads and plug them into the rows next to Pins 3 and 6 of the H bridge. The pins on the H bridge are numbered from 1 to 16. Pins 1 to 8 run down the left side of the H bridge, and Pins 9 to 16 run up the right side of the H bridge (Pins 1 and 16 are across from each other at the top). Each pin on the H bridge has a unique position and function in conducting the current in the circuit.



Credit: Eurah Ko

EDUCATOR NOTE

Review with students how to count the pins of the H bridge and where to place the wires next to each pin.

EDUCATOR NOTE

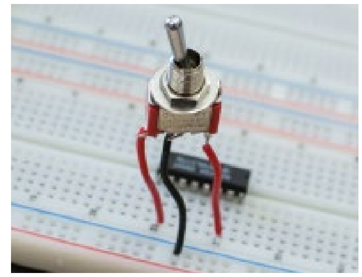
Make sure students don't jam the H bridge into the breadboard—the pins are easy to break. Demonstrate how to place the H bridge on the board gently first.

EDUCATOR NOTE

Remind students, as you circulate, to keep the switch in the center (off) position while connecting the wires to the **breadboard**.

- **Attach the switch to the breadboard.**

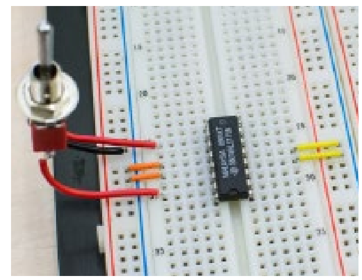
  Take the two red wires of the SPDT switch and plug them into the rows next to Pins 2 and 7 of the H bridge. Connect the black wire from the middle leg of the switch to the ground column of the power rail on the left side of the breadboard (marked with a "-" sign) to ground the switch. Make sure the switch is in the center (off) position.



Credit: Eurah Ko

- **Ground the H bridge.**

  Use small jumper wires (choose black if available) to connect Pins 4 and 5 on the left side of the H bridge to the ground column ("-") on the left side of the breadboard. Use another set of jumper wires to connect Pins 12 and 13 on the right side of the H bridge to the ground column on the right side of the breadboard.

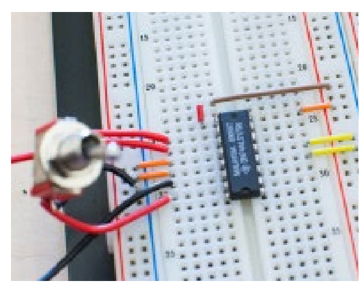


Credit: Eurah Ko

Tip: Do not connect the battery to the circuit until the circuit connections have been checked.

- **Power the H bridge.**

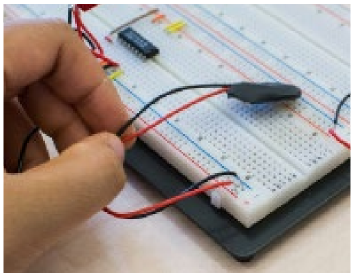
  Your H bridge needs power and a ground, just like your motor! This H bridge chip needs about 5V to work, but always check the specs of your chip to identify how much power it needs. You are going to use four alkaline AA batteries, which add up to 6V (1.5V x 4 batteries).



Credit: Eurah Ko

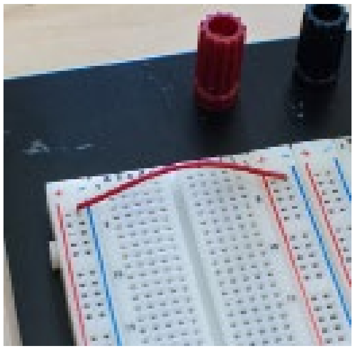
  Plug the black wire from the battery holder into the ground column on the right side of the board and the red wire into the power column ("+") on the right side. These batteries are the power source for your H bridge.

Use a long jumper wire to connect Pin 1 of the H bridge to the power column on the right side. Use another jumper wire to connect Pin 16 of the H bridge to the same power column. Now your H bridge has power.


Credit: Eurah Ko

- **Power your motor.**

H bridges and motors usually require different amounts of power, which is why breadboarding works well. Connect your motor battery to the power and ground columns on the left side of the breadboard. **NOTE**: All power is running through the H bridge, although the motor and H bridge are using different sources of power, and the bridge can only handle 1A of current.

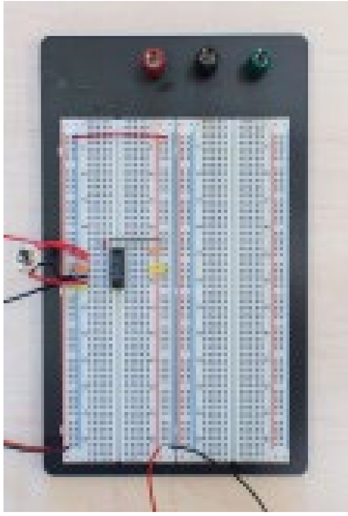

Credit: Eurah Ko

- **Connect the two sources of power.**

Use a long jumper wire to link the two ground columns across the board.

- **Now you're ready to give your motor current.**

Connect Pin 8 of the H bridge to the motor power column on the left side of the board. Flip the switch and watch your motor move! Move the switch to all three places: on, off, and on. See how the motor spins.


Credit: Eurah Ko

DISCUSS AND SHARE

Have students discuss any challenges and fixes with the whole group. Have them share, as inventors, how they tested and solved any problems they encountered.

EDUCATOR NOTE

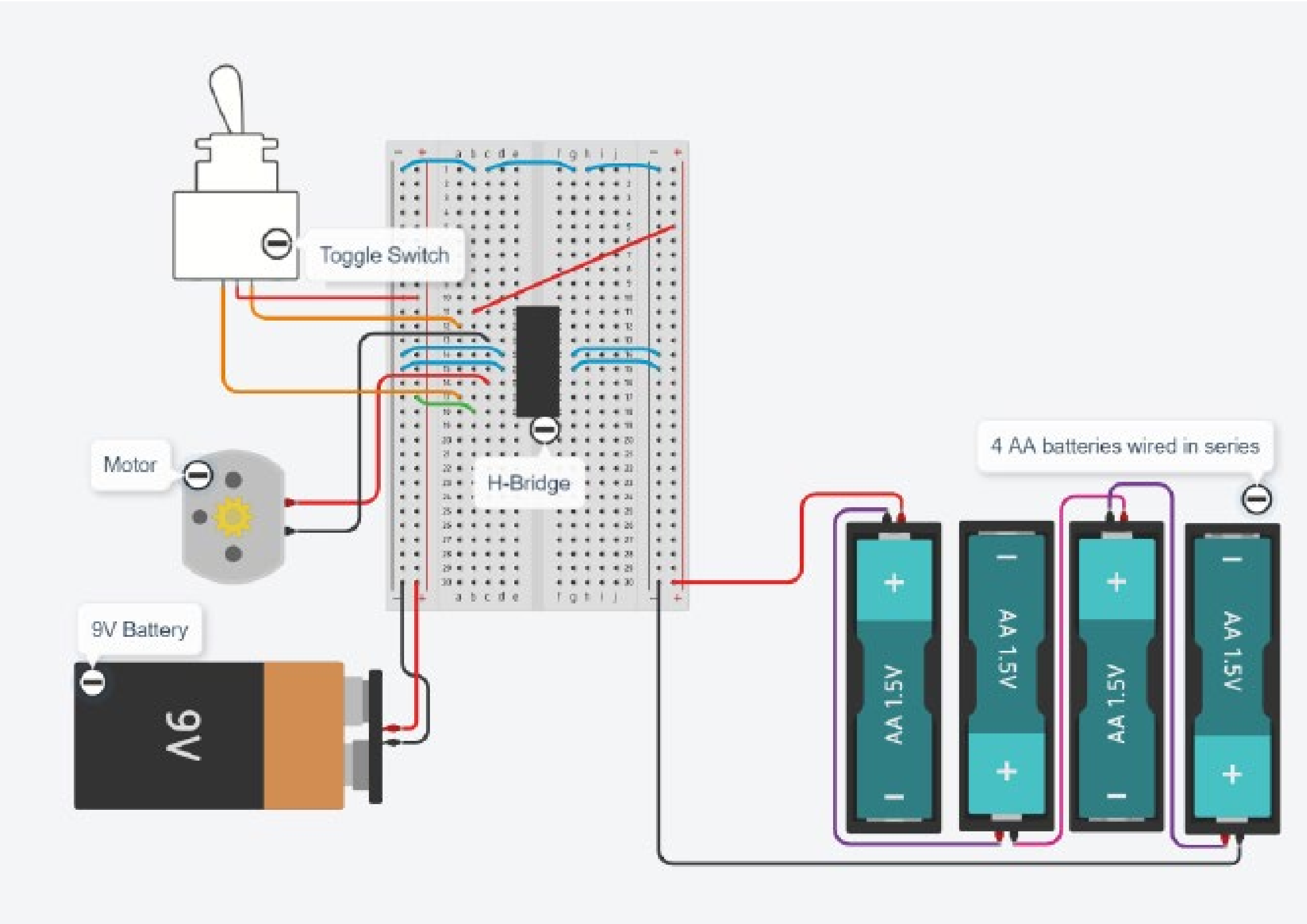
Troubleshooting

Are the teams' motors not turning on? Make sure the students' wires are securely connected to the breadboard. Have them double-check that the wires are connected to the correct locations on the breadboard.

EDUCATOR NOTE

Have teams disconnect the batteries from the bread-boards and put them away. They will use them again in Meeting 6.

FULLY ASSEMBLED BREADBOARD



SELF-ASSESSMENT

Collect the completed self-assessments as exit slips when students leave.

INDICATORS OF A SUCCESSFUL MEETING

Students build a simple **circuit** to understand **polarity** in a **circuit**. Students demonstrate an understanding of devices used to control the motion of a motor, including **H bridge** motor devices, switches, and **breadboards**. Students successfully connect a **breadboard** with a servo motor to a switch to control the motor's motion.

KEY TERMS

Input effort (n): The effort or force exerted on an object.

Lever (n): A rigid object used with a pivot point, or fulcrum, to move a load.

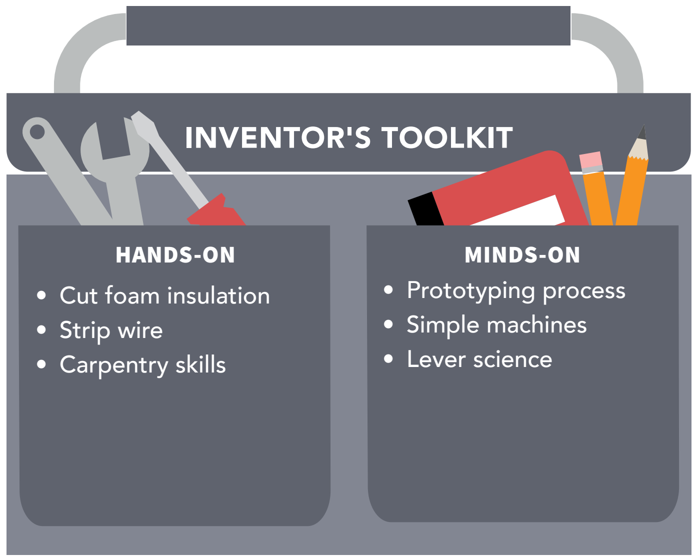
Mount (n): A backing, setting, or support onto which something is fixed.

Output effort (n): The effort or force produced by an object.

Pitch (v): To present your idea to someone or to a group to attract their support.

Production sample (n): A more finished version of a working prototype.

Proof of concept (n): A version of a model built to test or demonstrate a concept, sometimes incomplete.



Tools

Whole Group

- Hot glue gun and hot glue sticks (for educator use only)

Per Team

- Jewelry pliers
- Screwdrivers
- Utility knife
- Wire strippers/cutters

Materials

Whole Group

- Student Guides
- Self-Assessments

Per Team

- Foam insulation door from Meeting 3
- Breadboard and motor setup from Meeting 5
- Extra foam insulation from Meeting 3 (to make **mounts**)
- 1 pair of 9-inch metal ties
- 5 screws (#8-32 tpi, 1 1/2-inch)
- 5 nuts (#8-32)
- Washers (#8)
- 6 inches of solid core

Procedure

- Simple Machines: The **Lever**
- Build a Mechanical Door Opener
- Discuss the Invention Process (optional)
- Meet Eben Bayer
- Self-Assessment

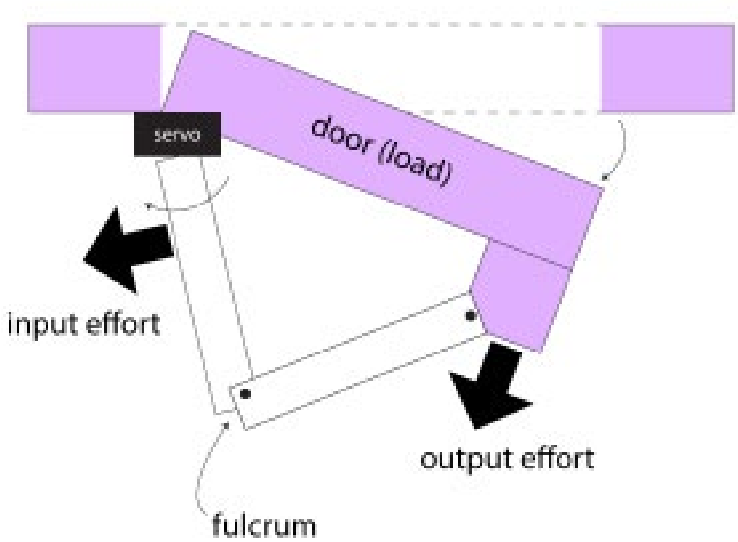
SIMPLE MACHINES: THE LEVER

1. Review the following section to introduce students to **levers**. Tell students that the control arms of their mechanical door are an example of this type of simple machine. Read the section aloud to students.

2. Address any questions students have after reading. Have them try the **lever** activity and discuss the experience.

The control arms you will use for your door opener are one of the most important simple machines on your door. They function as a **lever**. **Levers**, as you recall, are one of the six simple machines. **Levers** have three basic parts: a **fulcrum** (or pivot point), an **input effort** (force), and an **output effort** (load or resistance). Where these parts are in relationship to each other determines how the **lever** works. The **input effort** (the motor's power) in the control arms is applied between the fulcrum and the **output effort**. The length of your control arms and where they are placed is important.

Look at the image of the finished door opener you will create below. **The input effort is applied to the top arm, which is between the fulcrum and the output effort**:



The control arms to your mechanical door opener function as **lever**s.
Credit: Eurah Ko

MEETING 6

KEY TERMS (CONT'D)

Working prototype (n): A more complete version of a model built to test or demonstrate a concept.

JV InvenTeams LEMELSON·MIT

It's important to note that even though the **input effort** is applied between the **fulcrum** and the **output effort**, it is generated past the **fulcrum**, where the motor is. We've increased the distance between the place where the **input effort** is generated and the **fulcrum** by adding the control arms from the motor, allowing the motor to gain more torque.

LEVER ACTIVITY

Try closing a door by pushing on it about 3 or 4 inches from the hinges (the **fulcrum**) to experience how **levers** are useful. Now try pushing on it near the edge of the door. Quite a difference, right? This is because you increased the distance between the **input effort** and the **fulcrum**. You gain more torque (rotational force) to close the door as you increase the distance between the **input effort** and the **fulcrum**.

HIGH SCHOOL CONNECTION

The 2015 South Brunswick High School InvenTeam (Monmouth Junction, New Jersey) worked on a passenger-side bicyclist detection system for cars. This device detects objects in the path of an opening car door by using a proximity sensor. The proximity sensor will alert the driver by emitting an alarm if it detects a potential obstruction in the car door's opening radius. This invention will help reduce the risk of accidents and improve the safety of drivers, pedestrians, and cyclists. Read more here: South Brunswick InvenTeam

Credit: Lemelson-MIT Program

MEETING 6

BUILD A MECHANICAL DOOR OPENER

1. Tell students that they will finish constructing their mechanical door opener with their teams during this meeting. They'll be using many of the skills they've developed over the course of the unit, including wire stripping and cutting foam insulation.

Materials for the meeting.
Credit: Eurah Ko

2. Review each step's instructions with students before they begin that step. These instructions are in their guides.

3. Have students refer to the photo of the finished design to get an idea of what they are building.

4. Encourage teamwork with different tasks for everyone. Have students consider assigning roles within the team to divide up the work.

5. Have students reflect on their work by sharing their ideas of what worked and what didn't work when they were building the door. Ask them:

- How could you improve the mechanical door opener?
- What other designs or other materials could you use?

Step One: Attach the mounts to the door and the door frame

You'll need **mounts** to attach the motor and the control arms to the door frame and the door, respectively. You'll use foam insulation board as **mounts**. Follow these instructions:

- Cut two pieces, roughly 2-inches x 2-inches square, out of the 1-inch foam insulation.
- Position one piece of insulation at the top right corner of the door. Align the edge of the insulation with the top and side edge of the door. Place it vertically, coming out from the door. This will be your control arm **mount**.

Control arm **mount**.
Credit: WGBH

EDUCATOR NOTE

Students will complete their mechanical door openers with their teams. Teams will need the following materials, which you should gather ahead of time:

Jewelry pliers, screwdrivers, utility knives, wire strippers/cutters, metal ties, screws, nuts, washers, and solid core wire. They will also need their doors and extra foam insulation board from Meeting 3, and their breadboards and motor setups from Meeting 5.

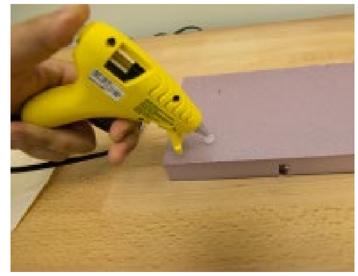
EDUCATOR NOTE

Have students review the safety instructions for using utility knives in Meeting 3. Collect the utility knives after students have finished using them so they won't create a distraction and a safety hazard among team members.

Tip: It is important to correctly use the hot glue gun.

Do not press the tip of the hot glue gun directly on to the foam insulation board. This will cause the foam insulation board to melt as seen in the pictures below.

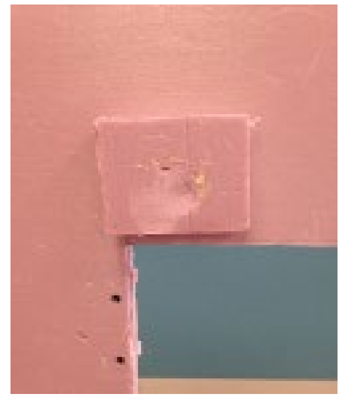
- Secure the **mount** with hot glue. Hold the **mount** in place for three minutes or until secure.
- Position the other piece of the foam insulation board flat against the door frame, directly above the top left corner of the door. This will be your motor **mount**.
- Secure it with hot glue. Hold it in place for three minutes or so until secure.



Credit: Eurah Ko

Step Two: Glue the motor to the top mount

- Position the motor on the door frame **mount** so that the **gear arms are facing down**, and the **wires are coming out of the top of the motor and down the left side** (these are the wires that will connect to the breadboard). Make sure the gears on the motor (the motor arms) clear the door so they do not collide with the door. **Look at the photo to make sure you have the correct position before gluing**.
- Hot glue the side body of the motor to the **mount**. Hold it in place for three minutes or so until secure.



Motor **mount**. Credit: WGBH

Step Three: Construct the control arms

- Cut a small square of 1-inch x 1-inch foam insulation board.
- Make an arm shape with the two 9-inch metal ties. Place the foam insulation board between the arms at the fulcrum (the pivot point).
- Using the photo above as a guide, insert a machine screw through the hole in the end of the upper arm. Press it through the foam insulation board (carefully) so it comes out through the end hole in the lower arm. Secure it with a nut. Make sure the arms can open and close easily.

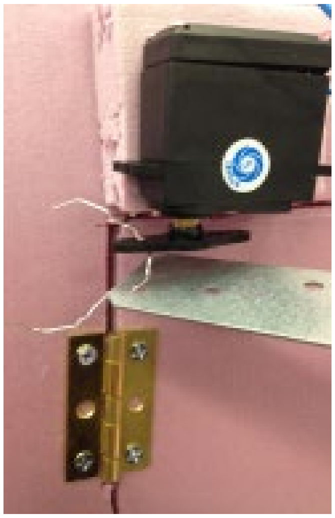
Credit: WGBH

Step Four: Attach the control arms to the motor and the mount on the door

Make sure the motor arms are facing down.
Credit: WGBH

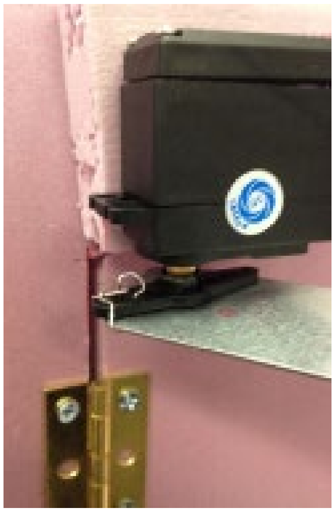
- Use the wire cutters/strippers to strip the entire length of a 6-inch-long piece of solid core wire.
- Attach the BOTTOM arm to the arm **mount** with a screw and a bolt while someone is holding the TOP arm. Have someone hold the arms in place as you complete the next steps.

NOTE: It is important that the top arm attaches to the motor, and the bottom arm attaches to the door. See the photo of the completed control arm setup to make sure you're placing the arms correctly.



Feed the wire through both holes.
Credit: WGBH

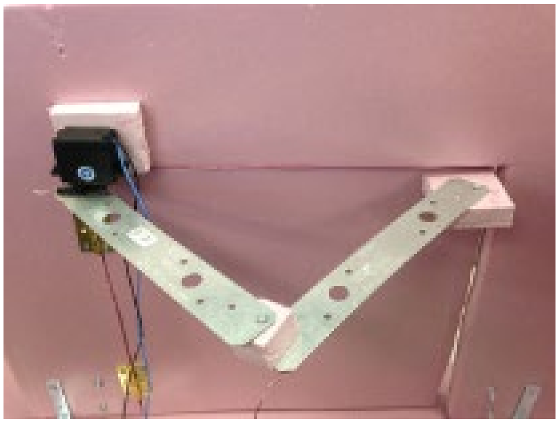
- Feed the wire through the hole of the motor arm and the hole closest to the edge in the piece of metal.
- Secure the wire by twisting it with pliers.



Press the wire together with jewelry pliers to secure.
Credit: WGBH

Step Five: Attach the motor to the breadboard

- Attach the two wires of the motor to the breadboard. The wires go into the rows next to Pins 3 and 6 on the left side of the breadboard.
- Reattach the two 4-AA battery holders to the right and left power rails of the breadboard.
- Flip the switch to watch your door open and close!



Completed control arm setup | Credit: WGBH

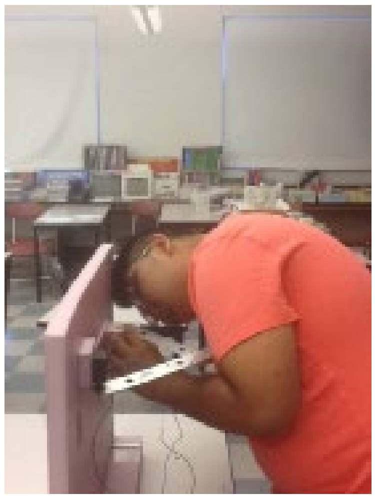
EDUCATOR NOTE

Make sure students apply the hot glue to the correct side of motor before mounting it! Have them look at the photograph to confirm the position.

DISCUSSION

1. Congratulate students on building their mechanical door openers. Have students discuss the following questions with their teams. Ask them to record any ideas or drawings in their guides.

- What improvements would you make to the design now that you've finished making your door opener? What other uses or applications can you think of?
- Are there any other materials you think would work better?



Check to make sure the control arms are securely fastened before turning the motor on | Credit: WGBH

A mechanical door opener! Credit: WGBH

DISCUSS THE INVENTION PROCESS (OPTIONAL)

Have students read (independently or aloud) and discuss the following information about the invention process:

You've just made a "**proof of concept**" prototype, in invention terms. What that means is that you've made an early prototype that "proves" your concept (a mechanical/electrical system that opens a door) works! It may not look great—nothing like a real automatic door opener—but it will open a door. The **proof of concept** prototype allows inventors to experiment with the design before making a more mature **working prototype**.

The **working prototype** is usually more refined in appearance and looks more like the intended final product. Inventors use the **working prototype** for **pitching** to potential investors, publicizing on social media and crowdsourcing websites, and testing with a wider selection of prospective users.

The final stage is the **production sample**, which designers use to make sure the factory has created the product according to the CAD or technical drawings and instructions they have been given. It's the last stop before the invention hits store shelves.

INVENTION SPOTLIGHT

Some automatic doors use an infrared sensor that points down at a sharp angle so the door only opens if you are standing very close to it. Other types of automatic doors have sensors that may open the door accidentally as you walk by, or are triggered by just about anything. A team of researchers at Japan's University of Electro-Communications and Hokuyo Automatic Company has made major improve-ments to automatic door design by incorporating 3-D "time-of-flight" technology into the sensor. This tech-nology allows the sensor to estimate the positions, speed, and number of people it senses. The door knows when and how wide to open, which saves time and energy. Read more and watch the researchers introduce their invention: Smarter Automatic Door

Credit: Ecovative

MEET EBEN BAYER

Eben Bayer is what is known as a "green designer" and inventor—someone who develops and invents with sustainability in mind. He is the co-inventor of MycoBond, an organic adhesive that turns agricultural waste into a foam-like material that can be used for packaging and insulation (like foam insulation board). Eben is committed to creating better materials, and believes that materials should be created with three guiding principles in mind. First, they should be able to be produced almost anywhere on the planet; second, they should require less energy to produce than current materials; and third, they should be able to be disposed of by being reintroduced into nature's "open-source" recycling system at the end of their life. Eben is also the co-founder of Ecovative, a company "driven to produce materials that are healthier for people, the planet, and for profits."

Did you have any role models as a young person? Who were they?

My family and friends. Also, Steve Jobs.

Did you do any tinkering or inventing at a young age?

Yes, all the time. I began very early in life by taking things apart (poorly, with hammers), and then later I got better about taking things apart with the correct tools. Eventually I was able to put them back together, too! Two of my favorite projects when I was 10 were building radio transmitters and rockets. Both were fascinating in their own ways.

How did you get interested in alternative materials? Describe your journey.

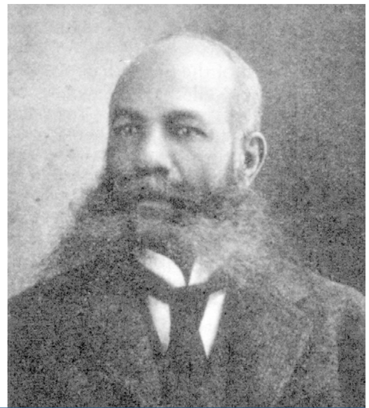
I have always been interested in natural materials, particularly the beauty of living things, like wood. I think this mostly came from the many opportunities I got to spend in nature, seeing how living systems create solutions for the environments they thrive in.

What advice can you give young people who want to become inventors?

Learn and create! Find out what way you learn best (reading, listening, watching, doing with your hands) and then do as much of that as possible in the subjects that interest you the most. Second, look for problems or things that are missing in the world. Imagine what you would like the world to look like, based on the important unfulfilled needs you see. Go ahead and create a solution using what you know.

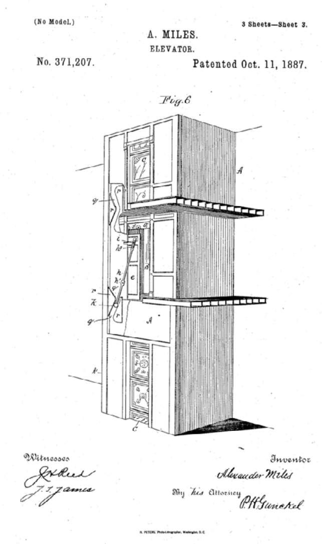
What do you do for fun outside of work?

Learn and create!


Credit: Wiki Commons

INVENTION SPOTLIGHT

Alexander Miles, an African American inventor from Minnesota, invented automatic elevator doors in 1887. Early elevator doors had to be manually opened and shut, which posed a danger for people accidentally falling down the shaft if they forgot to do so. Miles invented a mechanism that triggered the shaft doors to open and close along with the elevator doors, making the ride safer.



Patent for the 1887 elevator doors.

SELF-ASSESSMENT

Collect the completed self-assessments as exit slips when students leave.

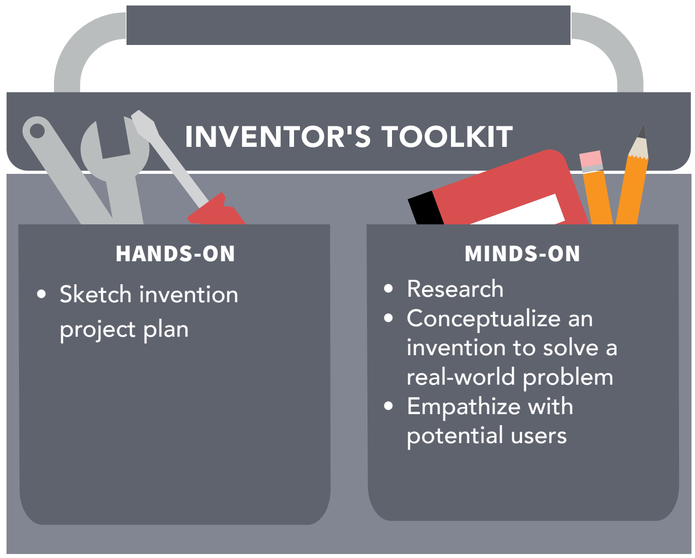
INDICATORS OF A SUCCESSFUL MEETING

Students finish building a mechanical door opener that operates successfully. Students use their knowledge of materials, building, and mechanical systems to brainstorm ideas for a production-quality prototype.

U CONTROL
MEETING 7: INVENTION EXTENSION

KEY TERMS

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



Tools

- Writing utensils

Materials

- Student Guides
- Mechanical door openers from previous meeting
- Computer for research
- Self-Assessments

Procedure

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

LEMELSON-MIT JV InvenTeams

INTRODUCTION TO INVENTION CHALLENGE

Read the following aloud to students. This section gives students 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, mechanical and electrical systems, and motor science. You have gained hands-on skills such as making circuits, cutting and stripping wire, cutting foam insulation, and creating a mechanized door opener.

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.**

Students will conceptualize a project. Their 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 website**.

REVIEW REAL-WORLD EXAMPLES

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

Example 1

Morgan Glessing and Josh Horne, from Brigham Young University, won the "Move It" 2019 $10,000 Lemelson-MIT Student Prize for their invention of a wireless device that opens disabled-accessible doors. When they met with a friend who uses a wheelchair, they learned that most technologies do not work for all types of physical abilities. With Josh's skills in hardware and software and Morgen's business experience, the two developed a solution that makes automatic doors more accessible. Their invention, known as Portal, is a wireless device that opens disabled-accessible doors when a user approaches with the Portal smartphone app. Learn more here: **Move It**.

DISCUSS AS A CLASS

Can you think of any apparatus, other than a handle, that would work as a low-cost solution for enhancing a user's ability to open or close a door? What would the product do? How would it meet a user's needs? Who might benefit from this solution?

Example 2

Conventional electric motors are typically made of rare earth metals that produce radioactive waste when mined. The company HEVT (Hybrid Elec-tric Vehicles Technologies LLC) developed an affordable and reliable elec-tric motor that uses widely available metals like copper and steel. Their SRM motor (switched reluctance motor) features a higher starting torque (rotational force) and greater efficiency over a wide range of speeds. Read about HEVT's CEO, Heidi Lubin, and her work promoting the new motor here: HEVT Motors.

DISCUSS AS A CLASS

HEVT's motors are now being marketed for use in electric bicycles. How could you use these sustainable motors to power another mechanical system? What would you power? Who could benefit from them?

Example 3

The students from Benjamin Banneker Academic High School's InvenTeam (Washington, DC) developed a simple, efficient door-locking mechanism to help schools stay safe during an emergency. A teacher can simply slide the lock over the door arms to quickly barricade the door from inside. The team was motivated to come up with the invention after learning about school shootings in Connecticut and Massachusetts. Members of the Benjamin Banneker InvenTeam had been volunteering at schools, and empathized with the children and families affected by the shootings. Watch this video to learn more about their invention and the invention process: **Benjamin Banneker InvenTeam**.

DISCUSS AS A CLASS

How do the materials and design features meet the needs of the intended users? Can you think of some users and their unmet needs? What would you design and build for them? Make a sketch if you have time.

BRAINSTORM INVENTION IDEAS

1. Remind students that as they brainstorm invention ideas, they need to think first about WHO their invention will help.

2. Tell students that 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 building circuits and understanding machines and motors, and think of specific users and their needs. For example, could you build a mechanized door opener using a pulley instead of a lever? Could you create a low-cost mechanized door opener for farmers in developing countries to keep their animals protected and safe?

BRAINSTORM SOLUTIONS

1. Once teams have decided on needs they'd like to address, have them use SCAMPER to brainstorm design solutions.

2. Explain that 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 students can arrange the characteristics of what is challenging them to help 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** *(what if the laces of a shoe were placed on the bottom and not the top?)*

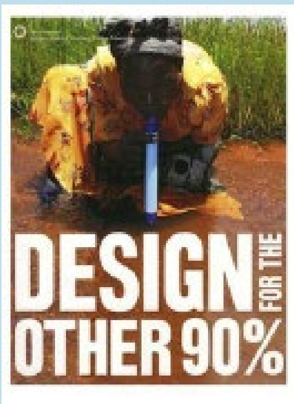
3. Say that to use the SCAMPER technique, you would first state the problem you would like to solve. Then, ask questions about it using the SCAMPER checklist.

4. Have students do some personal brainstorming using SCAMPER. Afterward, they should discuss their ideas with their teams and streamline them. They should select one idea (or a combination of multiple ideas) to take to the next step.

EDUCATOR NOTE

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.



MAKE A PLAN

1. Remind students that all ideas are good ideas. They should record all ideas in their guides.

2. Encourage students to ask themselves the following questions to make sure they 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. Have teams use the invention worksheet in their guides to document and sketch their idea. This is a version of what high school InvenTeams use in their project proposals.

4. Have teams share their ideas with the class in a culminating celebration of their work. Encourage students to **apply for InvenTeams grants** if they want to continue this work!

SELF-ASSESSMENT

Collect the completed self-assessments as exit slips when students leave.

INDICATORS OF A SUCCESSFUL MEETING

Students brainstorm a technological invention idea to meet a real-world need, incorporating new skills from this unit. They conceptualize and plan their new invention ideas. Planning can continue beyond the unit.

EDUCATOR NOTE

During Invention Planning

Walk around the room and make sure progress is being made. It would be ambitious for all teams to complete the worksheet pages by the end of the meeting. Ask them to continue researching and working on their ideas outside of meeting time. Emphasize that they can consider applying for InvenTeam grants if they want to continue their work.

INVENTION WORKSHEET

Our JV InvenTeam members are:

The product we are inventing is: ______________________________

to: ______________________________

____

It is useful for: ______________________________

____

because: ______________________________

____

____

It is unique because: ______________________________

____

It functions by: ______________________________

____

____

The tools we need are: ______________________________

____

The materials we need are: ______________________________

____

____

The estimated total cost of our invention is: ______________________________

JV InvenTeams™ (Lemelson-MIT)

The Lemelson-MIT Program congratulates ______________________________

on completing the U Control unit of JV InvenTeams on _____________________

You did a wonderful job as an inventor and made an incredible mechanical door opener!

Thanks for all your contributions to the team.

Award for ____

Signed,

____

Your JV InvenTeam Educator

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?

What problem do you want to solve?

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 the 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?)

engineering

invention

iteration

modification

patent

PhD

prototype

energy efficiency

force

inclined plane

input effort

lever

machine

motor

mechanical advantage

mechanical system

output effort

pulley

screw

system

torque

wedge

wheel and axle

work

foam insulation board

nut

pilot hole

washer

actuator

hydraulics

load

- -

Lorentz force

- -

magnetic field

millinewton meters

- -

nominal voltage

- -

Ohm's law

resistance

- -

revolutions per minute

- -

rotor

stator

- -

voltage

- -

velocity

breadboard circuit

- -

conductor

- -

electric current

ground

H bridge

polarity

short circuit

solder

switch
transistor

mount

Pitch

production sample

working prototype

empathy

U Control
Massachusetts Science and Technology/Engineering Standards - Middle School

Meeting	Science Standards	Engineering Standards	Cross-Cutting Concepts	Practices
Meeting 1: Invention Introduction		6.MS.ETS1-1 6.MS.ETS1-5* 6.MS.ETS1-6 6.MS.ETS2-2 7.MS.ETS1-2* 7.MS.ETS1-7 7.MS.ETS3-4 8.MS.ETS2-4	• Structure & Function • Systems & System Models • Cause & Effect	• Asking Questions & Defining Problems • Constructing Explanations & Designing Solutions • Engaging in Argument from Evidence • Obtaining, Evaluating, & Communicating Information
Meeting 2: Introduction to Simple Machines		6.MS-ETS1-1 7.MS-ETS3-4 7.MS-ETS3-5*	• Influence of Science, Engineering, and Technology on Society and the Natural World • Structure & Function • Systems & System Models • Cause & Effect	• Asking Questions & Defining Problems • Constructing Explanations & Designing Solutions
Meeting 3: Build a Door		6.MS-ETS2-2 6.MS-ETS1-5* 6.MS-ETS2-3 7.MS-ETS1-2* 7.MS-ETS1-4 7.MS-ETS1-7 7.MS-ETS3-4 7.MS-ETS3-5	• Influence of Science, Engineering, and Technology on Society and the Natural World • Structure & Function • Systems & System Models	• Developing and Using Models • Constructing Explanations & Designing Solutions
Meeting 4: Motors 101	7.MS.PS3-5* 7.MS.PS3-7*	6.MS.ETS1-6 6.MS.ETS2-1 6.MS.ETS1-4	• Energy & Matter • Scale, Proportion, & Quantity	• Constructing Explanations & Designing Solutions • Using mathematics and computational thinking
Meeting 5: Controlling a Motor		6.MS-ETS2-2 6.MS-ETS2-3 7.MS-ETS1-7	• Influence of Science, Engineering, and Technology on Society and the Natural World • Systems & System Models • Cause & Effect	• Developing and Using Models • Constructing Explanations & Designing Solutions
Meeting 6: Final Build		6.MS-ETS2-2 6.MS-ETS2-3 7.MS-ETS1-4* 7.MS-ETS1-7 7.MS-ETS3-5	• Influence of Science, Engineering, and Technology on Society and the Natural World • Structure & Function • Systems & System Models	• Developing and Using Models • Constructing Explanations & Designing Solutions • Analyzing and Interpreting Data
Meeting 7: Invention Extension		6.MS.ETS1-1 6.MS-ETS2-2	• Influence of Science, Engineering, and Technology on Society and the Natural World • Structure & Function • Systems & System Models	• Asking Questions & Defining Problems • Constructing Explanations & Designing Solutions

* Loosely aligned

Standards alignment conducted by graduate students at Boston College's Lynch School of Education

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Massachusetts Science and Technology/Engineering Standards - High School

Meeting	Science Standards	Engineering Standards	Cross-Cutting Concepts	Practices
Meeting 1: Invention Introduction		HS.ETS1-3 HS.ETS1-6 HS.ETS2-1	• Structure & Function • Systems & Cycles • Cause & Effect	• Asking Questions & Defining Problems • Constructing Explanations & Designing Solutions • Engaging in Argument from Evidence • Obtaining, Evaluating, & Communicating Information
Meeting 2: Introduction to Simple Machines		HS-ETS1-1 HS-ETS1-2	• Influence of Science, Engineering, and Technology on Society and the Natural World • Structure & Function • Systems & System Models • Cause & Effect	• Asking Questions & Defining Problems • Constructing Explanations & Designing Solutions
Meeting 3: Build a Door		HS-ETS1-2 HS-ETS1-3 HS-ETS1-5* HS-ETS2-1* HS-ETS2-4*	• Influence of Science, Engineering, and Technology on Society and the Natural World • Structure & Function • Systems & System Models	• Developing and Using Models • Constructing Explanations & Designing Solutions
Meeting 4: Motors 101	HS-PS3-3*		• Energy & Matter • Scale, Proportion, & Quantity	• Constructing Explanations & Designing Solutions • Using mathematics and computational thinking
Meeting 5: Controlling a Motor	HS-PS3-3*	HS-ETS1-2 HS-ETS2-2* HS-ETS2-3*	• Influence of Science, Engineering, and Technology on Society and the Natural World • Systems & System Models • Cause & Effect	• Developing and Using Models • Constructing Explanations & Designing Solutions
Meeting 6: Final Build		HS-ETS1-3 HS-ETS1-6 HS-ETS2-1 HS-ETS3-4*	• Influence of Science, Engineering, and Technology on Society and the Natural World • Structure & Function • Systems & System Models	• Developing and Using Models • Constructing Explanations & Designing Solutions • Analyzing and Interpreting Data
Meeting 7: Invention Extension		HS.ETS1-1 HS.ETS1-2 HS.ETS2-1	• Influence of Science, Engineering, and Technology on Society and the Natural World • Structure & Function • Systems & System Models	• Asking Questions & Defining Problems • Constructing Explanations & Designing Solutions

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Next Generation Science Standards - Middle School

Meeting	Core Ideas	Science Standards	Cross-Cutting Concepts	Practices
Meeting 1: Invention Introduction	ETS1.A ETS1.B	MS.ETS1-1 MS.ETS1-2	• Structure & Function • Systems & Cycles • Cause & Effect	• Asking Questions & Defining Problems • Constructing Explanations & Designing Solutions • Engaging in Argument from Evidence • Obtaining, Evaluating, & Communicating Information
Meeting 2: Introduction to Simple Machines	ETS1.A	MS.ETS1-1	• Influence of Science, Engineering, and Technology on Societyand the Natural World • Structure & Function • Systems & System Models • Cause & Effect	• Asking Questions & Defining Problems • Constructing Explanations & Designing Solutions
Meeting 3: Build a Door	ETS1.B ETS1.C	MS.ETS1-2* MS.ETS1-4	• Influence of Science, Engineering, and Technology on Societyand the Natural World • Structure & Function • Systems & System Models	• Developing and Using Models • Constructing Explanations & Designing Solutions
Meeting 4: Motors 101	PS3.B	MS.PS3-5*	• Energy & Matter • Scale, Proportion, & Quantity	• Constructing Explanations & Designing Solutions • Using mathematics and computational thinking
Meeting 5: Controlling a Motor	ETS1.B ETS1.C	MS.ETS1-4	• Influence of Science, Engineering, and Technology on Societyand the Natural World • Systems & System Models • Cause & Effect	• Developing and Using Models • Constructing Explanations & Designing Solutions
Meeting 6: Final Build	ETS1.B ETS1.C	MS.ETS1-3 MS.ETS1-4	• Influence of Science, Engineering, and Technology on Societyand the Natural World • Structure & Function • Systems & System Models	• Developing and Using Models • Constructing Explanations & Designing Solutions • Analyzing and Interpreting Data
Meeting 7: Invention Extension	ETS1.A ETS1.B	MS.ETS1-1 MS.ETS1-2	• Influence of Science, Engineering, and Tech-nol-ogy on Society and the Natural World • Structure & Function • Systems & System Models	• Asking Questions & Defining Problems Constructing Explanations & Designing Solutions

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Next Generation Science Standards - High School

Meeting	Core Ideas	Science Standards	Cross-Cutting Concepts	Practices
Meeting 1: Invention Introduction	ETS1.A ETS1.B	HS.ETS1-3	• Structure & Function • Systems & Cycles • Cause & Effect	• Asking Questions & Defining Problems • Constructing Explanations & Designing Solutions • Engaging in Argument from Evidence • Obtaining, Evaluating, & Communicating Information
Meeting 2: Introduction to Simple Machines	ETS1.B	HS.ETS1-1 HS.ETS1-2	• Influence of Science, Engineering, and Technology on Society andthe Natural World • Structure & Function • Systems & System Models • Cause & Effect	• Asking Questions & Defining Problems • Constructing Explanations & Designing Solutions
Meeting 3: Build a Door	ETS1.B ETS1.C	HS.ETS1-2 HS.ETS1-3	• Influence of Science, Engineering, and Technology on Society andthe Natural World • Structure & Function • Systems & System Models	• Developing and Using Models • Constructing Explanations & Designing Solutions
Meeting 4: Motors 101	PS3.A*	HS-PS3-3*	• Energy & Matter • Scale, Proportion, & Quantity	• Constructing Explanations & Designing Solutions • Using mathematics and computational thinking
Meeting 5: Controlling a Motor	ETS1.B ETS1.C PS3.A*	HS.ETS1-2 HS-PS3-3*	• Influence of Science, Engi-neering, and Technologyon Society and the Natural World • Systems & System Models • Cause & Effect	• Developing and Using Models • Constructing Explanations & Designing Solutions
Meeting 6: Final Build	ETS1.B ETS1.C	HS.ETS1-3	• Influence of Science, Engineering, and Technology on Society andthe Natural World • Structure & Function • Systems & System Models	• Developing and Using Models • Constructing Explanations & Designing Solutions • Analyzing and Interpreting Data
Meeting 7: Invention Extension	ETS1.A ETS1.B	HS.ETS1-1 HS.ETS1-2	• Influence of Science, Engi-neering, and Technologyon Society and the Natural World • Structure & Function • Systems & System Models	• Asking Questions & Defining Problems • Constructing Explanations & Designing Solutions

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