LEMELSON-MIT JV InvenTeams™

STUDENT GUIDE

Name

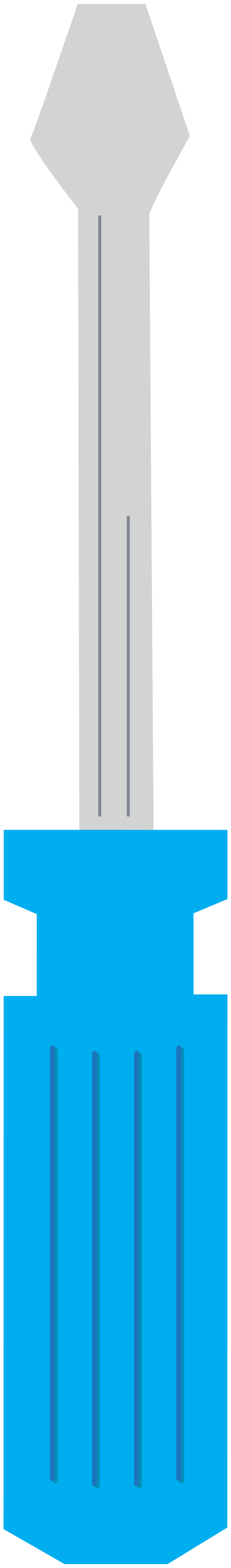
School

Grade

ACTIVITY OVERVIEW

MEETINGS

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

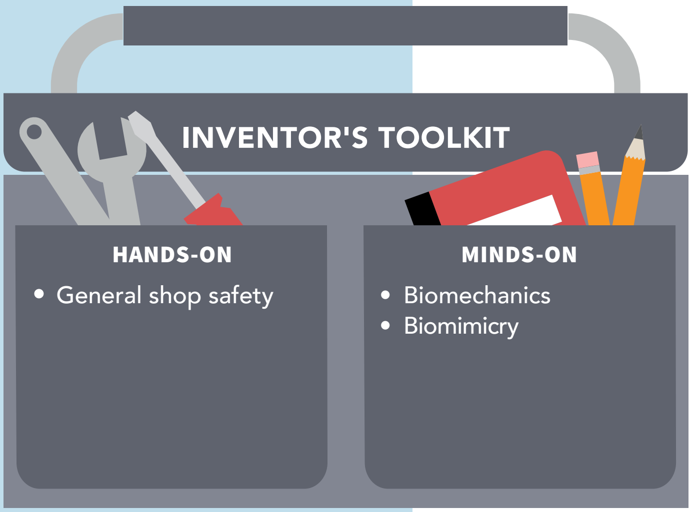
The goal of JV InvenTeams is to cultivate new ways of thinking and develop technical skills for students with limited access to hands-on STEM enrichment opportunities. Through prescribed activities, students will add to their own "toolkits" of minds-on knowledge and hands-on skills while having fun!

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?

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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)*

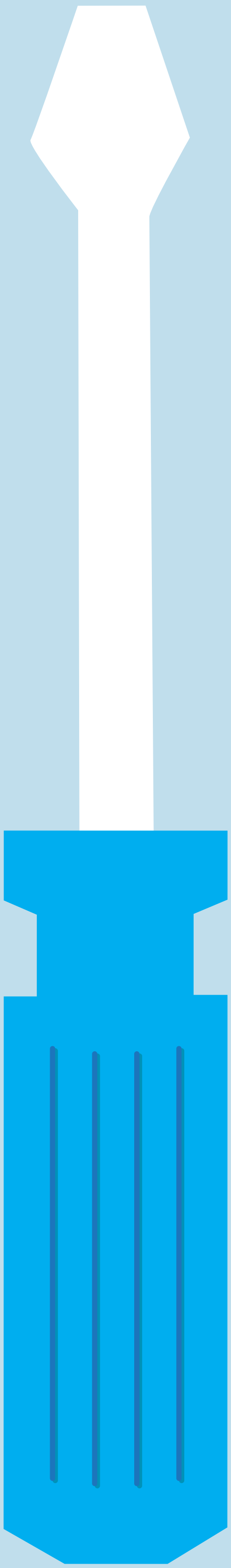
A = **Adapt** *(how would you eat your spaghetti without a utensil?)*

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 FOR EDUCATOR

UNIT SUMMARY

You will explore sound, speakers, instruments, and electric pickups in this unit. You will build and understand how a speaker and an electric pickup work. You will think about how to use your knowledge of sound to create purposeful and useful inventions.

Through readings and hands-on experimentation, you will understand the basics of sound waves, electromagnetism, and how a speaker functions. You will continue to explore sound creation and, through the iterative process, continue to improve both your products and your understanding.

You will also explore ideas of motion by building and exploring a musical instrument made from everyday materials. You will focus on three questions: What is vibrating? How can the user adjust the vibrations? How does the choice of material affect the sound?

You will have the opportunity in the final meetings of the unit to design and build your own electric instruments. You will also work in groups to conceptualize an invention related to your understanding of sound, speakers, instruments, and electromagnets.

MEETING SYNOPSES

1 Invention Introduction

You will be introduced to invention and JV InvenTeams. You'll complete warm-up activities and discuss invention, then play "Four Corners" to determine your strengths for team assignments.

2 Hearing Sound

You will brainstorm how you think sound works and you will be introduced to the basics of sound and human hearing. You will dissect earbuds to find and identify components of a speaker. You will be introduced to speakers and electromagnetism and will build your own electromagnet to examine its properties.

3 Build a Paper Speaker

You will use your understanding of speakers to build a paper plate speaker, and then work in groups to refine your speaker according to a goal you select.

4 Making a Sound

You will be introduced to the human larynx and how we make sound through speech. You will apply your knowledge of sound production as you design and build a musical instrument out of everyday materials.

5 Build an Electric Instrument

You will be introduced to electric instruments using the diddley bow as an example. You'll build an electric pickup and design a musical instrument to electrify. You will then build, test, and refine your electric instruments.

6 Invention Extension

You will conceptualize an invention project that incorporates one or more new skills from the sound unit.

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.

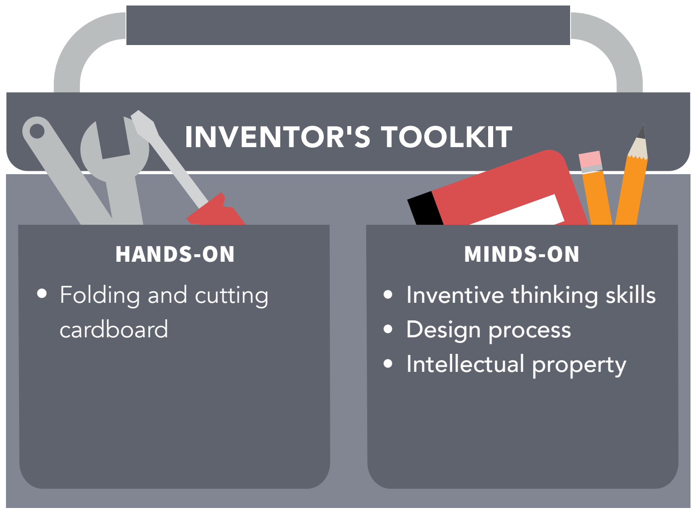
Iteration (n): A version of a design in a series of designs.

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.



Procedure

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

DISTRIBUTE GUIDES AND INTRODUCE JV INVENTEAMS

1. You will use your JV InvenTeams guide as an **invention** guide. This guide will be a portfolio of your work and ideas.
2. The grid paper and blank paper at the end of each meeting can be used to sketch, brainstorm, and document ideas.
3. Items written in **bold underline** represent links to be clicked.

INTRODUCTION TO INVENTION AND PROBLEM SOLVING

1. We all run into challenges on a daily basis. You will now get a taste of what being an inventor means by coming up with ideas to address some of these problems.
2. Your educator has written down some problems on strips of paper. You will work with a team to build a solution to one of these problems using everyday materials.
3. After you receive your problem, use the recycling bin to find building materials and work with your team to devise a quick **invention** to meet your need.
4. When you are finished, take turns sharing your simple solutions with the full group. Some questions to ask other groups include:
   - What else would you do if you had more time?
   - What would you add or change if you had a bigger budget?
5. Inventors often use inexpensive, everyday materials to create **prototypes** of their **inventions**. That's because they don't want to waste expensive materials in the early stages of designing. Failure and mistakes are common and part of the process.

Early prototypes of the Polaroid camera from the MIT Museum collection

MEETING 1

STUDENT NOTE

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.

JV InvenTeams LEMELSON·MIT

VIDEO NOTES

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

1.

2.

BRAINSTORM

Brainstorming ideas before you build is one way to make your final product better. Use the graph paper in the back pages of this meeting to brainstorm two different cell phone holders.

DESIGN A CELL PHONE STAND

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

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

3. Before you start, 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 you are having difficulty coming up with your own design, you can check out **Josh Ramos' Cardboard Phone Stand.**

5. When you're finished, respond to these Follow-Up Questions

   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. Share your design with another student.

7. How would you incorporate your comments and theirs in your next design? Describe this next design **iteration** in words or pictures.

8. During the JV InvenTeams initiative, you will learn about new tools and materials through invention activities like this one. You will think of iterations to improve or change your designs after successfully meeting these challenges.

WATCH SOME INVENTION VIDEOS

1. Each year, teams of undergraduate and graduate students apply for the Lemelson-MIT Student Prize. 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. 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.

photo credit: MIT 2.009

SAFETY

Continue watching Josh Ramos' Cardboard Videos to develop your skills when working with cardboard before doing the activity.

VIDEO NOTES

Write down some thoughts you have about the videos here:

1. General thoughts:

2. How can failure turn out to be a good thing?

3. What failure have you learned the most from?

RESEARCH AN INVENTION

1. 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. 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. You will conduct research on **inventions** using **Google Patent Search**. Google **Patents** lists 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. Take a few minutes to research the product you identified.

5. How can this product continue to improve?

6. What information can you gather from the technical drawings?

7. Why are detailed images such an important part of a **patent**?

PATENT PROFILE

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

DISCUSS IMPROVEMENTS TO AN INVENTION

1. You will work in a small group to brainstorm how you could improve one product or process you use during a typical day. You will respond to the following prompts in your guide:

    - 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?

2. You will learn to carefully observe the world around you in search of problems that can be addressed with a techno-logical solution.

MEETING 1

PRODUCT NOTES

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

1.

2.

3.

How could you improve these things?

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

1.

2.

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How could you improve these things?

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. Watch the **MIT Design Process Videos**. The videos cover: Design Introduction, Observation, Brainstorming, Idea Selection, and Prototyping.

2. Take time to outline the design process in your guide.

SET RULES AND DEVELOP TEAMS

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

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

2. Most of the projects require working in small teams. Diverse teams are successful teams.

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

EXTEND THE LEARNING

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

STUDENT NOTE

Steps of the design process are:

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

SELF-ASSESSMENT

Turn in your completed self-assessment as exit slip when you leave.

INDICATORS OF A SUCCESSFUL MEETING

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

FOUR CORNERS GAME

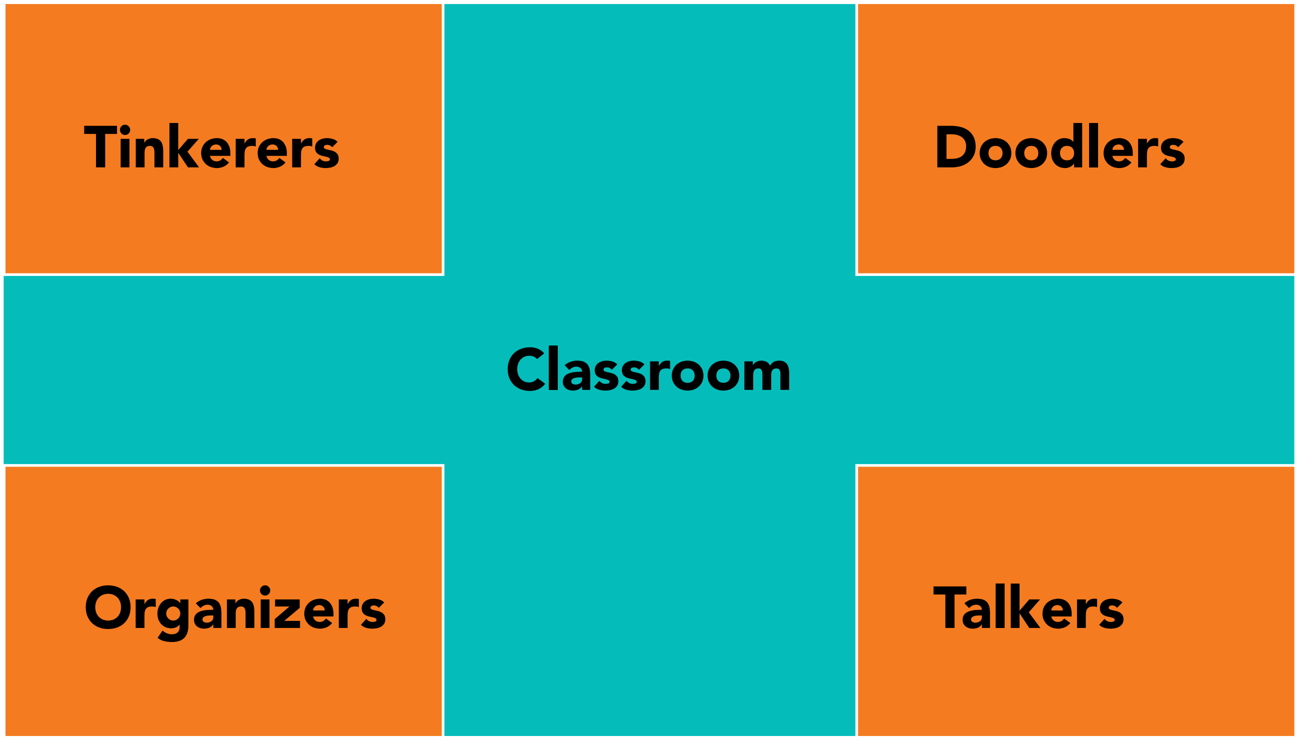
Teams of inventors include people with different interests and skills. Think about your own interests and skills; this will help your instructor organize the class into diverse teams. Draw a line from each type of team member on the left to the best-matching description on the right.

The corners of your classroom will be marked with the four types of team members. Which corner best matches your interests and skills?

Go to your respective corner, based on your "sounds most like me" description. The corners will have an equal number of students in an ideal world. If they don't, equal numbers are needed in order to make well-balanced teams. If you're in the larger group(s), look at your "sounds almost like me" description and compare with the corners needing students. Consider rearranging.

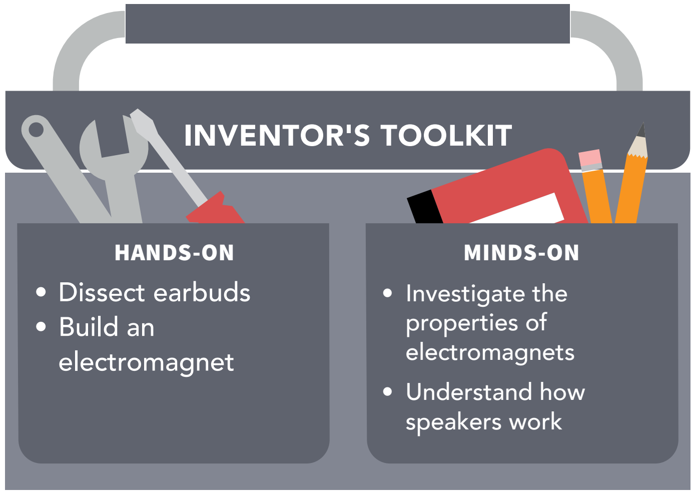
Types of Team Members	Your Interests and Skills
Tinkerer: I like to take things apart and build things.	Sounds most like me
Talker: I like to talk to people and I enjoy public speaking.	Sounds almost like me
Doodler: I like to draw things and express my thoughts through drawing.	Sounds a little like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

Count off within your corners once each has a nearly equal number of students. Finally, all 1s, 2s, 3s, and 4s will come together to form **invention** teams. These teams will come into action when you start team designing.



DRAW IT

NOISE MAKERS
MEETING 2: HEARING SOUND



Procedure

- Introduction to sound: round-robin and readings
- Review shop safety
- Dissect earbuds
- Introduction to speakers and electromagnetism
- Build an electromagnet
- Self-Assessment

KEY TERMS

Compass (n): A floating, magnetized needle that responds to the Earth's magnetic field to indicate direction for navigation.

Current (n): A flow of electric charge.

Cymatics (n): The study of sound waves and their visible representations.

Electromagnet (n): A soft iron or steel core surrounded by a coil of wire that temporarily becomes a magnet when an electric current flows through the wire.

Frequency (n): The number of cycles of a sound wave in a given amount of time.

Iron (Fe) (n): A chemical element with the atomic number 26.

Magnet (n): A piece of material that is able to attract certain metals.

Polarity (n): The direction of a magnetic or electric field.

Resonance (n): The tendency of a system to vibrate strongly at particular frequencies.

MEETING 2

INTRODUCTION TO SOUND: ROUND-ROBIN

1. Today you will be learning how we hear sound. You will use your knowledge of sound throughout the unit to design and refine musical instruments and sound amplification systems.

2. Your educator will demonstrate three different sounds:

- talking,
- plucking a stretched rubber band, and
- playing a song through a **speaker**.

3. Ask yourself as you listen, "What exactly is happening that allows me to hear this sound?"

4. Your educator will place three pieces of paper around the room: one labeled "human voice," one "rubber band," and one "**speaker**."

5. Your educator will divide your class into three groups. You have a few minutes to write or draw your ideas about how you think these sounds get from the object to your ear. Write your ideas on the piece of paper. At the end of the round robin, the entire class' ideas will be collected.

6. Once you are finished, respond to the prompt below:

- What do you still wonder about how sound works?

7. Turn to the next page and start the reading on sound if you finish early.

KEY TERMS (CONT'D)

Sound (waves) (n): Vibrations that travel through the air or another medium and can be heard when they reach a person's or animal's ear.

Speaker (n): A machine that converts electrical energy into movement producing sound.

Steel (n): A metal and modified form of iron.

Tympanic membrane (n): The part of the external ear that passes sound waves to the middle ear through vibrations.

Voice coil (n): The wire coil in a speaker that becomes an electromagnet when a current passes through it.

HIGH SCHOOL CONNECTION

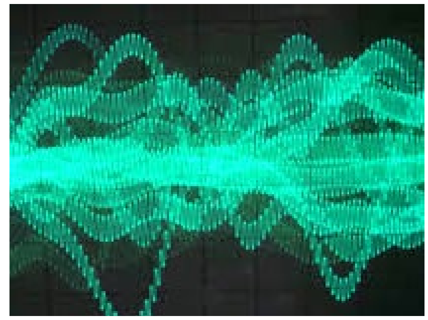
The 2011 Berlin High School InvenTeam (Cherry Plain, New York) invented a device for the deaf and hearing impaired designed to alert the user to incoming traffic when participating in a sporting activity. The device uses an ultrasonic sensor designed to trigger a feedback device. Learn more: [Alert Device]

Credit: lemelson.mit.edu

INTRODUCTION TO SOUND: READING

How do we hear sounds? Why do we hear some sounds and not others? What *is* sound, anyway?

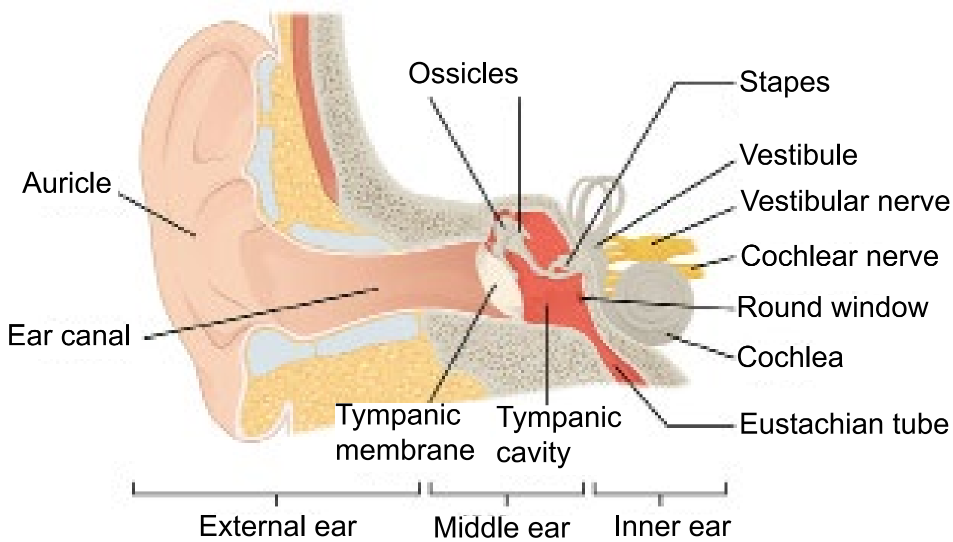
Sound starts as a motion that causes the particles around it to vibrate. These vibrations are called sound waves. Sound waves can travel through solids, liquids, and gases.



Credit: commons.wikimedia.org

We hear sounds when sound waves enter our ears in the form of vibrations. These vibrations are then translated into electrochemical impulses that can be understood by our brain.

Take a closer look at the anatomy of our ears. Notice that the ear is divided into three sections: the external ear, the middle ear, and the inner ear. Each of these sections plays a specific role in transforming sound waves into a form that our brain can understand.



Source: commons.wikimedia.org

Sound enters through the external ear, which is the part of the ear you are probably most familiar with, since you can see and feel it easily. The external ear focuses sound waves onto the **tympanic membrane**, also called the eardrum.

The **tympanic membrane** is connected to a series of three tiny bones called ossicles that lead to the inner ear. The vibrations travel to the inner ear through these bones when sound waves hit the **tympanic membrane**.

The inner ear is filled with liquid. Have you ever tried to listen to someone talking from land while you were underwater? Liquid resists sound waves passing through it more strongly than air does, which results in you hearing less of the original sound.

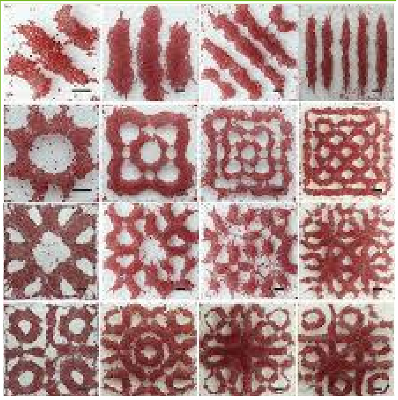
This does not happen in our ears, though. The ossicles act to accentuate the sound vibrations, enabling them to pass into the inner ear in a way that does not diminish the sound waves.

The cochlea, a bone in the inner ear, transforms sound vibrations into electrochemical impulses that are sent to the brain and recognized as hearing.

Watch **Do We Listen With Our Jaw Bones?** (4:10) to learn more about the role our bones play in hearing and how our hearing system may have evolved.

EXTEND THE LEARNING

Evan Grant makes sound waves visible in his TED talk: Making Sound Visible Through Cymatics (5:00). Watch this video to learn how scientists, linguists, educators, and artists are exploring cymatics as a way to understand and represent the world.



Source: commons.wikimedia.org

REVIEW SHOP SAFETY

1. You will be using hand tools such as utility knives. Tools should always be used in the way they were designed to be used. 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.

DISSECT EARBUDS

1. **Sound waves** are vibrations. We cause something to vibrate every time we make a sound.

2. Revisit the three pieces of paper you made as a class. Identify possible sources of vibration in the examples of the human voice, rubber band, and speaker. You may want your educator to make sound with the rubber band again so you can see how it vibrates.

3. You will look more closely at the vibrations that cause human speech later. Today's goal is to begin to understand how our electronic devices, like speakers, make sound.

4. Use the space in the left margin to answer the following question, "How do you think electricity is transformed into mechanical vibrations (**sound waves**)?"

Source: en.wikipedia.org

5. You will look specifically at earbuds. Just as you looked at the anatomy of the ear to better understand hearing, you will look at the "anatomy" of an earbud to better understand making sound.

6. Your educator will assign you a partner for the earbud dissection. You will get a set of earbuds and can use tweezers, pliers, and/or screwdrivers as tools.

Work together to dissect the earbud and make a detailed drawing or written observation of what you find. You can tape the parts to pieces of paper and use a magnifying glass to inspect them. Visit **Earbud Anatomy** to find a useful image.

7. Reflect on the following questions:

- What parts did you find in your earbud?

- What part do you think vibrates to create **sound waves**? Why?

- Why do you think there are batteries in earbuds?

INVENTION SPOTLIGHT

The latest in earbud evolution is the wireless earbud, first introduced in 2016 with Apple's AirPods. Wireless earbuds allow more freedom and comfort without wires pulling on your ears. They are stored in a compact, chargeable container. You can wear one earbud at a time, providing more opportunity to connect with your outside surroundings. Read more about this listening innovation here: **Earbuds**

Source: Wiki Commons

HISTORY

The modern speaker was developed in the 1920s using a magnetic field to move a coil. However, horns were the earliest form of amplification and did not require electricity. The first voice radios used the horn, but they were quickly replaced by the electrodynamic loudspeaker. Learn more about speaker history and the inventors who paved the way by visiting: **Loudspeakers**

INTRODUCTION TO SPEAKERS AND ELECTROMAGNETISM

Credit: lemelson.mit.edu

HIGH SCHOOL CONNECTION

The 2019 Valley STEM + ME2 Academy InvenTeam from Canfield, Ohio invented a danger alert system for schools. The system places microphones in classrooms to detect and locate gunshots. When a gunshot is detected, nearby classroom doors are shut and an electromagnetic lock is activated to keep people in the classroom safe. Red, green, and yellow lights are located in the hallway above each classroom to demonstrate the current threat level based on the closeness to the gunshot. Learn more here: [InvenTeam]

1. You should have found a **permanent magnet** and a wire coil (called a **voice coil**) in your earbuds.

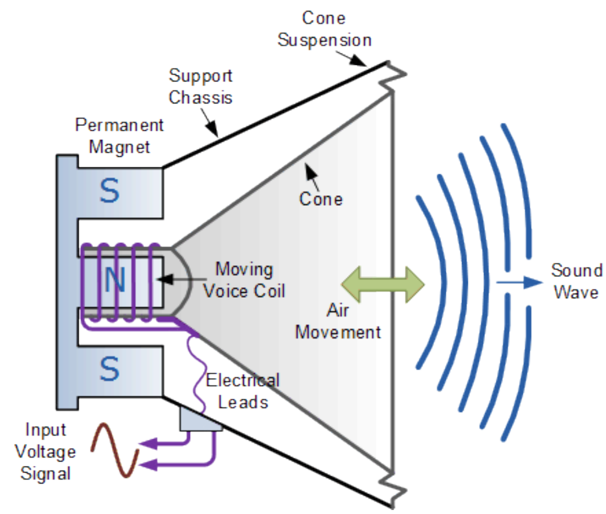
2. These components make up a miniature **speaker**. **Speakers** are machines that transform electric audio signals into sound.

3. The **magnet** inside the speaker has an invisible magnetic field around it. It can attract or repel other **magnets**.

4. When electric **current** flows through the **voice coil**, a different magnetic field is created. This is called an **electromagnet**. An **electromagnet** can also attract and repel other **magnets**, but unlike a permanent **magnet**, **electromagnets** can be "turned off" by stopping the flow of electric current through the **voice coil**.

5. When the **voice coil** becomes magnetized, it will interact with the permanent **magnet** by pushing or pulling against it. When you change the direction of the current moving through the **voice coil**, you change its **polarity**: a push becomes a pull, and a pull becomes a push. This motion of the **electromagnet** pushing and pulling generates sound vibrations in a speaker.

6. Watch **Speakers**: **[Magnetism and Sound]** (stop at 2:20) to see how speakers work using **electromagnets**.



Source: www.electronics-tutorials.ws

BUILD AN ELECTROMAGNET

*This activity is adapted from AAAS Science NetLinks: **Build an Electromagnet**.

You will build your own **electromagnet** so you can investigate some of its properties and predict outcomes.

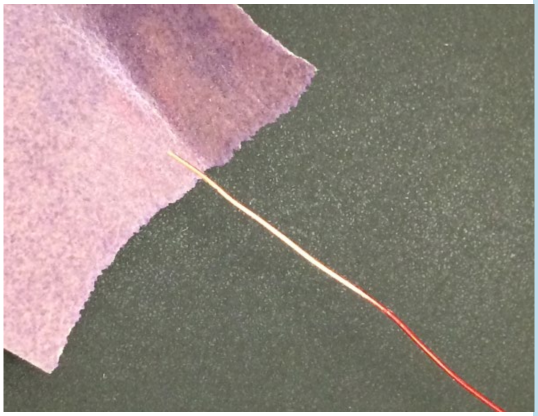
Instructions for building an electromagnet

1. Your educator will give you the following materials:

- 24-gauge red enamel-coated **magnet** wire cut into 3 yard lengths
- D cell battery
- Pink eraser
- Electrical tape
- Paper clip and other metal objects that can be picked up with **magnets**
- 3” nail
- 220-grit sandpaper torn into 3” squares

2. You will work in pairs. Every student should wear safety glasses to protect his or her eyes from the sharp ends of the wire. Dust masks should be worn during sanding.

3. Use the sandpaper to remove ½” – 1” of red enamel coating at both ends of the magnetic wire.



4. Gently push the tip of the 3” nail into a pink eraser. The eraser offers a base to hold the nail safely.

MEETING 2

EXTEND THE LEARNING

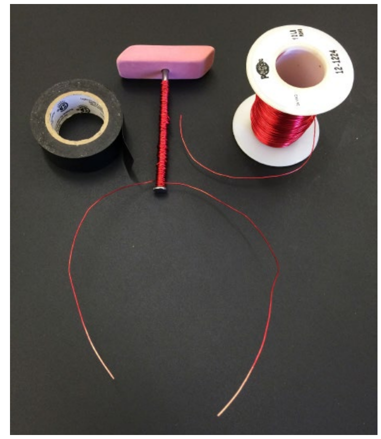
Glass has a natural **resonance** and will vibrate if exposed to a matching **frequency**. If the sound at this particular **frequency** is focused enough, the glass can vibrate so intensely that it shatters. See the power of sound for yourself: **Breaking Glass with Sound**

SUSTAINABLE SOLUTIONS

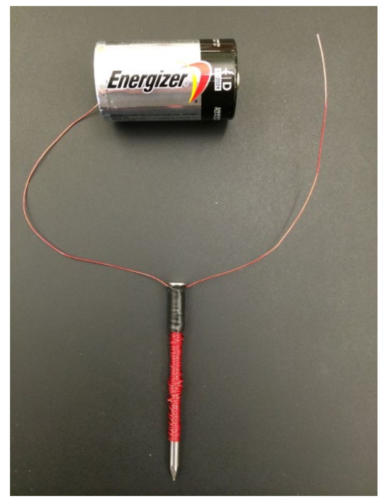
There are a lot of different types of batteries. Single use batteries change stored chemical energy into electrical energy to power things like flashlights, toys, and digital cameras. Alkaline batteries depend on a chemical reaction between zinc (negative electrode) in the presence of an alkaline electrolyte and manganese oxide (positive electrode) to produce electrical energy. Alkaline batteries are purchased as AAA, AA, C, and D size cells. Fully discharged or dead batteries should be discarded according to each state's regulations. Some states like California consider all batteries as hazardous waste and they cannot be discarded in the trash. How should batteries in your city or state be discarded? Learn more here:

[Recycling Laws Map]

Wrap the **magnet** wire around the nail in a clockwise motion. You should start wrapping the wire at the head of the nail, leaving 6” of wire loose. Wrap the 3 yards of wire to form a coil around the nail, and when you get toward the eraser base you should wrap back up to the head of the nail in the same clockwise motion until you have finished coiling. The coils should end at the head of the nail.

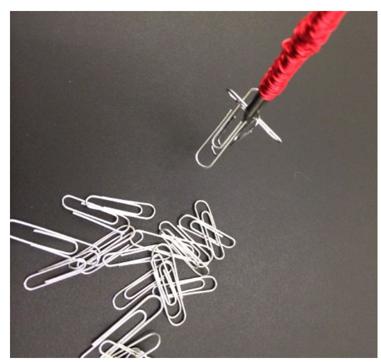


5. Tape the coil tightly at the head of the nail with electrical tape, allowing the two sanded ends of the wire to extend past the head of the nail.



6. Attach one sanded end of the wire to the negative (-) end of the D cell battery with electrical tape. Remind them that the negative end is the flat end.

7. Close the circuit by holding the other sanded end of the wire to the positive nub. The circuit gets hot so do not use tape to keep the circuit closed. You can use your fingers to open and close the circuit by touching the positive nub.



8. Pick up a paper clip with one end of the nail.

9. You have created an **electromagnet**! Use the prompts below and on the next page to guide your investigation of **electromagnet** properties.

Strength Test

How many paperclips can you pick up with your **electromagnet**?

Try to make your **electromagnet** stronger with the materials you have. What did you try? How did it work?

Pushes and Pulls

Opposite poles on **magnets** pull (attract) and the same poles on **magnets** push (repel). You can change the direction of the **current** moving through the wire, which changes the **polarity** of your **electromagnet**. A push becomes a pull (attract) and a pull (repel) becomes a push. It is this motion that generates sound vibrations in a speaker.

Can you predict how to change the direction of the **current** moving through the wire coil? Can you use a **compass** to test your prediction?

Speakers

How might a speaker with a strong **electromagnet** work differently than a speaker with a weak **electromagnet**? How could you test this idea?

Use the blank pages at the end of this meeting to draw a design for a simple speaker based on what you now know about speakers, sound, and **electromagnets**.

HISTORY

Watch: [How a Compass Works]

The magnetic or navigational **compass** points towards Earth's North magnetic pole. It was invented as early as the Chinese Han Dynasty (221-207 BC). The Song Dynasty (960-1279 AD), with its permanent navy, adopted the **compass** for navigation; Chinese sailors actively used the magnetized **compass** needle in 1119 AD. Uses of navigational **compasses** were referenced in medieval Europe and in a Persian book from the thirteenth century. Inventions of and improvements to magnetic **compasses** have continued into modern times. Today, there are even electronic **compass** applications for smart phones that aid navigation.

EXTEND THE LEARNING

Is there a difference between light waves and **sound waves**? In fact, there are many differences between light and **sound waves**. Watch [Making Waves with Sound and Light] to learn about these two different phenomena.

DRAW IT

DRAW IT

MY THOUGHTS

MY THOUGHTS

NOISE MAKERS

MEETING 3: BUILD A PAPER PLATE SPEAKER

KEY TERMS

AWG (n): American Wire Gauge; a standardized system for the diameters of electrically conducting wire.

Bass (n): Tones in low frequency or range.

Cone (n): A component of a speaker that is attached to the voice coil and has a large surface area to move more air.

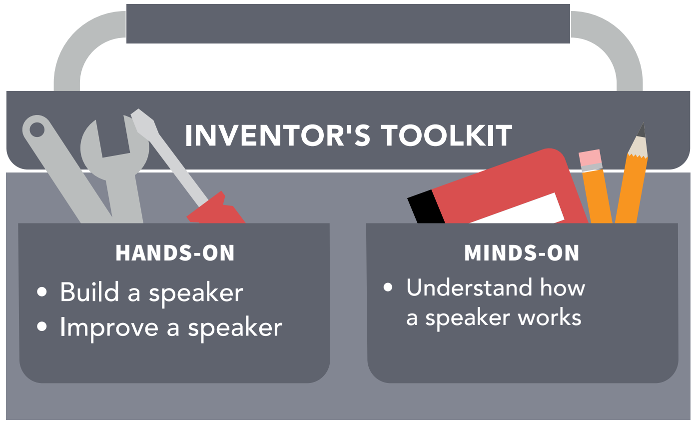
Criterion (n): Principle or standard against which something can be judged or decided.

Constraints (n): Limitations or restrictions.

Neodymium magnet (n): A widely used type of rare-earth magnet; a permanent magnet made from an alloy of neodymium, iron and boron to form the $Nd_2Fe_{14}B$ tetragonal crystalline structure.

Spider (n): The component of a speaker that helps keep the voice coil over the magnet.

Surround (n): The strong, sturdy, flexible roll at the edge of the cone in a speaker.



Procedure

- Review How Speakers Work
- Build a Paper Plate Speaker
- Meet Lee Zamir from Bose®
- Invent a Better Speaker
- Self-Assessment

REVIEW HOW SPEAKERS WORK

1. Remind students that speakers are machines that convert electrical energy into mechanical energy (sound waves). In the last meeting, students investigated two components of speakers—the **voice coil** and the magnet—to better understand how electrical energy is transferred into mechanical vibrations.

2. You also found a thin piece of plastic inside your earbud speakers. This plastic was attached to the **voice coil**.

- What do you think is the purpose of this plastic piece?

MEETING 3

3. This plastic piece is called the **cone**. The **cone** vibrates with the **voice coil**, creating strong sound waves.

  - What properties do you think it is important for the **cone** to have? Why?

4. **Cones** are purposefully designed to have a large surface area so that they can move more air with their vibrations. **Cones** are often made out of a lightweight, stiff material that can be moved easily without distorting.

5. You are going to build a speaker out of everyday materials. Your speakers will include a voice coil, a magnet, and a **cone**.

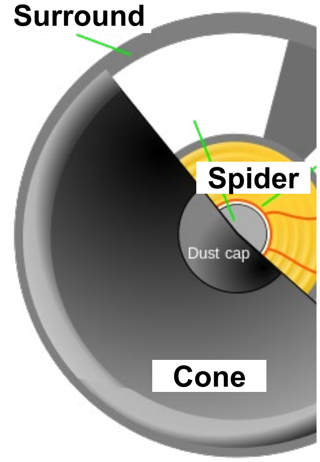
Cone made of paper pulp

Source: commons.wikimedia.org

SUSTAINABLE SOLUTIONS

The Defense Advanced Research Projects Agency (DARPA) created a system that can help put out flames using sound! The team arranged two speakers on either side of a flame to demonstrate how fire can be controlled by an acoustic field. The sound increases air velocity, which thins the area of the flame where combustion occurs, known as the flame boundary. Once the boundary area is thinned, the flame is easier to extinguish. Learn more: Wall of Sound

6. Check out two other parts of the speaker—the **spider** and the **surround**. The **spider** is attached to the bottom of the voice coil and is often made from fabric. The **surround** is a strong, sturdy, and flexible roll at the edge of the **cone**.

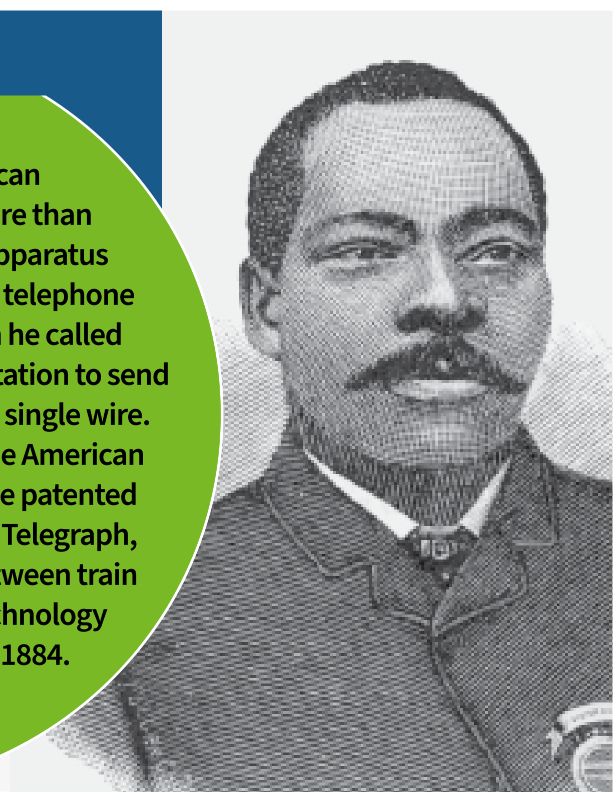


Source: commons.wikimedia.org

7. Together, the **spider** and **surround** help keep the coil centered over the magnet, and they move the coil and **cone** quickly back into place after they've been pushed or pulled by the magnet. They help keep the **cone** from wobbling, which can cause audio to sound scratchy.

HISTORY

Granville Woods was an African American inventor who held more than 50 patents. Woods patented an apparatus in 1885 that was a combination of a telephone and a telegraph. The device, which he called "telegraphony," allowed a telegraph station to send voice and telegraph messages over a single wire. He sold the rights to this device to the American Bell Telephone Company. In 1887, he patented the Synchronous Multiplex Railway Telegraph, which allowed communications between train stations from moving trains, a technology pioneered by Lucius Phelps in 1884.


Source: en.wikipedia.org

BUILD A PAPER PLATE SPEAKER

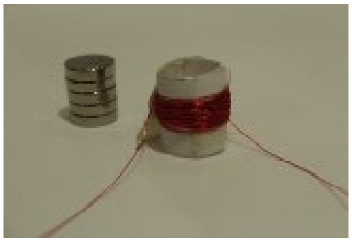
Work with a partner and follow the instructions below to build a simple speaker.

How to Build a Paper Plate Speaker

1. Gather the following tools and materials:
   - 5 **neodymium magnets**
   - Magnet wire
   - Tape and scissors
   - Scrap paper
   - 2 paper plates
   - Sandpaper
   - Glue and hot glue gun

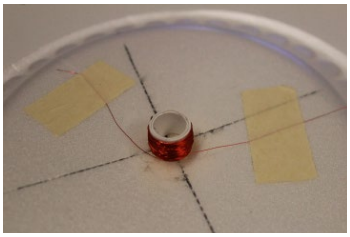
2. Wrap a strip of paper around the stack of magnets and tape it to itself. Do not tape the paper to the magnets!

3. Wrap another strip of paper around the first and tape it to itself. Separate the two and discard the inner paper tube—the one with the smaller diameter.



4. You should trim the paper tube so it is slightly longer than the magnets inside it.

5. Wrap a piece of magnet wire tightly around the tube 50 to 60 times. You should now have a hollow paper tube with magnet wire wrapped around it. Make sure both ends of the magnet wire are roughly 6 inches long.



6. Use a small piece of sandpaper to remove the coating from the ends of the magnet wire.

MEETING 3

INVENTOR PROFILE

Thomas Edison invented and improved on communications devices in the late 1870s. He tinkered with both the telephone and telegraph machines, and attempted to make a machine that could record the voice. Edison finally had success with his invention of the phonograph in 1877. The first audio recording was Edison reciting the nursery rhyme, "Mary Had a Little Lamb." Read more: Edison

Credit: en.wikipedia.org

EXTEND THE LEARNING

Team Up for Stereo Sound

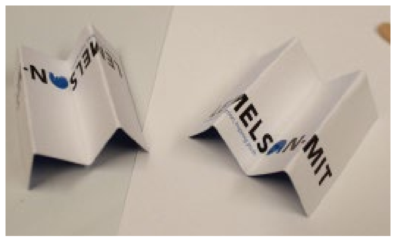
Partner with another team to connect both speakers to the computer for stereo sound! Connect one speaker to the right cable and the other to the left cable.

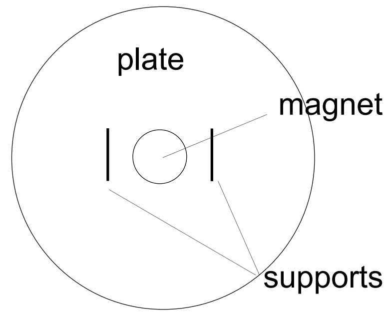
While the music plays, take turns placing your heads directly between the two speakers. Can they find a song that sounds like it has a voice or instrument floating between the two speakers?

7. Glue the voice coil you just made to the center of the bottom of a paper plate. You should use a ruler and marker to mark the center point before you glue. Tape the ends of the magnet wire to the plate.

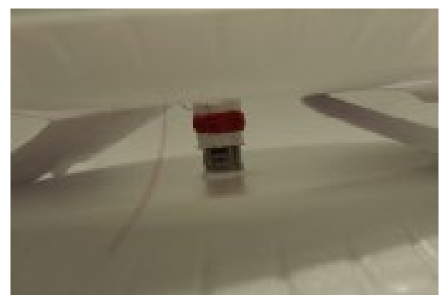
8. Glue the stack of magnets to the center of the bottom of a different paper plate.

9. Create two accordion-fold supports and glue the supports to the plate with the magnets using this diagram:





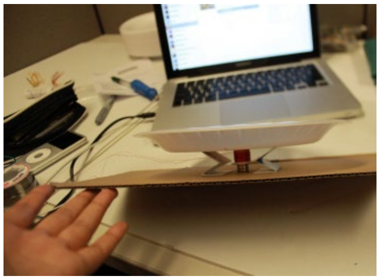
10. Place the plates so that the voice coil slides over the magnets, then glue the top of the supports to the plate with the voice coil.



SUSTAINABLE SOLUTIONS

Researchers from MIT, Adobe, and Microsoft have developed an algorithm to extract audio information from video footage. They recovered intelligible speech from a video of a potato chip bag that was shot at a distance of 15 feet behind soundproof glass. Learn more about their research: [Sound from Silence]

Source: en.wikipedia.org



11. You should use the alligator clips to hook your speakers to the audio cable at the computer or other device. Remember that audio cables can vary. For example, one type can have three wires, so you should test the various wires until it works. Test the speaker by playing a song!

Refer to the following troubleshooting tips if your speakers aren't working correctly.

General Troubleshooting

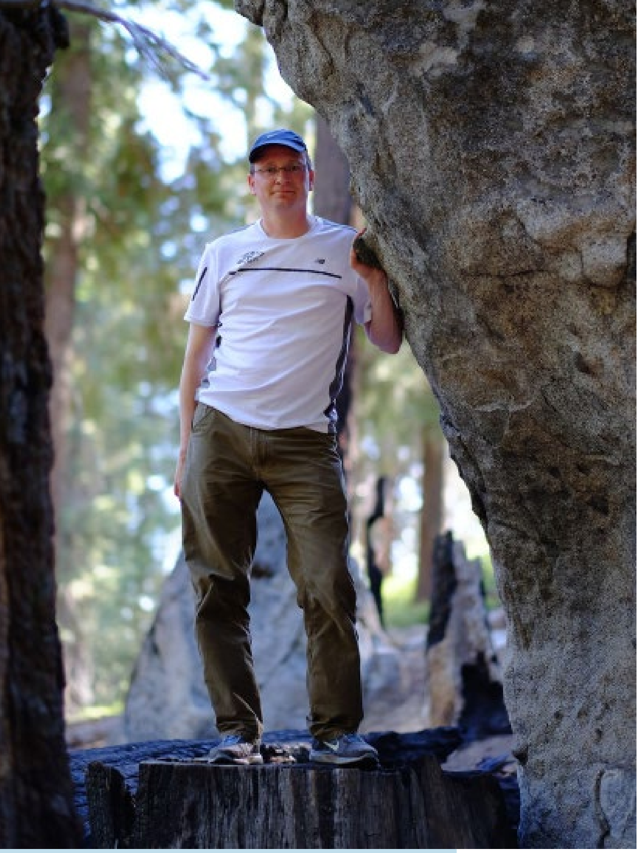
- Make sure the magnet is resting in the voice coil when not hooked up to the audio source.
- Make sure the magnet wire ends are sanded smoothly.
- Turn the volume up to max on your audio device.
- Make sure the magnets aren't resting too low.
- Make sure the coil isn't too low.
- Make sure the magnet sits in the coil when at rest.

If the speaker sounds terrible, check the following:

- Make sure the wires are coiled tightly and are not rubbing against other pieces.
- Make sure the voice coil is not touching the magnet.
- Make sure the **cone** (plate) is not damaged.

If the sound is too quiet or there is no sound, check the following:

- Be sure the voice coil is at the same height as the magnet.
- Make sure the supports are parallel. Try adjusting their position for better sound.
- Double-check your connections.



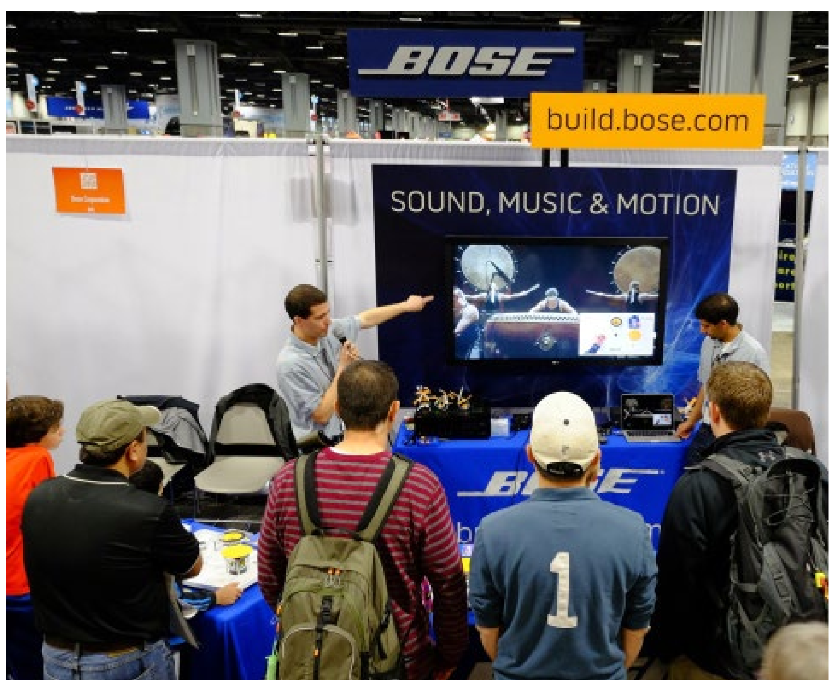
Credit: bose.com

MEET LEE ZAMIR FROM BOSE®

Lee Zamir went to MIT to study engineering. There, he received his bachelor's and master's degrees in electrical engineering and computer science. He joined Bose Corporation shortly after graduating from MIT in 1997. While at Bose, he has held various positions that span engineering, research, sales, and marketing. He became the director of the New Business Development Lab in 2012; there he and his team identify and develop new products that go beyond audio entertainment.

Who were your role models as a kid?

"My math teacher was a terrific role model because he made us not just try to get an answer to the math problems, but challenged us to bet him on the answer for points on the next test. This encouraged me to have conviction about the answer and to care about figuring things out. My parents were also great role models. They always encouraged me to make my own things instead of just buying them. That way you get what you want and you have a sense of joy and pride in the things you have."



Credit: bose.com

MEETING 3

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

"I was the youngest of three kids so there was a basement full of toys that had already been played with and built by my older brother and sister. I would take the old toys and try to invent new ways of using them so they would feel like new toys. For instance, I took an old block set and some old plastic train tracks and constructed a marble raceway. I would launch two marbles on the two train track grooves and see which marble would finish the course the fastest."

How did you get interested in speaker/sound technology?

"Like most kids, I was getting into music and had a simple little radio that I could listen to in my room. My parents decided to buy a sound system for their living room and I decided I would 'help' them research what to get—knowing that I would be able to listen to music as well. When I saw how much these systems cost, I thought I would never be able to afford one. So I found an after school speaker-building workshop and convinced my parents to let me enroll. The cost of the workshop was far less than any of the systems my parents were considering buying and I enjoyed making them myself."

What advice can you give kids who want to become inventors?

"Make things every chance you get. Anytime you want something, ask yourself if you could imagine making something for yourself that's even better than what you could buy. This can be anything - from a sandwich to a pair of sneakers to a speaker. Go for it and make it for yourself. It may end up better than what you could buy."

What do you do for fun outside of work?

"I play Ultimate Frisbee, I like to hike and I love making furniture and things out of wood."

EXTEND THE LEARNING

We have all seen slow motion, but what about slow sound? The MIT Lincoln Lab filmed in slow motion and slow sound in the 1960s many common sounds, such as popcorn popping, nails dropping, and glass breaking. Watch the video: [Slow Sound]

Source: en.wikipedia.org

LEMELSON·MIT InvenTeams

INVENT A BETTER SPEAKER

1. Your instructor will pair you with another student for this exercise. Discuss with your partner the speakers you just built. What are the strengths?

   - What are some weaknesses?

   - How could we improve our speakers?

2. Choose ONE improvement goal for a new speaker. Examples include:

   - louder sound
   - louder **bass** (low pitches)
   - smaller size
   - more stable **cone**
   - more contained structure

3. Use the rest of the meeting to design and build a speaker that will meet your selected goal.

4. Your selected goal is considered a design **criterion**. You will also be working within design **constraints**, which in this case are limited time and materials.

5. Use the blank pages in your guide to brainstorm ways to meet your **criterion**.

6. Show a written, or drawn, plan to your educator before getting materials and beginning your work.

7. As you work, ask yourself the following questions:

   - What is your goal for this speaker?
   - How does your design work?
   - What is working well in your design so far?
   - What is not working well?
   - How are you working together to meet your goal?

8. Test your speakers and informally evaluate your design. Ask questions such as:

- Does this speaker meet the goal we chose for it?
- How does this speaker compare to my first speaker?
- Why do we think this speaker does/does not work well?
- How would we improve our speaker if we had more time or different materials?

9. Share your design process final speakers with the class.

DRAW IT

DRAW IT

MY THOUGHTS

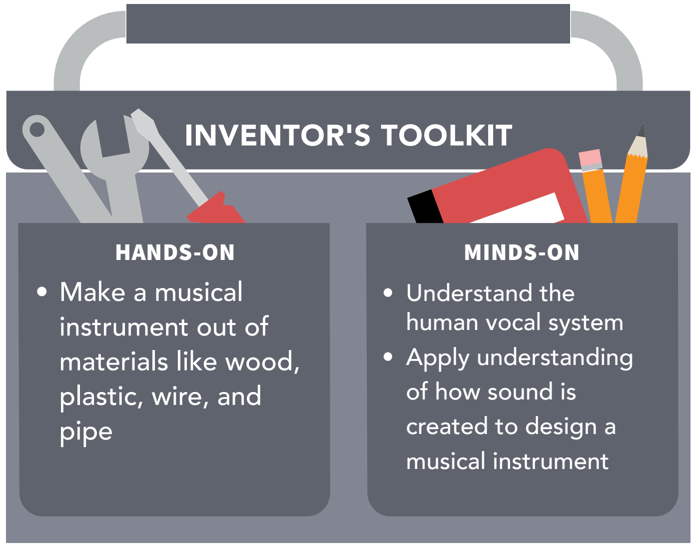
MY THOUGHTS

KEY TERMS

Larynx (n): The organ forming an air passage to the lungs and containing the vocal cords.

Pitch (n): In music, the number of vibrations per second; high and low pitches correspond to high and low notes.

Vocal cords (n): Folds of tissue that vibrate as air passes along their edges to create sound.



Procedure

- Introduction to the Larynx
- Meet Nate Ball
- Make a Musical Instrument
- Types of Musical Instrument
- Notes on Materials
- Self-Assessment

INTRODUCTION TO THE LARYNX

1. Today you are going to learn more about creating sound by building a musical instrument out of everyday materials.

2. First, you are going to learn more about how the human voice works so you can use that knowledge to inform your instrument design.

3. Remember, you hypothesized how the human voice works in an early meeting. If your instructor still has the papers with everyone's ideas on it, review those now.

4. Reflect on the questions below as a class:

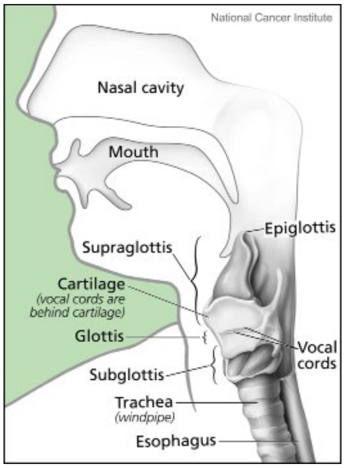
   - Based on what you know about sound, what do you think is vibrating that causes the human voice?

- How do you think we can make low sounds and high sounds?

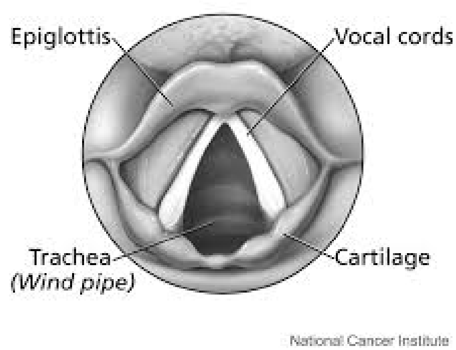
- Why do you think adults' and children's voices have different **pitches**?

- Do you think it's possible to make a high and low **pitch** at the same time with your voice? Why or why not?

5. Look at the diagrams below as your educator introduces how the human voice works. The first diagram shows a side view of the **larynx** and nearby structures. The second diagram shows a cross-section of the **larynx** directly over the **vocal cords**.



Credit: commons.wikimedia.org



Credit: commons.wikimedia.org

6. Our **vocal cords** (or vocal folds) are muscles that we can control. Sound waves come out through the mouth if we vibrate the **vocal cords** while exhaling. We can also stretch them to create differently-**pitched** sounds.

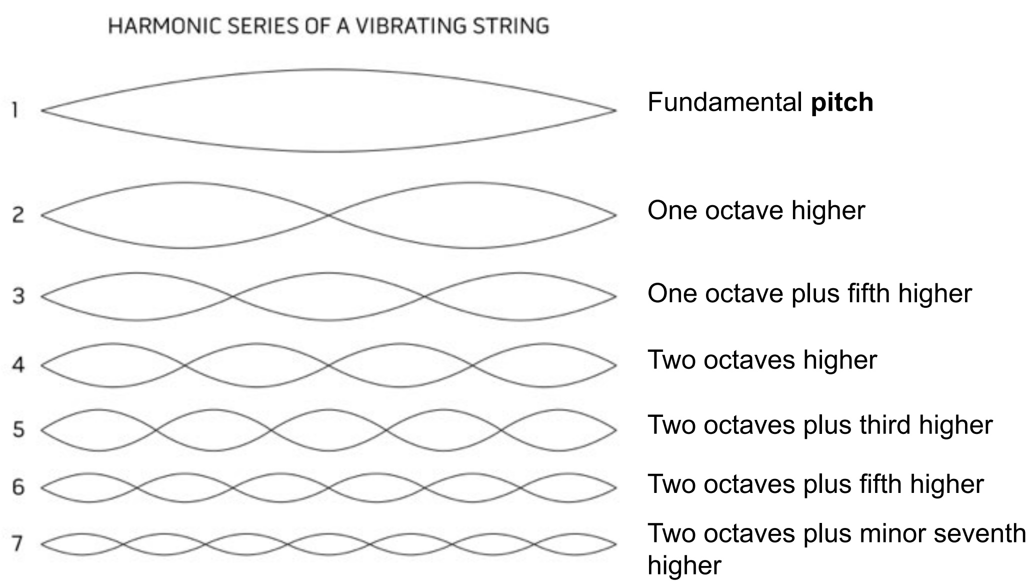
COLLEGE CONNECTION

In the fall of 2018, several cross-disciplinary projects at MIT explored the technological and visual limits of sound, resulting in new innovations. Some of these include motion-sensing headphones that allow runners to keep a steady pace, a virtual 3-D reconstruction of a spider's web with each strand tuned to a different note, and "The Laughing Room" installation that allows artificial intelligence to decide what is funny using a recorded laugh track. Learn more: [Sound Technology]

7. Adults tend to have longer, thicker **vocal cords** than children. Just as vibrating a long, thick rubber band will create a lower **pitch** than vibrating a short, thin rubber band, an adult will typically have a lower voice than a child.

8. Humans use more than just their vocal cords to create speech. We use our lips, tongue, and mouth to shape sounds and add percussive elements.

9. Do you think it's possible for humans to make a sound with more than one **pitch** at once? It turns out that we can! A vibrating string generates a fundamental frequency, which is what we tend to hear as **pitch**. If you divide the string into sections, the rate of vibrations increases (see the diagram below). These rapid vibrations generate other **pitches** that all relate to the fundamental **pitch** in some way.



10. We typically do not hear these **pitches** because they are weaker than the fundamental **pitch**. Some singers have learned to amplify these other **pitches** in order to sing multiple notes at once. Check out [Tuvan Throat Singing] to learn more.

Credit: en.wikipedia.org

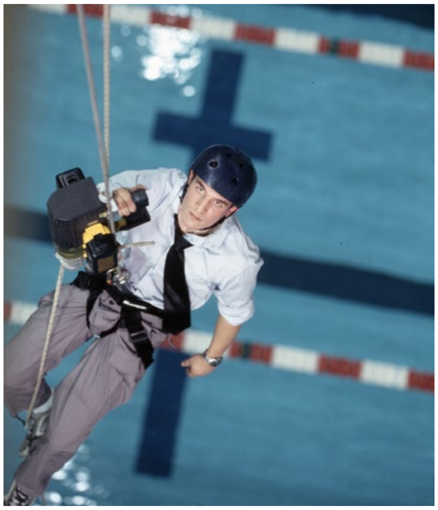
MEET NATE BALL

Source: lemelson.mit.edu

Nathan "Nate" Ball's passion for invention was coursing through his veins long before he could define the word. He created a bottle-rocket launcher in fourth grade that shot bottles of water 100 feet skyward. This was followed by a hovercraft powered by a vacuum cleaner motor, which he constructed in sixth grade.

By the time Ball was in the eighth grade, he was attempting to build a Tesla coil in his parent's garage, making capacitors out of glass bottles and aluminum foil. "I saw Tesla coils on the Internet shooting lightening," said Ball. "It was the coolest thing I'd ever seen, and I knew I had to build one."

Amazingly, Ball never touched a machine tool until he reached college. He credits limited resources during his formative years for his ability to think unconventionally about problems and to engineer efficient solutions.



Source: lemelson.mit.edu

Ball received his Bachelor of Science and Master of Science degrees in mechanical engineering at MIT. He cofounded Atlas Devices, LLC to develop and commercialize the ATLAS Powered Rope Ascender, which uses a rope-handling mechanism conceived by Ball. This portable device can raise more than 250 pounds at 10 feet per second, giving rescuers, emergency personnel and soldiers faster and more controllable climbing capabilities.

Ball is also trained in classical piano. For fun, he enjoys playing jazz keyboard and beat boxing. Check out **Nate Ball's TED Talk** (start at 10:14) to see a beatboxing **larynx** in action! Note how he uses his knowledge of sound and vibration to create deep bass.

Who were your role models as a kid?

"My dad and granddad were both great role models. I learned even more from them by observing than I did from having them teach me things, though they did plenty of that too. By seeing how they would approach a problem, I learned ways to go about 'figuring it out,' regardless of the project. It was awesome! They had many hands-on skills to begin with, and I loved watching them use tools to build things. It was also inspiring to see what they would do when they had to get past a challenge."

"I also loved reading kid's books about Leonardo Da Vinci, Thomas Edison, and Nikola Tesla, and hearing stories of ancestors of mine who were also inventors (look up Elisha Gray, my great-great-grand-uncle!)."

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

"All kinds. I loved playing with blocks and legos and wanted to build forts constantly. In fourth grade I built my first 'real' project that had plans and an awesome outcome when it worked: a 2 liter bottle rocket launcher! I realized I could build lots of cool things in real life—not just models out of blocks and legos. I started dreaming up other cool things to build, like an alarm system for my bedroom, a catapult for my back yard, and a go-kart powered by the wind that I could drive on the beach. Though every project came with its own challenges and setbacks, I loved every minute of every project, and I've really never stopped."

How did you discover beatboxing?

"I still remember it so clearly: I had just used Napster to download an mp3 of the famous beatboxer Rahzel doing the 'beat and the chorus at the same time,' and I was utterly amazed. I played that track for everybody I knew. My parents were amazed. My friends were amazed. I couldn't stop thinking about it! How did he beatbox and sing at the same time? I grew up playing music and loved making drum noises with my mouth from an early age, so finding out that "beatboxing" was an actual thing people were good at was pretty exciting. But especially exciting was the idea you could do two things at once—the beat along with the words. I spent about a month straight working on it, and finally figured it out. It didn't sound very good early on, but the satisfaction was immense and I was totally hooked! Spread out through the day, I often still beatbox for 30 to 60 minutes. It kind of runs along in the background for me, like humming for some people. But I get to keep improving as I go."

What advice can you give kids who want to become inventors?

"Dive right in! Do it! And enjoy the process. It really helps to have a project that you're just so excited about, you can't even think of not trying to make it happen. Inevitably, it will get hard—you'll be in over your head, not knowing what the next step is, frustrated that it's not going how you planned, and unsure if you should continue. But if you're really driven and can still envision that goal, it can help you get through those tough times. The more driven you are to bring that idea into reality, the more ways you'll identify to make it happen, even when it gets hard."

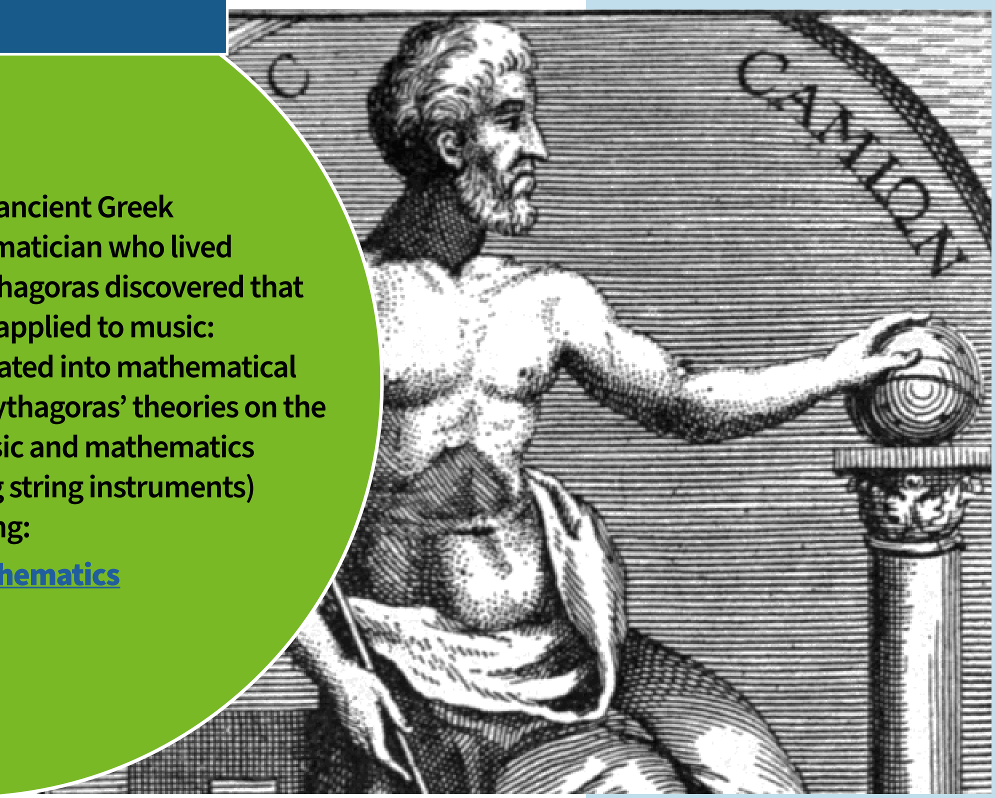
What do you do for fun (besides beatboxing) outside of work?

"I still do some pole vaulting and parkour tricks, play piano (mostly jazz), make TV shows (Design Squad!), write kids' books, build extra-fun projects like a web-enabled temperature monitor for my house, do awesome stuff with my partner Catherine, and enjoy how much fun it is to learn and do new things with our baby son Calvin."

HISTORY

Pythagoras was an ancient Greek philosopher and mathematician who lived in the late 6th century BC. Pythagoras discovered that scientific law could be applied to music: musical notes could be translated into mathematical equations. Learn more about Pythagoras' theories on the relationship between music and mathematics (specifically with vibrating string instruments) by visiting:

[Music and Mathematics]



Credit: commons.wikimedia.org

MAKE A MUSICAL INSTRUMENT

1. You will spend the rest of today's meeting designing and building a musical instrument. Use this time to investigate a component of sound that is interesting to you.

2. Ask yourself the following questions as you work:

   - What is vibrating?

   - How can the player control and change the vibration?

   - How does the choice of material impact the sound?

3. You have access to a variety of everyday materials. You can also use tools like saws and hammers if you want to work with wood.

4. The resources on the next two pages will help you determine the type of instrument you want to make and also what materials might be helpful to you.

5. Use the blank pages at the end of this meeting to brainstorm ideas and sketch designs before building.

6. Share your instrument with the class at the end of the meeting.

SAFETY

Dust masks and safety glasses must be worn when cutting wood.

TYPES OF MUSICAL INSTRUMENTS

There are many instruments in the world and many ways to organize them into categories. One popular sorting system is the Hornbostel-Sachs system, which divides instruments into four types.

Credit: en.wikipedia.org

Idiophones

These instruments make sound when the body of the instrument vibrates. Examples include sticks, gongs, bells, and xylophones.

Photo: the triangle

Credit: commons.wikimedia.org

Membranophones

These instruments make sound when a stretched membrane vibrates. Examples include drums and kazoos.

Photo: a drum set

Credit: en.wikipedia.org

Chordophones

These instruments make sound when a stretched string vibrates. Examples include guitars, violins, and pianos.

Photo: piano strings

Credit: commons.wikimedia.org

Aerophones

These instruments make sound when a column of air is made to vibrate. Examples include flutes, accordions, and trumpets.

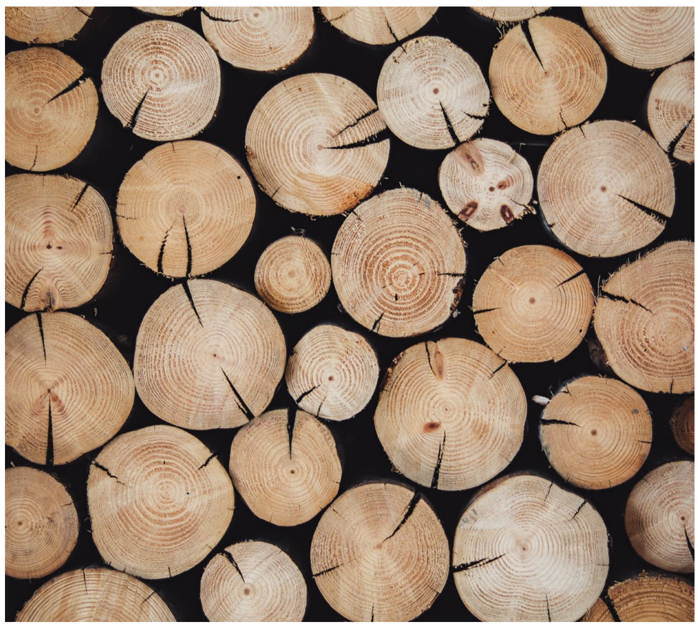
Photo: a wooden recorder

Not all instruments fit neatly into this sorting system, but it is a helpful way to think about the source of vibrations in an instrument. What type of instrument will you create?

NOTES ON MATERIALS

Everything has natural frequency at which it vibrates. This means that the material you choose has a lot to do with what sound you get. You can adjust the vibrations and alter the sound by adjusting certain properties like tension, weight, and length.

What materials will you choose for your instrument?



Credit: Zuzana Kacerová | Unsplash.com

Credit: commons.wikimedia.org

INVENTOR PROFILE

Hedy Lamarr was an Austrian actress who became a prominent inventor when she moved to the United States. She developed a "Secret Communications System" to help defeat the Nazis during World War II. Lamarr manipulated radio frequencies at irregular intervals between transmission and reception to form an unbreakable code to prevent classified messages from being intercepted by enemies. Her "spread spectrum" technology laid the groundwork for future wireless technologies. Learn more:

[Spread Spectrum Technology]

Credit: commons.wikimedia.org

DRAW IT

DRAW IT

MY THOUGHTS

MY THOUGHTS

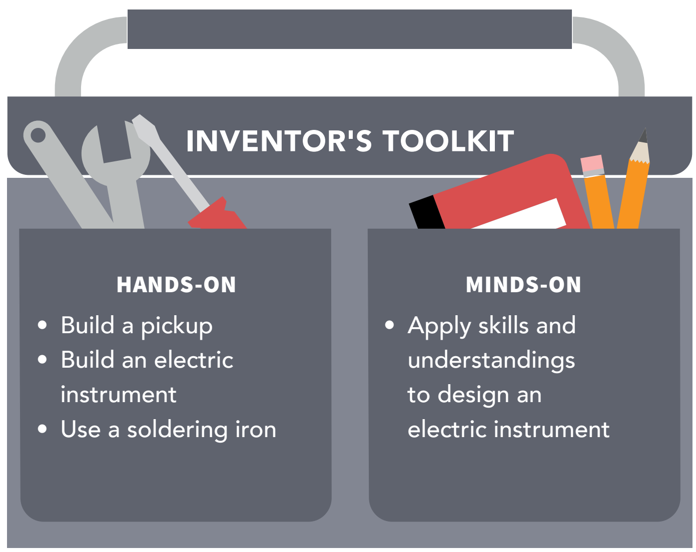
MEETING 4

KEY TERMS

Gauge (n): The thickness, size, or capacity of something, especially as a standard measure, in particular.

Humbucker (n): Type of electric guitar pickup that uses two coils to cancel out sound interference.

Pickup (n): A device that captures mechanical vibrations from stringed instruments and converts them to an electrical signal.



Procedure

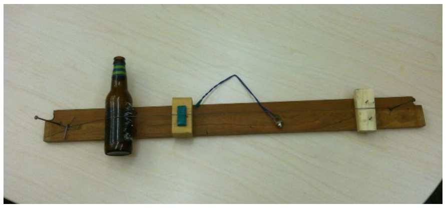
- Introduction to the Diddley Bow
- Invent an Electric Instrument
- Meet Jay Silver
- Self-Assessment

INTRODUCTION TO THE DIDDLEY BOW

1. You have a solid foundation in understanding how sound works. You will now have the opportunity to build your own musical instrument, incorporating your new minds-on skills in electromagnetism and sound.

2. Have you ever heard of a diddley bow? The diddley bow is a one-stringed guitar made out of a piece of wood with a wire tensioned between two nails over a glass bottle for amplification.

3. The diddley bow was first popularized by African-American blues musicians; its sound greatly influenced the development of American blues music.



4. Musicians began creating electric instruments in the 1920s, including electric diddley bows. Electric instruments use a **pickup** to capture mechanical vibrations and convert them to an electrical signal.

5. **Pickups** have three main components: a metal core, a magnet, and many coils of wire. What do you think the functions of these three components are?

6. The metal core acts much like the cone in a speaker. Instead of vibrating the air with its surface area, it picks up vibrations from the instrument and transfers these vibrations to the magnet. The vibrating magnetic field then causes a vibrating current to flow through the coils in the form of electricity.

Credit: commons.wikimedia.org

7. Watch **[Jack White Makes an Electric Guitar]** to see an electric diddley bow being constructed and to hear its powerful sound. Read **[How Electric Guitars Work]** to learn more about electric instruments.

INVENT AN ELECTRIC INSTRUMENT

1. You will spend the rest of this meeting and the next one designing and constructing an electric instrument.

2. You will work in groups of four. Your group can create any kind of instrument it wants.

3. One component every instrument will have in common is the **pickup**. Review the instructions for building the **pickup**.

Where would you place the pickup on this instrument?

Credit: en.wikipedia.org

4. Take some time to figure out what type of instrument you would like to create. You can use what you learned to plan your instrument design.

5. Decide on the criteria and constraints for your instrument design.

Examples of criteria are:

- The **pickup** must amplify the desired sounds while not picking up other movements
- The instrument will be ___________ type of instrument
- The instrument will have _________ strings

Examples of constraints are:

- Limited time
- Limited tools and materials

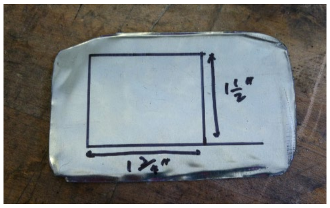
6. Once you have established the criteria and constraints for your design and have decided on a plan, you can start to build.

How to Make a Pickup

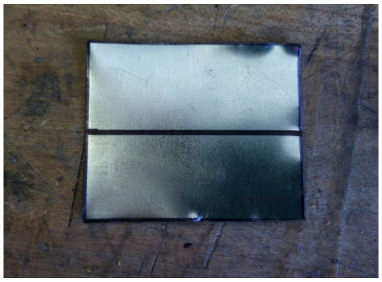
1. Gather the following materials:
   - small rectangular tin box with hinges
   - neodymium magnet
   - tin snips
   - sandpaper
   - permanent marker
   - ruler
   - 32-**gauge** wire
   - 18-**gauge** wire
   - ¼” mono jack
   - clamp
   - soldering equipment

2. Cut out the bottom of the tin with tin snips. Edges will be sharp, so you should use sandpaper on the edges to make them safer to handle.

3. Flatten out the metal as much as possible. Measure a 1 ½” x 1 ¾” rectangle, then cut the rectangle with tin snips.



4. Measure ½ the length and draw a line with a permanent marker across the middle of the rectangle to mark a fold line.



SAFETY

Wear safety glasses during all building steps.

STUDENT NOTE

While other students are coiling the wire in step 8, you can research how to build a musical instrument.

Credit: lemelson.mit.edu

INVENTOR SPOTLIGHT

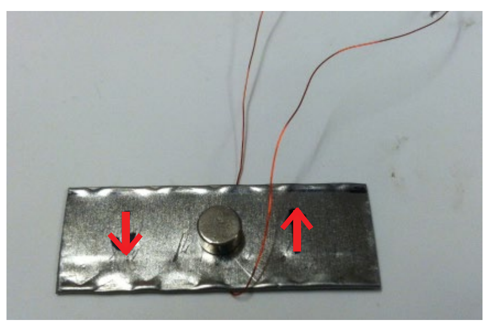
Amar Bose invented stereo speakers that produce high-end sound in spite of being modest in size. Bose was raised in Philadelphia in the 1930s, the son of an immigrant from Calcutta, India. He first became interested in technology at age thirteen when he started repairing model trains to provide additional income for his family. Amar Bose attended MIT and soon after became determined to invent a stereo loudspeaker that would reproduce the vivid sound of being in a concert hall. In his lifetime, he earned over two dozen patents for his inventions.

Learn more: [Amar Bose]

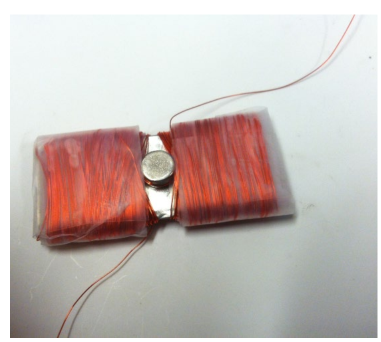
5. Fold the metal in half, and clamp the metal down on a desk (with the bend mark right at the edge of the desk).

6. Place a neodymium magnet in the middle of the folded metal piece.

7. Prepare the materials for making the wire coil. Coil the wire in one direction on one side of the magnet and in the other direction on the other side of the magnet (see the arrows in the photograph). This coiling method is called a **humbucker pickup**, which minimizes interference. Lay the wire underneath the metal so you have two ends to begin coiling with.

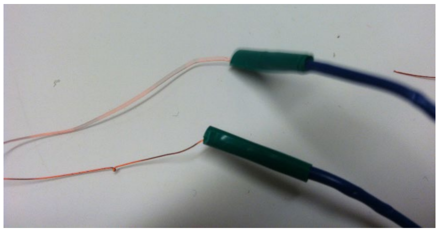


8. Coil the wire as shown in the photograph; you will need 400 wraps of the wire on each side of the magnet! Take turns with your teammates. You may want to occasionally wrap the wire in tape to make sure the coils don't slip. Once you are finished, tape it up again. Each end of wire should have about two inches sticking out.



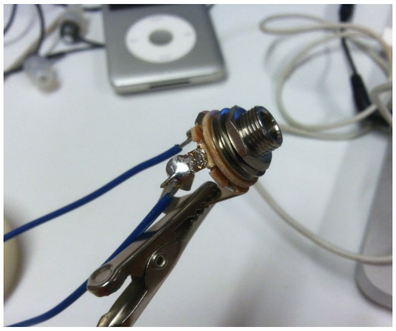
9. The thin 32-**gauge** wire is covered in enamel, so you should sand approximately ½” of each end to expose the bare wire.

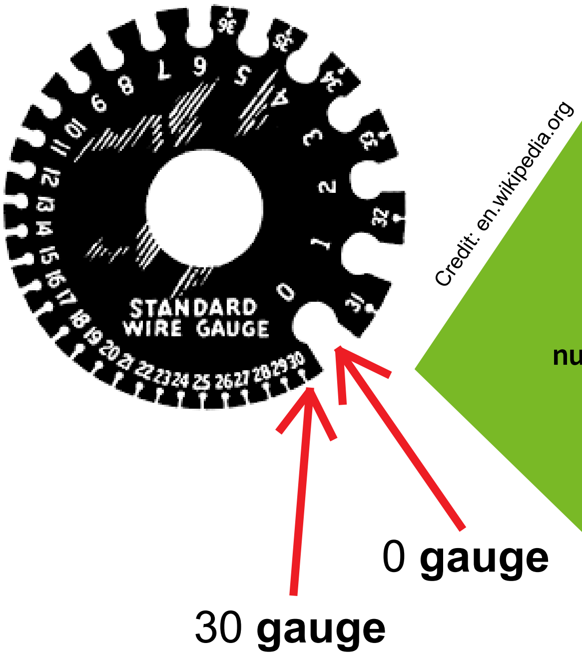
10. Solder the thin wire to a thicker 18-**gauge** wire, and wrap the connection in electrical tape.



11. Solder the 18-**gauge** wire to a ¼” mono jack. Your **pickup** is now complete!

12. Use the iRig and an iPhone or iPad. Plug the **pickup** into the iRig to turn your device into an amplifier.





EXTEND THE LEARNING

Increasing **gauge** numbers denote decreasing wire diameters, which is similar to many other non-metric gauging systems. This **gauge** system originated in the number of drawing operations used to produce a given **gauge** of wire. When you look at the image below you can see the difference in between the 30 **gauge** wire and the 0 **gauge** wire diameters. Learn more: [Wire Gauge]

Credit: lemelson.mit.edu

MEET JAY SILVER

Jay Saul Silver received his PhD in the Lifelong Kindergarten Group at MIT Media Lab, and works for Intel Lab's "Interaction Experience Research" group, helping develop a Maker Culture. Time named one of his inventions "Top 15 Toys for Young Geniuses," and he has put out many creative platforms, including **Drawdio**, **Singing Fingers**, and **Scratch**, collectively in the hands of millions.

Jay has given talks at TEDx Sacramento, TEDx Santa Cruz, and TEDx Amherst. He has exhibited internationally at museums such as the National Taiwan Museum of Fine Arts, the Exploratorium, and ARS Electronica. He also runs digital prototyping workshops for clients such as IDEO, LEGO®, and Intel®.

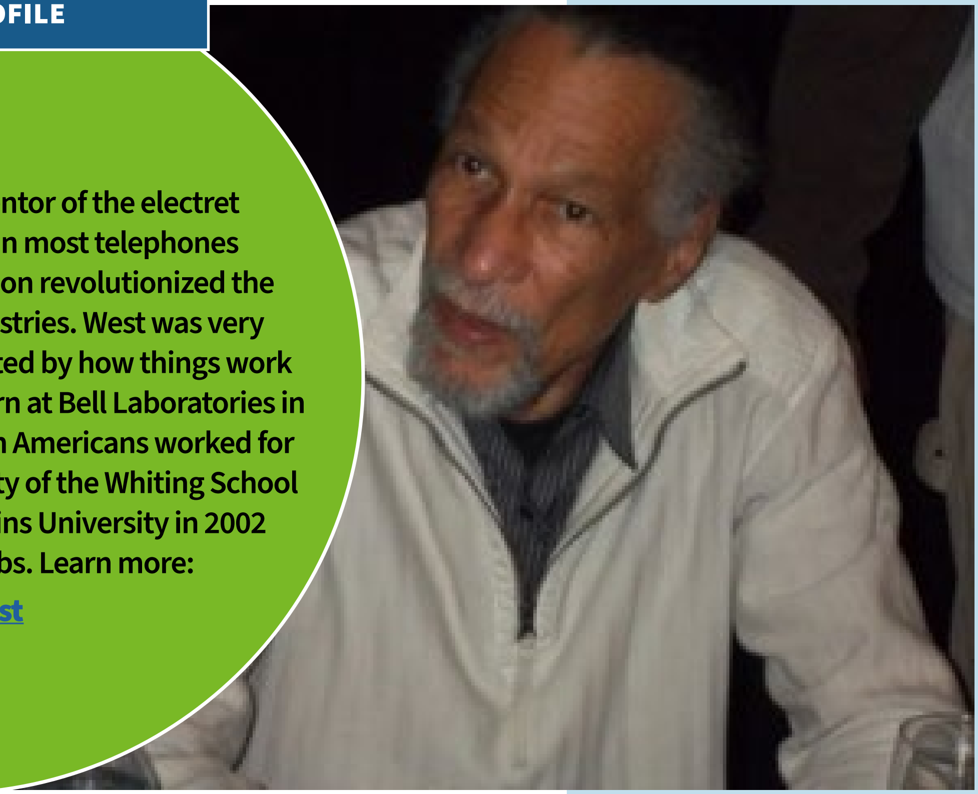
Jay studied electrical engineering at Georgia Tech where he was named Engineer of the Year. He was awarded a Gates Scholarship to earn a master's in Internet Technology from Cambridge University. He also holds a master's in Media Arts and Sciences from MIT Media Lab, where he invented "Camera for the Invisible."

Watch Jay Silver's TED talk, **Hack a Banana, Make a Keyboard!** to learn more about Jay's work and inspiration.

SUSTAINABLE SOLUTIONS

A group at the MIT Media Lab called the "Opera of the Future" explores concepts and techniques to help advance the future of musical composition, performance, learning, and expression. Their research includes musical instrument design, concepts for new performance spaces, interactive touring and permanent installations, and "music toys." Learn more: Opera of the Future

INVENTOR PROFILE



James E. West is the co-inventor of the electret microphone, which is used in most telephones and tape recorders. His invention revolutionized the telephone and recording industries. West was very young when he became fascinated by how things work and why. He was hired as an intern at Bell Laboratories in the mid-1950s, when few African Americans worked for laboratories. He joined the faculty of the Whiting School of Engineering at Johns Hopkins University in 2002 after working for Bell Labs. Learn more:

James West

Credit: commons.wikimedia.org

DRAW IT

DRAW IT

MY THOUGHTS

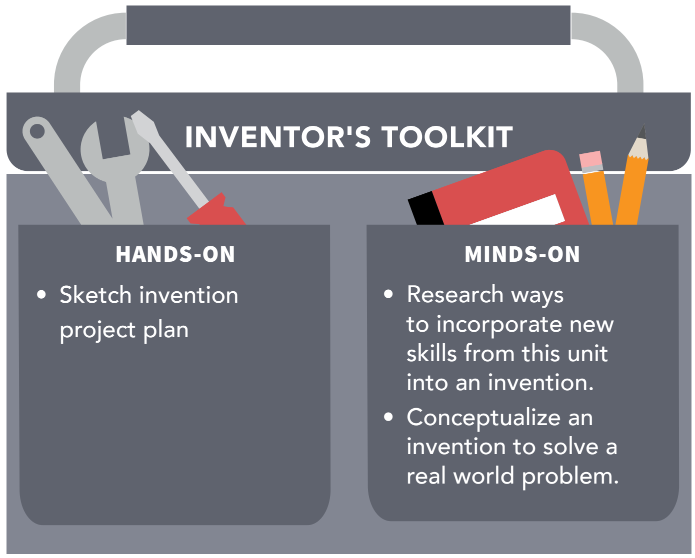
MY THOUGHTS

MEETING 5

NOISE MAKERS
MEETING 6: INVENTION EXTENSION

KEY TERM

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



Procedure

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

INTRODUCTION TO INVENTION CHALLENGE

1. Today you will conceptualize a project using the hands-on and minds-on skills you have developed within this unit.

2. Although time and resources will limit the design process to conceptualization, you can continue working on projects outside of meeting time. The most useful and unique ideas have the possibility of becoming InvenTeams projects in subsequent years.

3. Invention is centered on **empathy** and fulfilling the need of an individual or group of people with a unique solution to a real-world problem. The most important thing today is identifying a real need and conducting research before jumping into project development.

4. People throughout the world use products pertaining to sound—whether it's speakers to listen to music, machines to record speech or music, or musical instruments to produce music.

REVIEW REAL-WORLD EXAMPLES

1. Review the following examples as a class. These projects may inspire your design thinking.

Example 1: Jabberstamp

Jabberstamp is the first tool that allows children to synthesize their drawings and voices. First, children create drawings, collages or paintings on normal paper. They then press Jabberstamp's special rubber stamp onto the page to record sounds into their drawings. When children touch the marks of the stamp with a small trumpet, they can hear the sounds play back, retelling the stories they have created.

Jabberstamp can be used as a communication tool, as a learning tool, and as a step toward writing.

Watch **Jabberstamp** to see this invention in action.

Credit: lemelson.mit.edu

HIGH SCHOOL CONNECTION

The 2014 School of Dreams Academy InvenTeam (Los Lunas, New Mexico)invented "Police ALERT," a monitoring device that detects potential threats within a 40-foot radius around a patrol car.

The police officer in the car is warned via an in-cab indicator when motion is detected. The in-cab indicator includes both audio and visual cues.

Learn more: **Police ALERT**

Example 2: Clear Lake High School InvenTeam

The 2012 Clear Lake High School InvenTeam (Houston, Texas) invented a compact, multifunctional medical unit that generates power, sterilizes water, and stores medical equipment.

Credit: lemelson.mit.edu

Sterilization occurs in an ultrasonic machine that employs high-intensity sound waves to eradicate pathogens. The invention costs $2,500 and is aimed at providing clean drinking water to people in Bangladesh.

Example 3: Mt. Edgecumbe High School InvenTeam

The 2014 Mt. Edgecumbe High School InvenTeam invented a search and rescue unmanned aerial vehicle (UAV) for the Sitka Search and Rescue in Sitka, Alaska. The UAV addresses the issue of lost and injured individuals on remote waterways and mountains that surround Sitka.

Credit: lemelson.mit.edu

The UAV includes a high-resolution camera, a forward-looking infrared camera, and a two-way audio communication system. The open, two-way communication system helps alleviate the fear that arises in these situations to reduce the danger to rescue workers. The communication system has a range of a one-mile line of sight and a flight time of 10 minutes. Visit **Search and Rescue** to learn more.

SUSTAINABLE SOLUTIONS

The world generates approximately 1 billion tons of garbage each year. The people of Cateura, Paraguay in South America transform the trash that surrounds their community into musical instruments. Watch the Landfill Harmonic Video (3:27) to see this group of children and music teacher create instruments solely out of garbage.

Example 4: Woody Norris


Credit: lemelson.mit.edu

"What if you could aim sound the way you aim light?" asks Woody Norris.

Norris' hypersonic sound (HSS) system is designed to control and focus sound, just as lasers focus and control light. When aimed directly at a listener it has the effect of wearing headphones, almost like a voice inside one's head.

Norris anticipates his HSS system to be used in advertisement, noise-cancellation, entertainment, and for military purposes. What do you think this system could be used for?

Watch **Woody Norris' TED talk** to learn more.

Example 5: InvenTeams

Flip back through this unit and check out the High School Connection pop-outs. They are all examples of former InvenTeams projects related to sound.

These projects all demonstrate a clear beneficiary, a unique solution, and technological means for solving a real-world problem. Moreover, all of these students connected with local partners and mentors to facilitate the completion of their project.

Your idea should be ambitious enough to span the course of an academic year. However, it should also be realistic and doable.

Visit the **InvenTeams website** to search current and past teams to get more information about their projects.

IDENTIFY A NEED

1. Reflect on the new toolkit of skills you have acquired in this unit. You have gained minds-on skills such as understanding sound, electromagnets, speakers, and electric instruments. You have practiced hands-on skills such as making electromagnets and speakers, cutting wood, and soldering.

2. Invention is centered on **empathy** and fulfilling people's needs.

3. How could you use these 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.

4. 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 the last, you can research the needs of a particular country or region to develop a product that may be useful. Perhaps your school has a partnership with a "sister city" in another country.

5. For additional information on problems/needs in other countries, explore the **World Bank** website.

6. Share your ideas with your team and work together to brainstorm new ones. You should try to apply your new hands-on and minds-on toolkits as you brainstorm. Examples are:

- Modify your speaker to meet a real-world need
- Address an educational need
- Address a social need
- Incorporate sound into your invention

7. Use the Invention Challenge Brainstorm on page 72 of this meeting to develop and track your team's ideas about needs it would like to address.

Credit: lemelson.mit.edu

HIGH SCHOOL CONNECTION

The 2017 Pine School InvenTeam from Hobe Sound, Florida invented a device using audio and video components to monitor the health of the Indian River Lagoon. The device consists of a hydrophone and camera that are enclosed in a waterproof housing and can be lowered 5 - 7 ft. Learn more: Pine School InvenTeam

BRAINSTORM SOLUTIONS

1. Once your team has decided on needs it would like to address, use SCAMPER to brainstorm design solutions.

2. 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 you can arrange the characteristics of what is challenging you 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. 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. Do some personal brainstorming using SCAMPER. Afterward, discuss your ideas with your team and streamline them. You should select one idea (or a combination of multiple ideas) to take to the next step.

Make a Plan

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

2. Ask yourself the following questions to make sure you are on target:

- Is the product offering something useful and unique?
- Who will benefit from the invention?
- Does your project incorporate sound in some way?
- Are you excited and motivated to develop your idea?
- What additional research would you need to conduct?
- What new tool and/or material skills would you need to learn?
- If the product meets a local need, would a community group, university, or company want to get involved with the project?

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

4. Share your team's plan with the class if time allows. Are you interested in continuing your work? Consider **applying for an InvenTeams grant**.

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?)

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: ______________________

DRAW IT

DRAW IT

MY THOUGHTS

MY THOUGHTS

WARNING: THE MATERIALS, TOOLS, AND EQUIPMENT INCLUDED IN THIS KIT ARE NOT APPROPRIATE FOR USE BY CHILDREN UNDER AGE 11 AND SHOULD ONLY BE USED WITH PROPER TRAINING AND ADULT SUPERVISION.

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