



## STUDENT GUIDE

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Name

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School

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Grade



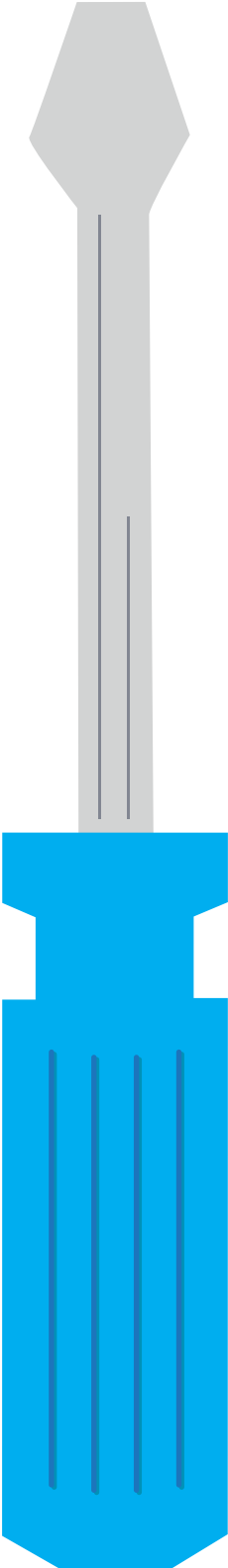
## **ACTIVITY OVERVIEW**

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# 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!

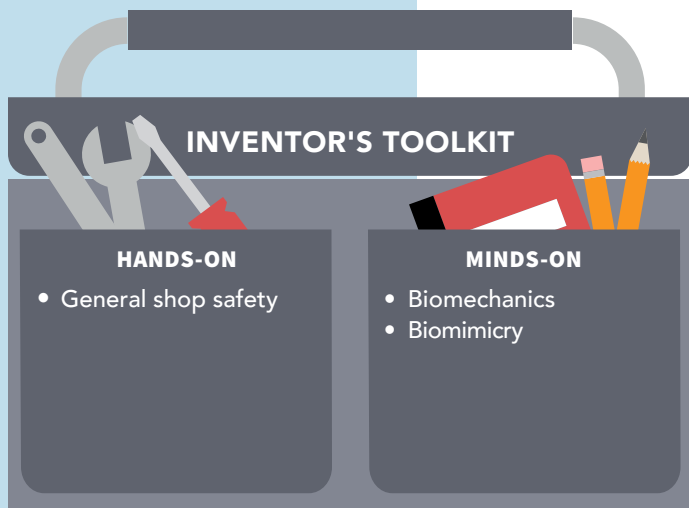
Students will learn how to identify a need in their lives or in the world around them and develop their own invention after completing the main activity in each unit. They will pull from their expanding toolkit to come up with solutions.

### **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.





### 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.

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

### SAFETY

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

### INVENTOR SPOTLIGHT

In 1902, mechanical engineer Willis Carrier patented the air conditioner, a device he originally invented to solve a problem facing a paper printing plant in Brooklyn, New York. Read more about his invention—and how the invention of air conditioning helped expand Southern cities such as Houston and Atlanta.

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

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

## Group Size

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

## Partnerships

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

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

## Flexibility

The JV InvenTeams has built flexibility into the program to meet the needs of educators, school systems, and grants-based clubs and organizations. Following are some examples:

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



## Inventive Thinking

Both educators and students will develop an understanding of the invention process as you navigate through JV InvenTeams. This new way of thinking, part of the minds-on toolkit, may take some time to adopt since learning within the school day increasingly focuses on standardized tests of academic knowledge.

Invention is a variable, non-linear process. JV InvenTeams introduces the curiosity and creativity of recognizing problems and addressing them with novel solutions. You will not need to worry about knowing the “right” answer since there are countless possibilities. Experiencing failure is part of the invention process.

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

## User-Centric

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

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

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

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



After learning from the user, the student can further investigate. Questions he or she might ask include the following:

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

These questions will inform research and allow the student to develop meaningful solutions.

## Deciding on a Good Problem to Solve

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

## Scamper

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

**S = Substitute** (*playing basketball with a softball*)

**C = Combine** (*toothbrush combined with a pencil to create a new product*)

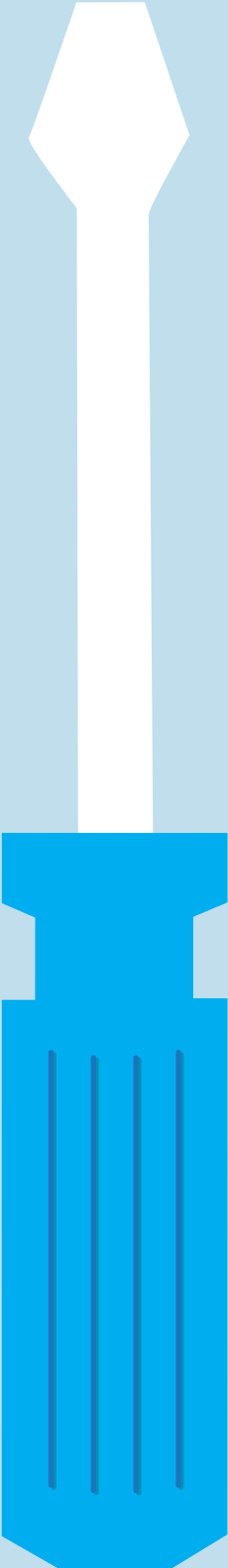
**A = Adapt** (*how would you eat your spaghetti without a utensil?*)

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

**P = Put to Other Uses** (*could your fork be used as a comb?*)

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

**R = Rearrange** (*what if the laces of a shoe were placed on the bottom and not the top?*)



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

## **Documentation**

Students should be encouraged to document their progress along the way. This includes saving sketches, designs, research data, graphs, images, and early prototypes. Most of this work, with the exception of the actual prototypes, can be compiled in the Student Guides. Students should routinely review their guide, adapting what they have learned and experienced to new challenges.

## **Patents**

Since this program is all about invention, it is important that educators and students familiarize themselves with the United States laws that protect the intellectual property of inventors.

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

According to the U.S. Patent and Trademark Office, patents provide legal protection to inventors' intellectual property by excluding others from profiting from their property in the U.S. for a specific amount of time, in exchange for the inventors' disclosure of their idea according to the criteria for granting a patent. There are three different types of patents. Utility patents are granted to inventors who discover a new and useful process, machine, article of manufacture, or a new and useful improvement. Design patents are granted to those who invent a new, original, and ornamental design for an article of manufacture. Finally, a plant patent is granted to an inventor who invents a new variety of plant. The basic components of a U.S. patent are: patent number, title, inventors, assignee

(optional transfer of intellectual property to a company or other individual), abstract (short overview of invention), drawings, description (technical details), and claims (legal information). To learn more about the patent process, visit: <http://www.uspto.gov/>.

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

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

It is important to keep in mind that not all inventions are patented. Some inventors purposefully do not seek a patent with the idea that their inventions are immediately and widely available. An example is open source software, which allows anyone to use the software without paying a fee.

This openness can spur further invention since anyone can access it and make adaptations. In spite of the changes in patent law through the Innovation Act of 2013, students should adopt the habit of recording and dating their work, including early sketches and research. This practice will be useful for future science exploration and invention. To learn more, visit: <https://govtrack.us/congress/bills/113/hr3309>.

# UNIT SUMMARY FOR EDUCATOR

## UNIT SUMMARY

This unit will guide you through how to design and build a lunchbox cooled with a thermoelectric tile and heat sink fans. You will learn about heat and heat transfer, and explore how engineers and inventors apply these concepts in fields ranging from food safety and transportation to green design to public health. Focusing on the idea of keeping foods and beverages at an ideal temperature, you will consider the design of currently available coolers, lunchboxes, and other food transportation and storage devices. You will also consider new designs for improving these devices and new users of them, ultimately designing and prototyping a thermoelectrically cooled lunchbox using Peltier tiles.

You will first learn about heat and heat transfer through readings and hands-on activities demonstrating convection, conduction, and radiation. You will also experiment with materials with a variety of thermally conductive and insulating properties as you explore some of the coolers and lunchboxes you may already be familiar with. You will learn about methods for removing heat from systems, and will build a Peltier cooling unit using a Peltier tile and two heat sink fans. Finally, you will build a prototype of a lunchbox that uses a Peltier cooling unit to keep one side cool and the other side warm. You will test the performance of your prototype and brainstorm ways to improve it.

You will gain both minds-on and hands-on skills in this unit. Minds-on skills include understanding heat and heat transfer, recording data and calculating differences and rates of change, learning about biomimicry, and practicing the prototyping process. Hands-on skills include using a utility knife to cut cardboard, cutting and stripping wire, sketching and drawing, and building with cardboard. You will consider how to incorporate your new skills into a new invention in Meeting 6. You will learn what it means to be inventive thinkers and practice inventive thinking as you progress through the unit.

## LEARNING PRINCIPLES

- ▶ Heat transfer
- ▶ Electricity and circuits
- ▶ Heat and energy
- ▶ Prototyping

## MEETING SYNOPSES

### 1 Invention Introduction

Do warm-up activities and discuss invention. Play “Four Corners” to help the educator assign diverse teams.

### 2 What is Heat?

Do hands-on activities that demonstrate convection, conduction, and radiation, and begin to discuss problem solving and invention in the context of food safety and transportation.

### 3 Keep Your Cool

Explore the thermal properties of various materials, then design and build a simple device that will both keep a cold item from warming up and a warm item from cooling down.

### 4 Removing Heat

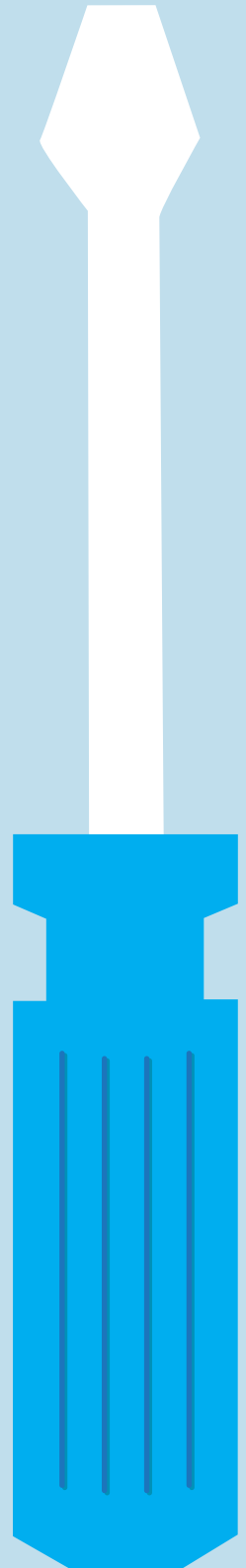
Learn about evaporation and evaporative cooling. You will also learn about the thermoelectric effect, experiment with Peltier tiles, and brainstorm ways you might use these devices in your invention.

### 5 Peltier Prototyping

Build a Peltier cooling unit, made of a Peltier tile sandwiched between two heat sink fans. Compare how the tiles function, with and without being attached to a heat sink. Then design and build a lunchbox prototype out of cardboard and a Peltier cooling unit. Finally, test out your lunchboxes and provide feedback to other teams.

### 6 Invention Extension

Conceptualize a purposeful invention that uses your new minds-on and hands-on skills.



# CHILL OUT

## MEETING 1: INVENTION INTRODUCTION

### KEY TERMS

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

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

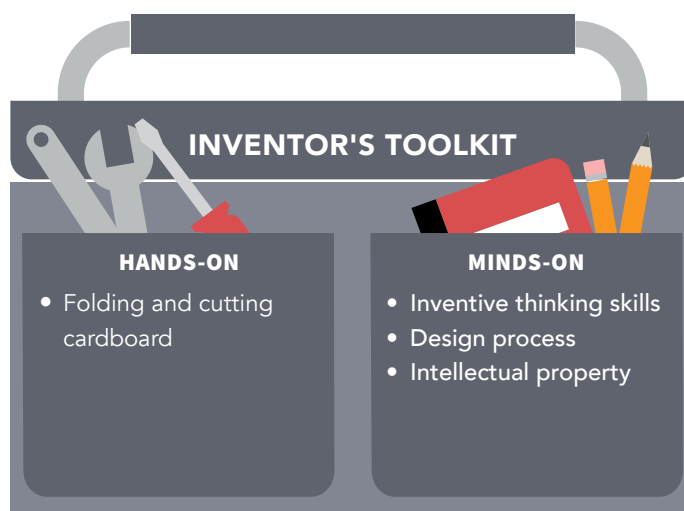
**Iteration (n):** A version of a design in a series of designs.

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

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

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

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



### Tools & Electronics

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

### Materials & Shop Supplies

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

### Procedure

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

## YOUR GUIDE

1. You will use your JV InvenTeams guide as an invention guide. This guide will be a portfolio of your work and ideas.
2. The grid paper and blank paper at the end of each meeting can be used to sketch, brainstorm, and document ideas.

## INTRODUCTION TO INVENTION AND PROBLEM SOLVING

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

### 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.



Early prototypes of the Polaroid camera from the MIT Museum collection

## 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.



CO\_S\_122220

## 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 technological solution.

### 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?

## 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?

## 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

Tinkerer: I like to take things apart and build things.

Talker: I like to talk to people and I enjoy public speaking.

Doodler: I like to draw things and express my thoughts through drawing.

Organizer: I like to organize people and things.

### Your Interests and Skills

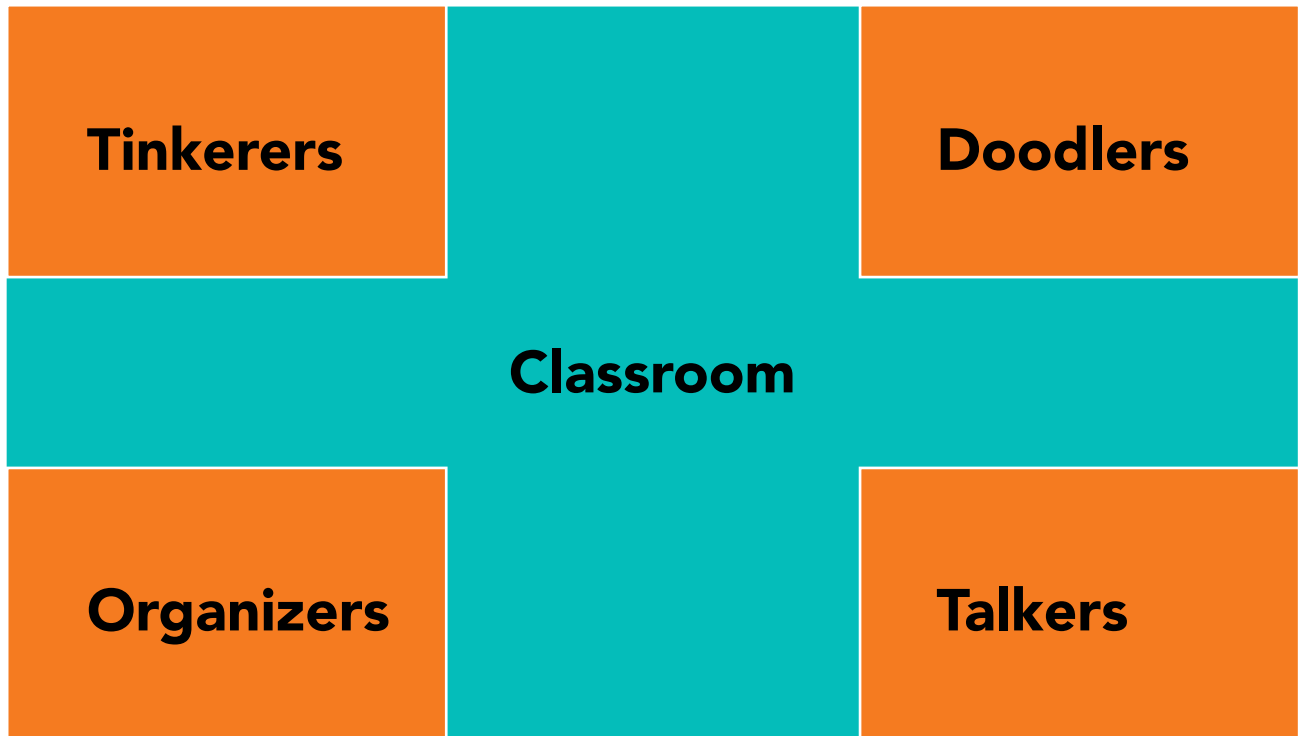
Sounds most like me

Sounds almost like me

Sounds a little like me

Sounds least like me

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**

## KEY TERMS

**Cold (n):** The absence of heat energy.

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

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

**Electromagnetic waves (n):** Waves that carry energy from a source like the sun.

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

**Energy (n):** The ability to do work; thermal energy is energy associated with the motion of molecules.

**Heat (n):** A form of energy associated with the motion of molecules.

**Heat transfer (n):** The exchange of thermal energy between physical systems.

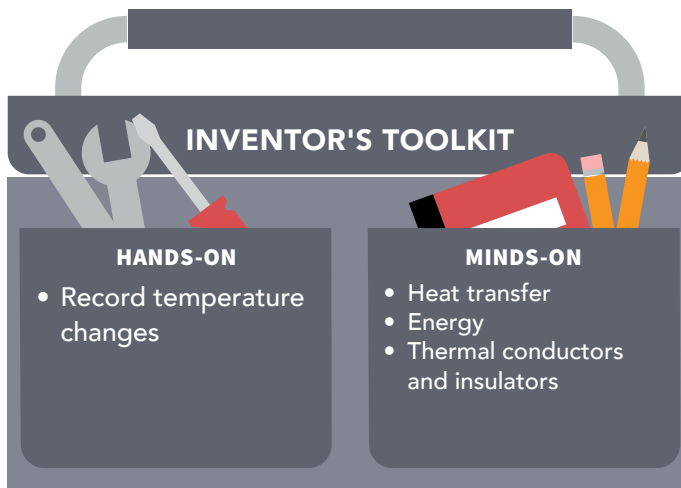
**Kinetic energy (n):** The energy of a body as a result of being in motion.

**Radiation (n):** The emission of energy as electromagnetic waves.

**Temperature (n):** A measurement of heat energy.

# CHILL OUT

## MEETING 2: WHAT IS HEAT?



### Tools

- ▶ Writing utensils
- ▶ Computer and projector to show videos
- ▶ Thermometers (showing both °F and °C), two per pair of students

### Materials

- ▶ Student Guides
- ▶ Shop safety rules
- ▶ Safety glasses
- ▶ Electric tea kettle
- ▶ Funnel
- ▶ Aluminum foil
- ▶ Ice cubes or a small bag of ice (ice will need to be stored in a freezer or cooler)
- ▶ 2 metal lunchboxes
- ▶ 2 nylon-insulated lunchboxes
- ▶ 2 neoprene lunch bags or neoprene beverage sleeves

- ▶ 2 glass measuring cups, 4-cup capacity
- ▶ 4 6-quart clear plastic bins (shoebox size)
- ▶ 4 16-ounce insulated cups, such as a foam cup or insulated travel coffee cup\*
- ▶ 4 7.5-ounce soda cans\*
- ▶ 20 2-ounce plastic bottles\*
- ▶ 2 different colors of liquid food coloring
- ▶ Gooseneck lamp with an incandescent bulb
- ▶ Chocolate bar
- ▶ 10 plastic or paper plates
- ▶ Self-Assessments

\* These items may be found in the recycling bin. Check there first!



## Procedure

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

## INTRODUCTION TO SHOP SAFETY

1. Tell students that shop safety is of the utmost importance so that nobody gets hurt. They will be using hand tools such as utility knives. Tools should always be used in the way they were designed to be used. Have students watch a general [shop safety](#) video (10 min).
2. Review the general shop safety rules:
  - Wear safety glasses.
  - If you are in doubt about how to use a tool, ask!
  - Have a plan for what you are going to do with the tool.
  - Be mindful of others who might enter into your working space accidentally.
  - Secure the workpiece.
  - Have a balanced stance while using a tool.
  - Remove all jewelry, watches, and loose clothing before working with machinery.
  - Pin up long hair and wear closed-toe footwear.
  - Never work when you are tired or not focused.
  - Leave the workspace cleaner than you found it.

### KEY TERMS (CONT'D)

**Thermal conductor**

**(n):** Material that allows the transfer of thermal energy or heat.

**Thermal insulator (n):**

Material of relatively low heat conductivity.

## WHAT IS HEAT?

Read the following paragraphs about **temperature** and **heat**:

Have you ever eaten frozen ice cream or hot-out-of-the-oven pizza? Have you enjoyed iced tea or hot chocolate? If so, you've benefited from inventions and technologies that make and keep foods and beverages at the "right" **temperature** for us to enjoy them. When **heat** is transferred to or from a substance (like food or drink), **energy** is added to or taken away, which changes its **temperature**.

The terms "**temperature**" and "heat" are sometimes used to mean the same thing, but they are different. The **temperature** of a substance increases as **heat** is added and decreases as it is removed. A thermometer measures **temperature**, not **heat**. The amount of **heat** necessary to change the **temperature** of a substance a given amount is a property of the substance. This is called **heat** capacity. Think about a pot of water on the stove. **Heat** from the burner can be applied to the pot to increase the water's **temperature**. When the burner is turned "off," the water's **temperature** will decrease because the **heat** is transferred to the lower **temperature** surrounding surfaces and air surrounding the pot.

If two bodies at different **temperatures** are placed in contact, **heat** will flow from the initially higher **temperature** body to the lower **temperature** body. The result is that the **temperature** of the high-**temperature** body decreases and that of the low-**temperature** body increases. **Heat** flows until the two bodies come to the same **temperature**.

Lunchboxes, coolers, and vacuum flasks (think of a Thermos®) are inventions meant to help keep foods and drinks at the "right," or desirable, **temperature**. You want your hot chocolate or soup to stay at a high **temperature** while it sits in your lunchbox all morning at school. Similarly, you want your ham-and-cheese sandwich to stay at a low **temperature**. So, how do lunchboxes, coolers, and vacuum flasks keep **heat** from transferring between substances at lower or higher **temperatures**? Do the materials these products are made from affect how well they work?



### EXTEND THE LEARNING

Heat regulation is an important fact of life for animals all around the globe. The fennec, for example, is a small fox that lives in the Sahara Desert. It has enormous ears that radiate heat away from its body, helping to keep its body from heating to dangerous levels. [Learn more here](#)

Credit: Wikimedia Commons

You and your team will design and build a type of cooler in this unit to keep food at a desirable **temperature**. You will come up with a way to cool the interior of the device – or, more precisely, transfer **heat** from it. First, let’s take a step back and think about some of the terms we’ve just used.

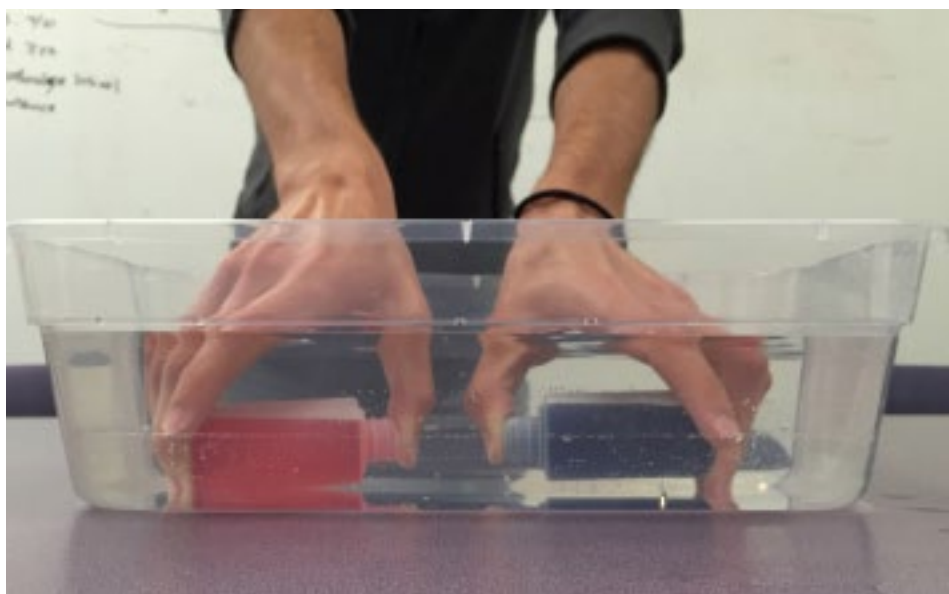
1. Use the space in the right margin to answer the following questions:
  - What is **temperature**? Where does the **cold** go when a glass of juice “warms up”?
  - What happens to the **heat** when a hot bowl of soup “cools down”?
  - How might learning about **heat** help you design a product that will help keep beverages cool?
2. Watch the following: [\*\*The Science of Keeping Cool\*\*](#).  
 This is a five-minute video about an invention designed to help soldiers stay cool in extremely hot desert environments. The video explores how the U.S. military is researching, designing, and testing clothing that helps keep soldiers from overheating during long days in extremely hot environments. Take notes about **heat**, **temperature**, and **cold** as you watch.
3. Discuss as a class:
  - What is **heat**?
  - What is **temperature**?
  - What is **cold**?
  - Is “hot” a real thing? How do you know if something is **cold** or hot?
  - What does Dr. Castellani mean when he says, “There is no such thing as **cold**”?
  - What invention is Dr. Castellani testing, and what problem is it meant to address? Who are the users he identified for this invention?
  - How does the invention address the problem?
  - How do you think this video relates to the challenges of keeping foods hot or **cold**?

## EXPLORING HEAT TRANSFER

Now, let's explore some of the concepts you saw in the video. In the following activities, you will explore the three processes through which **heat transfer** occurs—**conduction**, **convection**, and **radiation**—as you rotate through the stations.

### Convection

1. What do you think will happen to a hot drink left to sit in a **cold** room? Write a prediction in your guide.
2. Let's get to the activity! With a partner, follow the instructions and answer the questions that are in your guide.



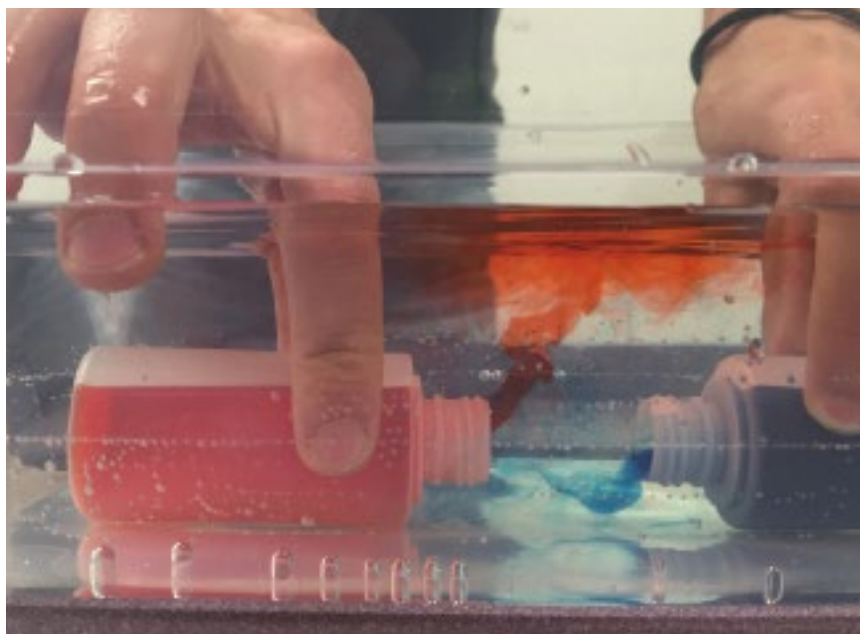
Credit: Jennifer Cutraro

**What do you expect to happen to the water in each bottle when this student removes his thumbs?**

- Fill one two-ounce plastic bottle with water that feels very warm to the touch. Use the funnel to carefully pour water from the glass measuring cup into the bottle. Add several drops of red food coloring and gently shake to distribute the color evenly throughout the liquid.
- Fill the other two-ounce plastic bottle with cool water. Add several drops of blue food coloring and shake.
- Place a finger over the opening of one bottle and gently place it on its side inside the large container that's filled with water. Have your partner do the same with the other bottle.

# MEETING 2

- Kneel or sit so that you are eye level with the bottom of the large plastic container.
- Next, gently remove your finger from the bottle at the same time your partner does. Observe what happens.
- Record your observations in your guide, using sketches and descriptions.



Credit: Jennifer Cutraro

**Heated water, which is red, rises to the top, while cold water, which is blue, sinks to the bottom.**

- Pour the water from the large container and the two small bottles down the sink.
  - Prepare for the next rotation of students: fill the large container with clean water and place two more small bottles next to it.
3. When you finish the activity discuss the following with the class:
- What happened to the colored water?
  - Can you describe how it moved?
  - Why do you think it moved in this way?

Hot water has more **kinetic energy** than cool water. That is, its molecules are moving more quickly than the molecules in the cool water. You can see this in the way that the hot colored water more quickly escapes from its bottle.



## HIGH SCHOOL CONNECTION

The 2013 Ella T. Grasso Southeastern Technical High School InvenTeam from Groton, Connecticut invented a water heater powered by compost units that provides continuous hot water. The invention can be used to heat small greenhouses and rooms in rural areas. It can also preheat water as it reduces energy costs associated with boiling water. [Learn more here.](#)

LEMELSON-MIT  
**InvenTeams**

You also observed a type of **heat transfer** called **convection**. **Heat transfer** is the movement of heat from one substance to another. **Heat** always moves from substances with higher **kinetic energy (temperature)** to substances with lower **kinetic energy**, a phenomenon known as the second law of thermodynamics.

In the activity you just completed, the hot water rose to the top of the container as it left the bottle. Hot water has less density, or particles per unit volume, than cool water. Because of this, the hot water in this experiment rises. Along the way, the hot water exchanges some of its heat with the cooler water it is mixing with. If we kept a constant heat supply running beneath the six-quart plastic container, we would make a convection current. The heated water would rise, losing heat to the cooler water at the top of the tank. The cooled water at the top of the tank would then sink to the bottom, where it would be reheated and rise again.

Convection currents operate in liquids as well as gases. Just as the heated water in this exercise rises, heated air does as well. Heated air produced by a home heating system, for example, rises and then begins to fall as it cools. As more heated air takes its place, the motion creates currents that move heated air through a chilly room. When the Sun warms the air at the Earth's surface, convection currents are produced, creating wind and also playing a role in the production of thunderstorms.

Credit: Jennifer Cutraro



**This thermometer shows an initial temperature of 5°C (41°F).**

To see convection in action, watch this short animation showing [how convection works](#). With this understanding, can you explain what you expect will happen to a hot drink left to sit in a cold room?

## Conduction

Think again about the kinds of containers and packaging materials we use for foods. Do you think cardboard is the best material for keeping pizza hot? Are the paperboard containers for ice cream ideal for keeping ice cream cold? Why or why not? Consider these questions as you complete the following activity

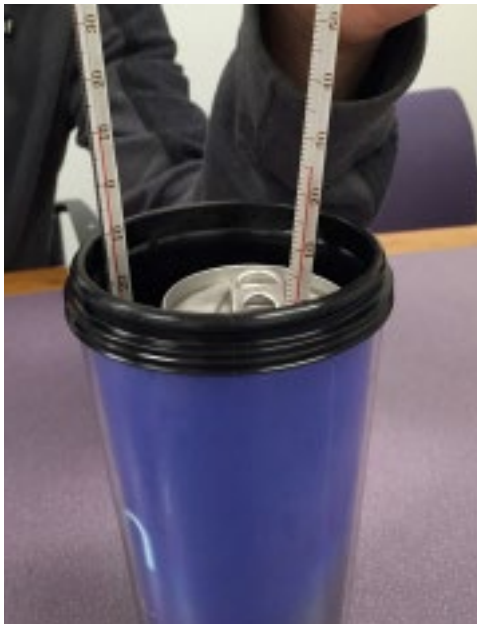
containers for ice cream ideal for keeping ice cream **cold**? Why or why not? Encourage them to consider these questions as they complete the next activity.



# MEETING 2

Work with your partner to complete the following steps:

- Fill the 16-ounce insulated cup halfway with cold water from the faucet. Place a thermometer in the cup. Observe the thermometer for several seconds. When the indicator line stops moving, record the temperature in the table on page 17 in the row “0 seconds (initial temperature).”
- Carefully fill the 7.5-ounce metal soda can halfway with hot water from the sink. Place a thermometer in the can. When the indicator line stops moving, record the temperature in the table in the row “0 seconds (initial temperature).”
- Place the metal can in the foam cup. Observe each thermometer, recording the temperature of each one every 30 seconds for two minutes. Record these data in the table in your guide.
- Dump the water from the containers into the sink to prepare for the next rotation of students.



Credit: Jennifer Cutraro

**What happens to the temperature of the water in each container?**



Credit: Jennifer Cutraro

**This thermometer shows a final temperature of 34°C (93°F).**

Time	Temperature Inside Cup	Temperature Inside Can
0 Seconds (initial) (T1)		
30 Seconds (T2)		
1 Minute (T3)		
1.5 Minutes (T4)		
2 Minutes (final temperature) (T5)		
Difference between initial and final tem- perature		

1. Discuss these questions after you finish the activity:

- What happened to the **temperature** of the liquid in the metal can over time?
- What happened to the **temperature** of the liquid in the cup over time?
- Can you explain your observations in the context of **heat transfer**, or where and how **heat** was moving?
- How do these observations help explain why “there is no such thing as **cold**”?

2. Read the following on conduction:

- You should have seen the **temperature** of the water in the metal can dropping as the **temperature** of the water in the foam cup rose.
- This is an example of another type of **heat transfer** called **conduction**, or the transfer of **heat** between two parts of a system in physical contact. In this demonstration, **heat** moved from the hot water inside the can across the metal and into the water in the foam cup. This means it’s more accurate to say that heat was removed from the water in the can than to say the water “cooled down.”



We all experience **conduction** as we go about our daily activities. Any time you touch an object, **heat** will transfer between you and that object! When you sit on a metal park bench or bleacher seat on a **cold** day, for example, **heat** from your body transfers to the much colder metal surface. Your body interprets this **heat transfer**—the act of **heat** leaving your body—as the bench or seat feeling **cold**.

## Radiation

1. Work with your partner to complete the following steps:
  - Break off a square of chocolate from the chocolate bar.
  - Place it on a plate directly under the gooseneck lamp.
  - Turn on the lamp so that the bulb shines directly on the chocolate.
  - Observe the effect of the lamp on the chocolate.
  - Clean up the station when you are finished.
2. When you finish the activity, discuss these questions as a class:
  - What happened to the piece of chocolate?
  - Can you explain what happened using the terms **heat** and **heat transfer**?
3. Did the chocolate begin to soften? It probably did, demonstrating another type of heat transfer called radiation. **Radiation** is the transfer of **heat** with **electromagnetic waves**, or waves that carry **energy** from a source such as the sun. You can feel this form of **heat transfer** when the sun shines on you on a sunny day. Sunlight is solar **radiation**— **electromagnetic waves** that carry the sun's **energy**.

View the interactive "[Heat Transfer: Conduction, Radiation, Convection](#)," to see an animation of radiation.

Credit: Wikimedia Commons



## EXTEND THE LEARNING

The video “Misconceptions About Heat,” talks about commonly held, but incorrect ideas about heat. Ask yourself which is hotter: a cake coming out of the oven or the metal pan holding the cake? Then, [watch this video](#). Would you change your answer after watching the video? Why or why not? As the video explains, it’s a trick question: neither is hotter than the other. However, metal is a much more efficient conductor of heat than cake. For this reason, you’re more likely to burn yourself by touching the pan.

## HEAT TRANSFER IN THE REAL WORLD

1. Read the following paragraphs:

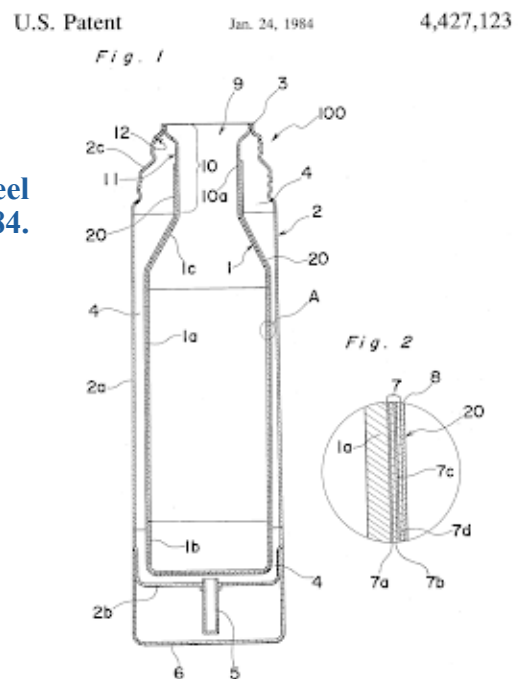
What do all these examples of **heat transfer** have to do with designing and building lunchboxes? The main goal of a lunchbox, vacuum flask, or other food or beverage container should be to minimize **heat transfer**. When you place your hot chocolate in a vacuum flask, you don't want the heat of the hot chocolate to transfer to the cooler air on the outside. You also don't want **heat transferring** to your **cold** ham sandwich. So what are some things you can do to prevent **heat transfer** from taking place?

You probably already use materials that minimize **heat transfer** every single day. You just never thought about them in those terms. Have you ever used oven mitts to remove a hot tray from the oven? The oven mitts act as **thermal insulators**, minimizing the transfer of heat from the tray to your hand. Have you ever used a foam sleeve to keep a soda can cool on a hot day? Then you've used an invention that minimizes the transfer of heat from the air surrounding the can to the cool beverage.

2. You're going to look at some of the materials that lunchboxes, vacuum flasks, and coolers are made from. Your educator will divide you into two groups and assign one group to each table. Examine the items on the table and make a sketch of each item. You should work with a partner to answer the following questions about each item:
  - What kind of material is it made from?
  - What do you think the item would look like in cross-section? Make a sketch.
  - Why do you think the engineers who designed it chose to use those particular materials?
  - Do any of the items contain liquids or gels? What do you think these materials do?
  - How do the items keep hot things hot? How do they keep **cold** things cold?
  - What other things do you notice about the coolers, lunchboxes, and beverage containers?

- Rank the items in order from the most insulating (will keep cold things cold for the longest period of time) to the least. Your teacher will place one ice cube in each container. Predict in your guide which will be the first to melt, which will be the second, etc. You will check on the ice cubes in 15 minutes.

USPTO drawing of stainless steel thermos bottle from 1984.



Credit: Wikipedia Commons

One of the most familiar consumer products that minimizes heat transfer is the metal vacuum flask. It was invented (but not patented) by the Scottish chemist and physicist, Sir James Dewar, in 1893. A vacuum flask is often called a thermos, which is now a “genericized” trademark because it has been used so widely. The Thermos Company was founded in 1904 to manufacture and sell vacuum flasks to eliminate all three forms of heat transfer between the inside of the container and the outside environment.

#### INVENTION SPOTLIGHT



Credit: Jennifer Cutraro

Samples of lunchboxes and other materials designed to keep foods and beverages at the right temperature.

4. When the time is up, observe each ice cube. Which item performed the best? Which performed the worst? Compare these results and your predictions. What does this tell you about the materials that would be good candidates for minimizing heat transfer in a lunchbox? You should expect to see the ice cubes melting within about 15 minutes. The cube in the metal box will melt the fastest, melting completely into a puddle within about 30 minutes. The other containers will likely still contain solid—but smaller—cubes.

## HISTORY

People kept food and drinks cold with iceboxes and ice-houses before the invention of electricity and refrigeration. Thomas Jefferson, third president of the United States, built an icehouse on his Virginia property, Monticello. It could keep foods chilled from December, when he filled the house with ice, until the middle of the following October. But where did his ice come from? The ice likely came from towns around Boston, Massachusetts. Read more about the [history of keeping food cool](#)—and how the New England ice trade laid the groundwork for the food industry we all benefit from today.



Credit: Wikimedia Commons from Harper's Weekly, 30 August 1884

## IDENTIFY USERS AND THEIR NEEDS

1. Work with a partner to brainstorm users or scenarios in which keeping things cool might be especially important. Some ideas include:
  - People who spend all day on the road, such as taxi, bus, or truck drivers; or, who spend all day in the sun, such as landscapers
  - Camping or other outdoor activities
  - Athletes or spectators at athletic fields
  - Healthcare personnel who need to store medications in places that lack electricity
  - Food vendors at outdoor events

Use the problem/ solution graphic organizer in your guide to organize your brainstorm.

User	Problem	Need	Possible Solution
Person who drives a bus	Has no access to a refrigerator, microwave or stove	A container that reduces heat transfer through conduction or convection	A vacuum flask
High school soccer player	Wants to keep water bottle cool on the field during long practices on hot days	A container for the bottle that reduces heat transfer through radiation and conduction	A shiny bottle with a reflective surface; solar cells?

2. Then conduct research to address any or all of the following:
  - Find images and stories about other technologies and inventions that either limit or facilitate **heat** exchange. For example, how do cars keep from overheating? What about computers?

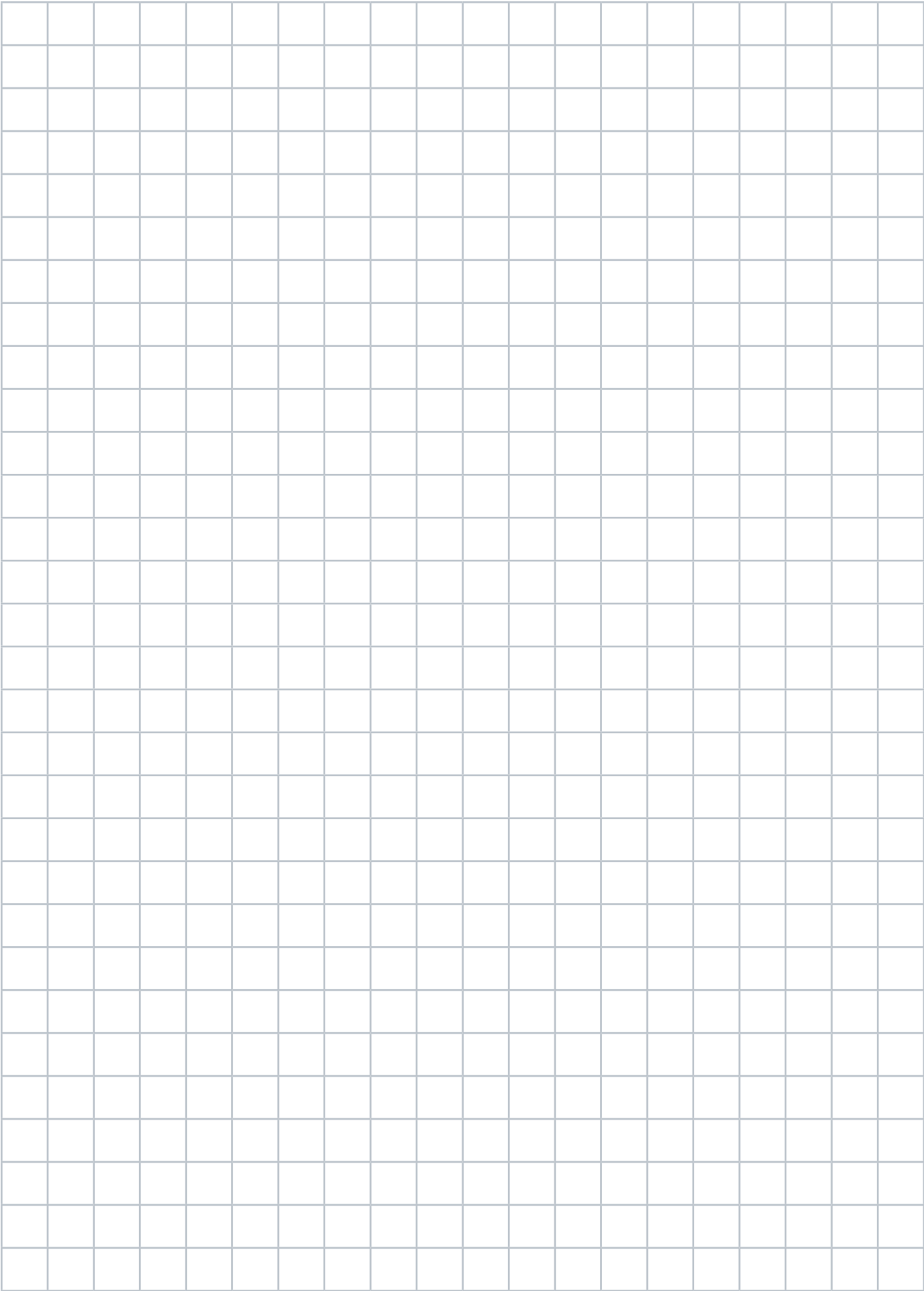
### HIGH SCHOOL CONNECTION

The Tesla Engineering Charter School InvenTeam from Appleton, Wisconsin, invented a refrigerator for northern climates. It takes advantage of cold outdoor air temperatures in the winter to lower the energy consumption of a standard household refrigerator. The students describe their invention and the motivation behind it in [this video](#) from Lemelson-MIT's annual EurekaFest.



- Think of ways in which these technologies can be used in novel ways to address other problems.
- Identify other potential users.
- Research food storage and safety systems, and why **temperature** regulation is so important to food safety. Identify other industries where **temperature** regulation is essential.

## MY THOUGHTS



# CHILL OUT

## MEETING 3: KEEP YOUR COOL

### KEY TERMS

**Biomimicry (n):** The design of new products or materials inspired by living things.

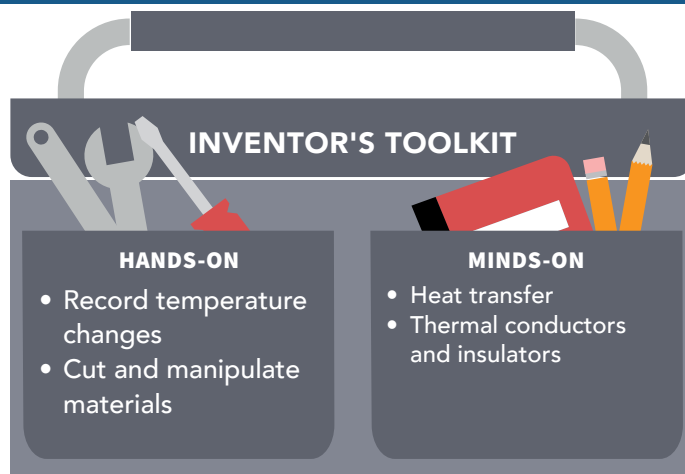
**Non-renewable resource (n):** Any natural resource from the Earth that exists in limited supply and cannot be replaced if it is used up.

**Photon (n):** A particle of light energy.

**Sustainable design (n):** An approach to building and construction that aims to minimize waste and produce healthy environments.

**Thermal mass (n):** The measure of a material's ability to absorb and store heat energy.

**Wavelength (n):** The distance between the peaks of two successive waves.



### Tools

- ▶ Writing utensils
- ▶ Computer and projector to show videos
- ▶ Spoons
- ▶ Rulers
- ▶ Thermometers (showing both °C and °F)
- ▶ Scissors

### Materials

- ▶ Student Guides
- ▶ Shop safety rules
- ▶ Safety glasses
- ▶ Electric tea kettle
- ▶ Glass measuring cup, 4-cup capacity
- ▶ Funnel
- ▶ Ice (ice will need to be stored in a freezer or cooler; a bag of ice from the grocery store will work)
- ▶ Supply of water (if you don't have a sink in the room)
- ▶ Vegetable shortening, 4 cans
- ▶ Paper or cloth towels (for drying hands)
- ▶ Packing "peanuts" (preferably recycled)
- ▶ Feathers
- ▶ Aluminum foil
- ▶ Paper
- ▶ Scrap cloth or squares of colored felt
- ▶ Plastic wrap
- ▶ Wax paper
- ▶ Cardboard or paperboard, such as broken-down cereal boxes (recycled)
- ▶ Masking tape
- ▶ Plastic or paper plates
- ▶ String
- ▶ 2 6-quart clear plastic bins (reuse from Meeting 2)
- ▶ Per Pair
- ▶ 2 gallon-size plastic reclosable bags
- ▶ 2 two-ounce clear plastic bottles (reuse some from Meeting 2)



## Procedure

- Color, Light, and Heat
- Insulators
- Emperor Penguins
- Conductors
- Keep the Heat Out and Keep the Heat In
- Sharing Inventions
- Wrap-up
- Self-Assessment

## COLOR, LIGHT, AND HEAT

1. Read the following paragraphs:

How would you decide on materials and colors if you were to design an outdoor playground? Would you use dark or light colors? Would you use metal, wood, or plastic for the equipment and surface material? You will try to choose materials made from lighter colors if you want to keep cool on the playground—just as you probably try to wear lighter-colored clothing on hot, sunny days. That’s because the sun emits energy in the form of solar radiation, which we observe as light and heat. Dark colors absorb this light and heat, while light colors and reflective materials deflect it, absorbing the heat more slowly.

Light coming from the sun includes **wavelengths** of light in the full visible spectrum—all of the colors of the rainbow. Black items absorb all of these colors; white items reflect them. Dark colors also absorb more **photons** than light ones.

The ability of materials to differentially absorb light is one factor that engineers and architects who work in **sustainable design** consider when they are planning a new building or other development. For example, the roofs of most buildings receive a substantial amount of sunlight every day. This presents both an opportunity and a challenge: Absorbing that heat and sunlight in the winter may help to offset heating costs—but in the summer, absorbing that heat increases demand for air conditioning or other means to remove excess heat. Many buildings today have dark-colored roofs, but what if a material existed that could absorb heat in the winter and deflect it in the summer?

## HIGH SCHOOL CONNECTION

The 2013 Ann Richards School for Young Women Leaders InvenTeam from Austin, Texas invented a non-electric cooling pressurized container to preserve food or medicine for those without electricity. Unlike current refrigeration systems, it uses no chemicals, and is small and transportable, weighing less than 30 lb. This low-cost invention can be used in developing countries or for use during camping trips, for food trucks, etc. [Learn more here.](#)



A team of MIT students took on this question as a challenge and invented roofing tiles that change color depending on the air temperature: They are black at cold temperatures, and turn white when the weather is warm.

Read more about the students and their invention [here](#). A material's ability to absorb or reflect heat from the sun is just one property related to heat transfer that designers and engineers consider when envisioning a new product. Then answer the questions below in your guide, or discuss them with a partner:

- What problem is this invention meant to solve? How does the invention work?
- How does the invention solve the problem?
- What are some of the challenges the team faced as they developed this product? How did they overcome them?
- What questions does the team still need to answer? How will they do this?
- How does this invention relate to the concept of heat transfer?

## INSULATION AND CONDUCTION

Today you will experiment with different methods to prevent heat transfer from taking place. Work with a partner to answer the following questions in your guides:

- What is heat transfer and what are some examples of it?
- What are some reasons that you might want to prevent heat transfer?
- What do you think are some challenges to preventing heat transfer?
- What are some reasons that you might want to encourage heat transfer?

Recall that you observed in the last meeting some of the materials food storage containers are made from: metal, plastic, foam, and neoprene. Today you are going to build a device to test the ability of each material either to keep an ice cube from melting, or to keep a bottle of heated water from cooling down. But first, let's do some review.

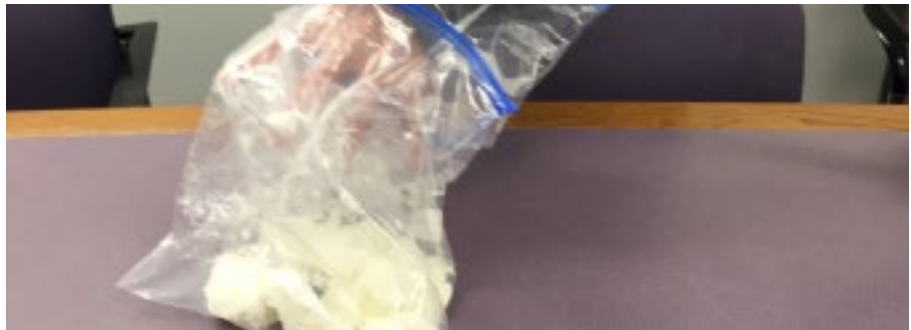
Some of the items you explored in the last meeting were made of **thermal insulators**, or materials that minimize heat transfer. In what situations might it be important to minimize heat transfer? Homes are insulated to prevent heat loss during the cold winter months. Insulation also helps prevent homes from heating up during the summer. You wear layers of clothing in the winter to keep your body from losing heat to the outdoor air.

## INSULATORS

Many marine mammals—especially those in polar environments, such as polar bears and walruses—have a thick layer of a type of fat called blubber beneath their skin. Like all fats, blubber is an effective thermal insulator. In this activity, experience how fats help to retain heat.



- Using a spoon, fill one of the reclosable bags about halfway with vegetable shortening.
- Cover your hand with a reclosable bag, and place this hand inside the bag filled with shortening.

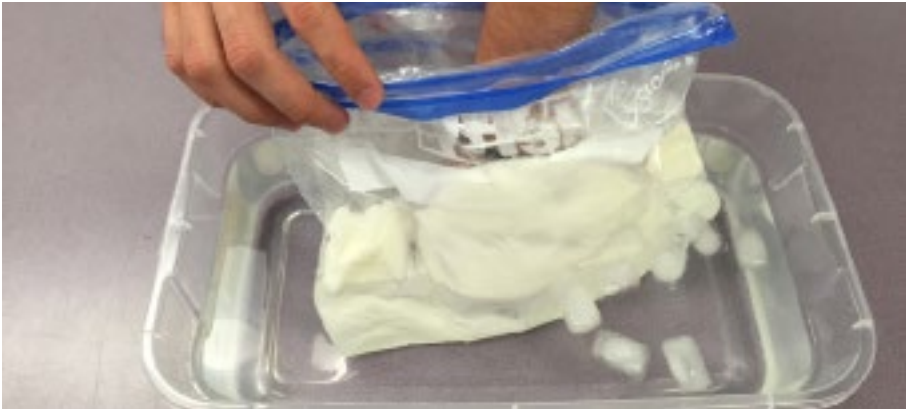


- Turn the other reclosable bag inside out. Place a hand into this bag. Stick this hand into the bag filled with shortening.



- Move your hand around to spread the shortening evenly around the space between the two bags.
- Remove the bags from your hand and seal them together so the shortening will not leak out the top. This is your “shortening mitt.”

- Next, submerge one of your bare hands in the container of ice water. Your partner may do the same.
- Can you withstand the cold for 10 seconds? How does it feel?



## SUSTAINABLE SOLUTIONS

Have you ever noticed, at the end of a sunny day, how bricks, pavement, and asphalt still feel warm even after the sun has gone down? That's because these materials have high thermal mass, the measure of a material's ability to absorb and store heat energy. One component of sustainable solutions is incorporating materials that can store the sun's heat energy during the day and then release it during cooler evening hours. Read more about [thermal mass](#).

- Put one hand inside your shortening mitt and submerge in ice water. Be sure that you do not allow water to pour over the top of the mitt.
  - Remove and dry your hands. Then place one hand inside the shortening mitt.
  - Place this hand into the ice water. Is it easier to withstand the cold? Why might that be?
  - Remove your hand, and allow your partner to take a turn.
2. Answer the following questions in your guide:
- How did the water temperature feel to your bare hand, compared with the hand in the shortening mitt?
  - Can you explain what happened, using the terms heat, heat transfer, and conduction?

## EMPEROR PENGUINS

Many marine mammals, such as whales, seals, and dolphins, have a thick layer of a fatty tissue called blubber beneath their skin. Blubber insulates their bodies by minimizing the amount of heat their bodies lose to cool ocean water. Penguins, which spend much time in the ocean, share this feature.

1. Watch the video “[Animals of the Ice: Emperor Penguins](#)”.
2. Name three body features or behaviors that help emperor penguins survive in the extreme cold of the Antarctic.

3. Next, read “[Feathers Trap Air to Provide Warmth: Emperor Penguin](#),” an informational text about the structure of penguin feathers and why engineers are looking to penguin feathers as inspiration for new insulating materials.



Credit: Wikimedia Commons

4. Answer the following questions in your guide:
  - How do a penguin’s outer feathers act as a barrier against water and wind?
  - How are a penguin’s inner feathers different from its outer feathers?
  - How does trapping air close to the body help insulate penguins from the cold?
  - What is **biomimicry**? How is the research described in this story an example of **biomimicry**?
  - How could you use the properties of penguin feathers in designing a product that helps to insulate a building or a person? What about keeping a person or a building dry during a heavy rain?

## CONDUCTORS

- Place a piece of paper and a piece of aluminum foil side by side on the table or countertop. Place one hand on each. Does one feel cooler to the touch than the other? Explain why this might be.
  - Discuss these questions as a class:
    - What did you notice when you put your hand on the aluminum foil? On the paper?
    - Do you think both materials are the same temperature? Why or why not?
    - Can you explain what happened, using the terms heat and heat transfer?
1. When you place your hands on the foil, the foil quickly conducts heat away from your hands to the countertop, which, at a room temperature of 20° to 26°C (68° to 79°F), has less thermal energy than your hand, with an average body temperature of 37°C (98.6°F). Paper is not as thermally conductive, so it doesn't feel as cool to the touch. Because both materials are sitting in the same environment, they have the same surface temperature. The foil does not have a cooler temperature, but your body perceives it as cooler because you are losing heat to it.
  2. Which direction is heat moving in this demonstration?
  3. How can you use this information about thermal conductors and insulators to design a variety of products? What kind of material would you use in a cooler to keep ice cream cool while you drive home from the grocery store? Which kind of material would work best for a radiator or another appliance meant to heat a space? Why are tea kettles, pots, and pans usually made from metals?

## KEEP THE HEAT OUT AND KEEP THE HEAT IN

You placed ice cubes in several different kinds of lunchboxes to see what would happen to them during the last meeting. From what kinds of materials were the lunchboxes made? What happened to the ice cube in each? You most likely observed that the ice cube in the metal lunchbox was the first one to melt. That's because metals are very good thermal conductors, and the metal lunchbox transferred heat from the room into the ice cube.



Today, your challenge is to design and build a container that will keep an ice cube inside a metal lunchbox from melting, and will also keep a bottle of heated water from cooling down. Work with a partner and follow the instructions below:

- Spend a few minutes brainstorming what properties this container should have. Should it facilitate heat transfer, block it, or do both? Why? What kind of materials do you know of that have these properties?

#### EXTEND THE LEARNING

A common misconception about insulators and conductors is that aluminum foil is a good thermal insulator. This is because hot foods such as hot dogs and burgers are sometimes wrapped in foil at sports arenas or fast-food restaurants. The opposite, in fact, is true. The choice of wrappers for hot foods also includes criteria such as durability, malleability, and cost. For more information on the variety of materials used in wrapping foods, visit “[Packaging Materials Defined](#).”

Credit: Wikimedia Commons



- Think about what you have learned about **biomimicry**. Can you apply the thinking behind **biomimicry** to the design of your container? How might nature inspire your design?
- Observe the materials on the table and, before selecting any, work with your partner to identify which materials you would like to use for your container. You also should look around the room for other materials you might use.
- Make a sketch of the container you will build. What size and shape will it have, what kinds of materials will it be made from, and how will these materials contribute to the container's ability to keep ice from melting? To keep a bottle of heated water from cooling down?



- Gather the materials you identified, and work together to build your device.
  - Ask your instructor for two ice cubes and two bottles of heated water. Note the time, water temperature (°F) in each bottle, and the dimensions of each the ice cube (length, width, and height in inches). Write the measurements in the table. Can you think of a reason you are also observing the ice cube on the plate and recording the temperature of both water bottles?
  - Set a timer for 15 minutes. Record temperatures and measure the ice cubes again after 15 minutes.
1. Why are we leaving one ice cube and one bottle of water on a plate of heated water? They serve as controls to help students determine whether their inventions kept ice from melting and heated water from cooling longer than if they had simply been placed at room temperature.

Beginning Time:	End Time:
Water Temperature Bottle 1	Water Temperature Bottle 1
Water Temperature Bottle 2	Water Temperature Bottle 2
Ice Cube Bottle 1 Length Width Height	Ice Cube Bottle 1 Length Width Height
Ice Cube on Plate Length Width Height	Ice Cube on Plate Length Width Height

## SHARING INVENTIONS

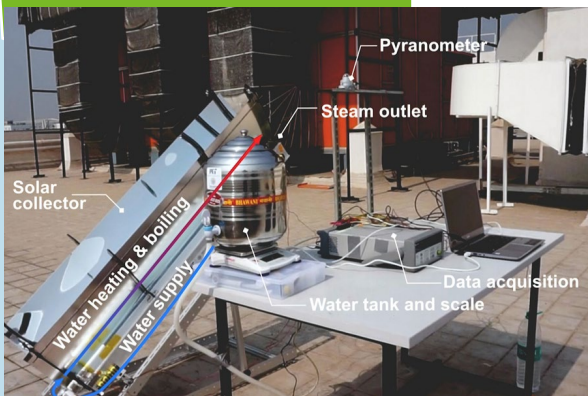
When you have finished both activities, answer the following questions in your guide, and be prepared to talk about them as a class.

- Describe the container you built. What materials did you use? Did you use different materials for the ice cube and the water bottle? Why or why not?

## SUSTAINABLE SOLUTIONS

Autoclaves, the devices used to sterilize medical equipment, need a steady supply of hot steam at 125 degrees Celsius. This typically requires electrical or fuel- based boilers. However, in developing countries electricity can be unreliable and fuel is very expensive. Researchers from MIT and the Indian Institute of Technology have successfully used the power of sunlight to generate the steam needed. The system works with the combination of a copper plate with mirrors to direct extra sunlight plus a new lightweight transparent foam for thermal insulation. With water pipes flowing under the device, hot steam can be produced. Learn more about this significant advance [here](#).

- How well did your container perform? Did the ice cube inside the container last longer than the control cube? Why or why not?
- Did the bottle of heated water inside the container retain more heat than the control bottle? Why or why not?
- What changes might you make to improve on your design?

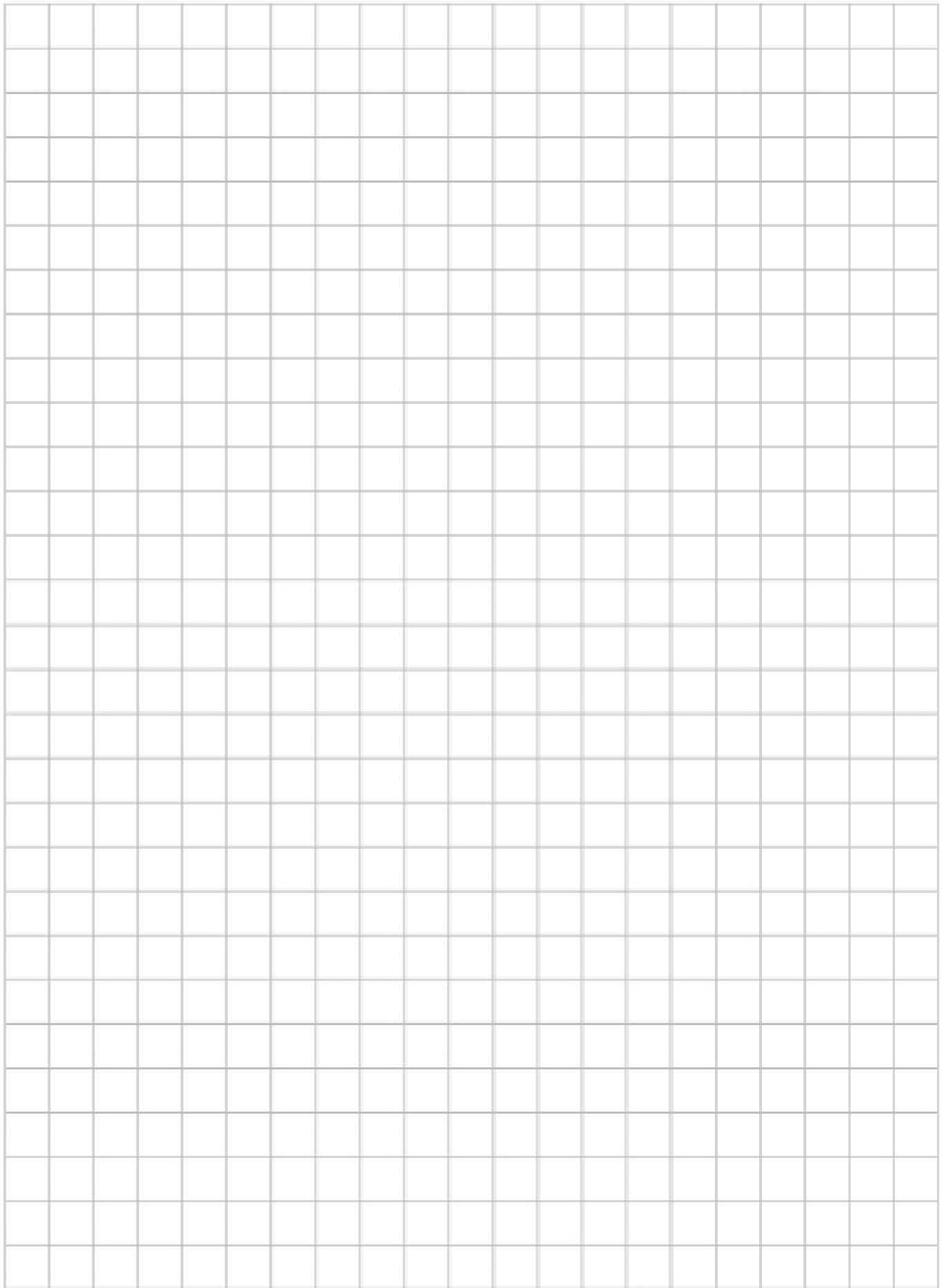


Credit: MIT News

## WRAP UP

1. Can you identify other potential users or applications for some of the technologies you learned about in this meeting, such as color-changing roof tiles? Brainstorm ways in which you might incorporate the technologies you learned about today into a portable cooler or lunchbox. For example, what are some ideal insulating materials, and how could you use them in the design of a lunchbox? If you had access to tiles that change from light to dark as the ambient temperature changes, how could you apply this technology in a useful product? How else could you use color in the design of your product?
2. In the next meeting, you will learn about still more technologies and materials for preventing and facilitating heat transfer, and will continue to brainstorm ways to build a better lunchbox.

## MY THOUGHTS



# CHILL OUT

## MEETING 4: REMOVING HEAT

### KEY TERMS

**Evaporation (n):** The process of changing from a liquid to a gas.

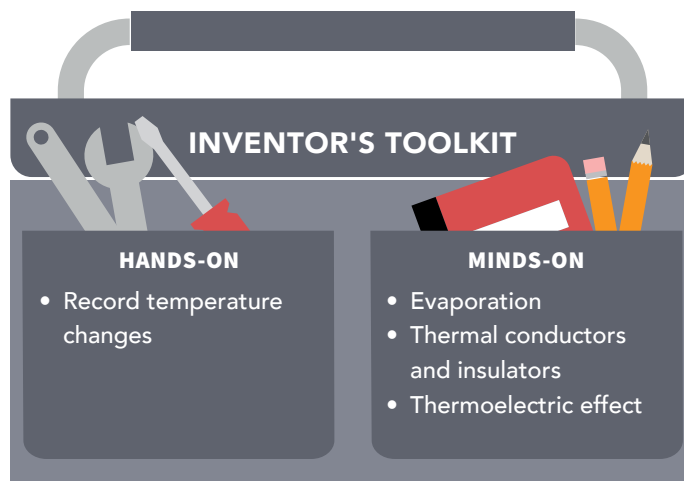
**Evaporative cooling (n):** The process of removing heat from a system through the evaporation of a liquid.

**Heat wave (n):** A period of abnormally hot and unusually humid weather.

**Humidity (n):** The amount of water vapor in the air.

**Infrared radiation (n):** A form of electromagnetic radiation that we feel as heat.

**Metabolism (n):** Chemical reactions that take place in the body's cells, such as breaking down food and building muscles.



### Tools

- ▶ Writing utensils
- ▶ Computer
- ▶ Projector to show videos (optional)
- ▶ Infrared thermometer (2 to share with class)

### Materials

#### Per Team

- ▶ Plastic spray bottle
- ▶ Thermometer (optional)
- ▶ AA battery holder
- ▶ 4 AA batteries
- ▶ D-battery holder
- ▶ 4 D batteries
- ▶ Peltier tile

#### Whole Group

- ▶ Shop safety rules
- ▶ Safety glasses
- ▶ Sand (optional)
- ▶ 20-inch terracotta pot (optional)

- ▶ 12-inch terracotta pot (optional)
- ▶ Duct tape (optional)
- ▶ Wet, light-colored cloth (optional)
- ▶ 2 empty plastic water bottles from recycling (optional)

### Procedure

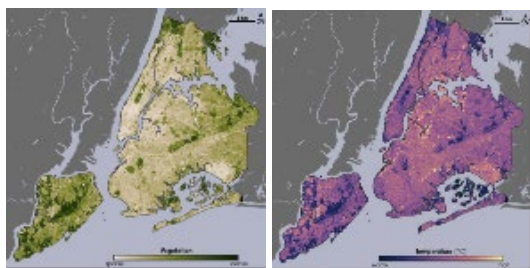
- ▶ Beat the Heat
- ▶ Explore Evaporation
- ▶ Cool Down
- ▶ Heat and the Human Body
- ▶ The Desert Cooler
- ▶ Build a Pot-in-Pot Cooler (optional)
- ▶ Keeping Hot, Keeping Cool
- ▶ Heat Transfer and Electricity
- ▶ Peltier Brainstorming
- ▶ Wrap up
- ▶ Self-Assessment

## BEAT THE HEAT

1. Have you ever heard of or experienced a **heat wave**? Describe it to the class if you have experienced one.
2. Read the following paragraphs about the effects of heat waves in urban areas:

In the summer of 1995, the city of Chicago faced a **heat wave**, a stretch of five days of unusually high temperatures and relative **humidity**. **Humidity** is a measure of the moisture content in the air. Hundreds of people died as a result of the extremely hot weather. The combination of high temperatures and high **humidity** can be dangerous for people—especially the elderly—because these conditions make it difficult, and in some cases impossible, for the body to rid itself of excess heat.

One factor that made this **heat wave** particularly harmful in the city is a phenomenon called the urban heat island effect. An urban heat island is a densely built-up area in a city that experiences hotter daytime temperatures than nearby suburban and rural areas. Meteorologists have noticed this phenomenon for close to two centuries. Many factors contribute to the urban heat island effect. Dark-colored surfaces, such as the asphalt on road surfaces and the tar and shingles on the roofs of buildings, absorb solar radiation throughout the day and release it through the night. The loss of naturally cooling trees and vegetation as cities develop also contributes to this effect, as the images below illustrate.



These satellite images of New York City show the relationship between vegetation cover and the urban heat island effect. The image on the right shows a gradient from little to no vegetative cover, in white, to dense vegetation, in dark green. The image on the right shows a range in surface temperatures, with the coolest temperatures in dark purple and the hottest in light yellow.

Credit: Robert Simmon/NASA Earth Observatory & Landsat

Since the **heat wave** of 1995, leaders in the city of Chicago have been looking for ways to cool the city in the summer and minimize the urban heat island effect. They've turned to scientists, engineers, and architects to envision new approaches to urban development, from using building materials that are less likely to absorb and store heat to planting grasses and even trees on roofs across the city.

### KEY TERMS (CONT'D)

**Permeable (adj):** Having openings through which liquids and gases can pass.

**Porous (adj):** Having small holes through which air or water can pass.

**Thermoelectric (adj):** Having the ability to convert temperature differences to electricity and vice versa.

**Urban heat island effect (n):** When cities experience higher summer temperatures than suburban and rural areas.

1. Explore Urban Heat Islands on Wikipedia. Look at the thermal images of New York City via infrared satellite imagery.
2. What kind of information is contained in the pictures. What story can you tell by seeing these pictures and knowing what the different colors represent? Can you find where Central Park is? How does vegetation affect the temperature of the area?



Credit: Tony the Tiger from Wikimedia Commons

**Green roofs, such as the one on Chicago's City Hall, are one solution to keeping the city from heating up in the summer.**

3. Watch the video [\*\*Urban Heat Islands Lighten Up to Cool Down\*\*](#). Have a short discussion about green roofs and urban heat islands. Are there green roofs in your community?
  - What problem are city leaders in Chicago addressing?
  - What solutions have they proposed?
  - How do innovations such as green roofs and permeable paving materials help minimize the urban heat island effect? What other benefits do they provide?
  - How do you think the color of roofing materials affect a building's internal temperature? The choice of material itself? The temperature of the surrounding environment?



## EXPLORE EVAPORATION

Today you will be exploring different methods for removing heat from a system. Discuss the following as a class:

- How is removing heat different from preventing heat transfer from taking place?
- What devices do you know of that remove heat? What happens to a room-temperature apple when you place it in the refrigerator? An ice cube tray of water when you place it in the freezer?
- Remember the device you built during the last meeting to keep an ice cube from melting. How did it prevent heat from transferring? How would its performance change if it also had the ability to remove heat from the inside of the device?
- Today you will learn about a technology that removes heat from systems. You'll also brainstorm and sketch ideas for using this technology to improve on the design of a traditional cooler or lunchbox.

## COOL DOWN

1. Review the instructions below as a class. You will be placed on a team of five students for this activity. Decide which two students will demo this activity for your team. Be aware that teams will need to share the infrared thermometers.
- In the last meeting, you built a device to keep an ice cube from melting. This device relied on materials called thermal insulators, which help prevent heat transfer. By preventing heat from entering the inside of the device, they slowed the rate at which your ice cube melted. Today, you are going to design and sketch a device, such as a cooler or lunchbox, that not only prevents heat transfer, but also removes heat from the system.
  - Try the short activity below to experience how **evaporation** removes heat from a system.
  - Make a small mark on your forearm with a pen. Measure the temperature of your forearm near this mark using the infrared thermometer. To do so, aim the thermometer straight at the mark on your arm. Hold the thermometer no more than 12 inches from your arm, pull the trigger, and note the temperature. A team member should record this number.

### EXTEND THE LEARNING

[Read more](#) about the factors that create urban heat islands in the video “Urban Heat Island.” Then, view a gallery of thermal images of New York City by photographer Nickolay Lamm.

- Next, spray your arm three times with water near this mark. A team member should record the temperature of your arm immediately after you spray.
  - Have a team member record the temperature of the wet area of your arm every minute for five minutes, or until your arm dries completely.
  - Repeat. This time fan your arm with a folded sheet of paper.
  - Switch roles and repeat the activity.
2. Use the space in the margin to answer the following questions:
- Describe the pattern you observed in your first test.
  - How did using a fan affect results in the second?
  - What does this tell you about the relationship between heat and **evaporation**?

## HEAT AND THE HUMAN BODY

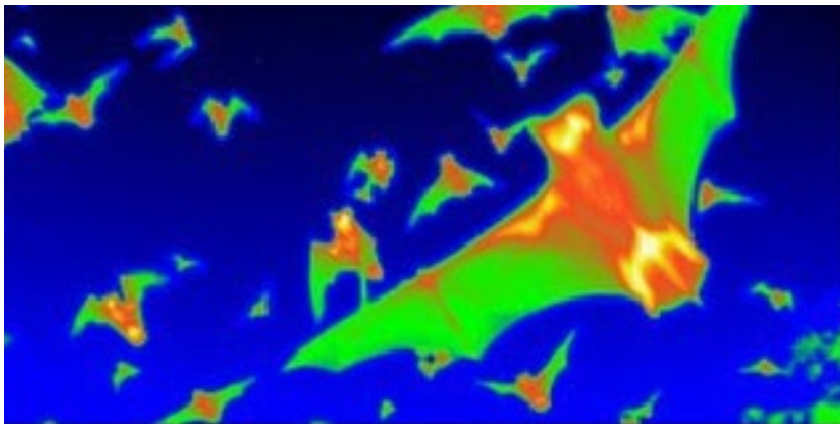
What is it about the human body that makes it susceptible to periods of excessive heat? Your body is constantly producing heat as a byproduct of **metabolism**. **Metabolism** is the many different reactions that take place in your body's cells to break down food, convert it to energy, and build new cells. **Metabolism** is one factor that determines normal body temperature, which for most people is 37°C (98.6°F). Heat in your body travels to your skin by conduction, where it is removed by convection as air or water currents move over your skin, and by radiation, as heat leaves your body through **infrared radiation**. **Evaporation**, or the change from a liquid to a gas, also removes heat from your body when you sweat.

## THE DESERT COOLER

**Evaporation** doesn't just help keep your body from overheating. Mohammed Bah Abba, a schoolteacher in rural Nigeria, saw a problem in the early 1990s that many of his neighbors shared. Access to electricity was scarce, and without refrigeration, it was difficult to keep foods from spoiling.

Bah Abba grew up in a family of clay pot makers and, having studied science in school, was familiar with the process of **evaporation** and its ability to remove heat from a system. He knew that clay is porous, meaning it has tiny holes through which air and water can escape. He began to wonder: Could he harness the power of **evaporation** to help keep perishable foods cool?

1. Watch the nine-minute video “[Mohammed Bah Abba, Rolex Laureate 2000.](#)”
2. Answer the following questions using the space in the margin, and then discuss them as a group:
  - How does this story show the design process?
  - How has this invention helped Mohammed Bah Abba?



Credit: Nickolay Hristov, Tom Kunz and Margrit Betke, Boston University

The image above was taken with a thermal camera, a device that detects the infrared radiation that different objects emit. This image of bats in flight shows areas of relatively high temperatures in yellow and red, and cooler temperatures in green and blue. You can see how bats' bodies are the warmest at their core, where primary organs such as the stomach, lungs, and heart are located, whereas the wings remain relatively cool.

Learn more about heat and how too much of it affects the human body in the back-ground essay under the Support Materials of “The Science of Keeping Cool.”

## BUILD A POT-IN-POT COOLER (OPTIONAL)

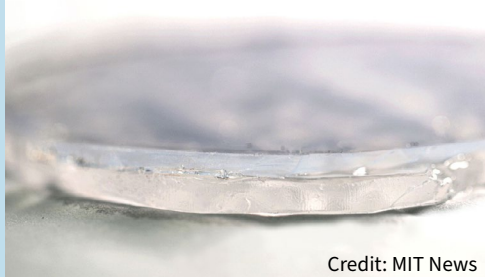
1. Review the instructions below, then complete the activity.
  - Cover the hole in the bottom of each pot with a small piece of duct tape.

Covering the drainage holes in each pot keeps water from leaking through the bottom.



Pot-in-pot coolers, like the one above, can keep vegetables cool in hot, dry climates through the process of evaporative cooling.

Credit: Peter Rinker | Wikimedia Commons



Credit: MIT News

## INVENTION SPOTLIGHT

Researchers at MIT have come up with a system for keeping things cool in hot environments without the need of a power source. Camels have thick fur in spite of living in the scorching hot desert. Their thick coat can help reduce the loss of moisture while allowing sweat evaporation to provide a cooling effect. MIT engineers created a two-layer material to achieve a similar result. The bottom layer of hydrogel mimics sweat glands from which water can easily evaporate. The top layer of aerogel imitates fur by keeping out external heat and letting vapor pass through. Learn more about this camel-inspired invention [here](#).



Credit: Wiki Commons

- Scoop enough sand into the large terracotta pot to cover the bottom to a depth of approximately two inches, or about the length of your thumb.
- Place the small terracotta pot inside the large one.
- Record the temperature of the outer surface of the large pot and the inner surface of the small one using the infrared thermometer.
  - The temperature of the surface of the outer pot is:
  - The temperature of the surface of the inner pot is:
- Fill the space between the two with sand until the sand reaches to within 1 to 2 inches of the top of the smaller pot.
- Pour room-temperature water onto the sand until it is saturated. You may need to pour a quantity of water, wait for it to seep through the sand, and then pour another quantity of water. Wait five minutes. Again, record the temperature of the outer surface of the large pot and the inner surface of the small one with the infrared thermometer.
  - The temperature of the surface of the outer pot is:
  - The temperature of the surface of the inner pot is:
- Fill two non-insulated plastic bottles, such as plastic drink bottles from the recycling bin, with room-temperature water.



Credit for all photos: Jennifer Cutraro

- Place one bottle inside the inner pot and the other beside it. Record the temperature of the water in each bottle using a thermometer.



- The temperature of the water in the bottle inside the clay pot is:
- The temperature of the water in the other bottle is:
- Cover the entire pot-in-pot cooler (with plastic bottle inside) with a light-colored wet cloth. Keep the other bottle beside the pot, uncovered.
- Return indoors, and revisit the pot at the end of the meeting, or after 45 minutes. At this time, record:
  - The temperature of the water in the bottle inside the clay pot is:
  - The temperature of the water in the other bottle is:
  - The temperature of the surface of the outer pot is:
  - The temperature of the surface of the inner pot is:

Compare this data with the initial data:

- Did the temperature of the water in the bottle inside the pot change between then and now?
- How does the temperature of this water compare with the bottle left in the sun?
- How can you explain this data?



## KEEPING HOT, KEEPING COOL

1. Meet with your partner from the last meeting, when you built a container that not only kept a cold item cold but also kept a hot item hot.
2. With your partner, take notes in your guide to address the questions below. You should be able to answer these questions well enough to explain them to a person unfamiliar with their design.
  - What worked well? How?
  - What didn't work as planned?
  - How might you change the product to improve its performance?

### INVENTION SPOTLIGHT

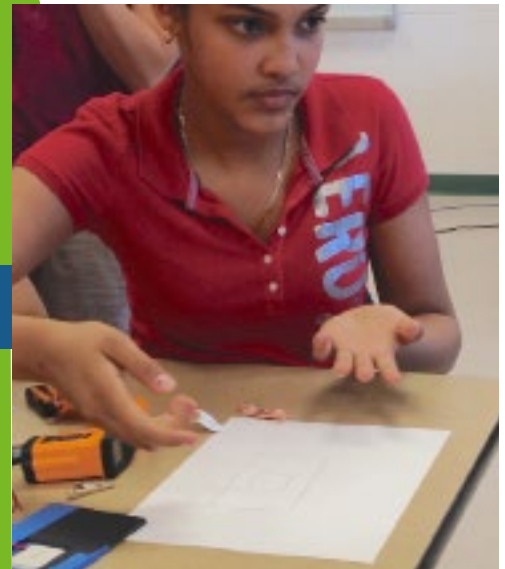
MIT student Quang Truong invented a cooler that takes evaporative cooling one step further by incorporating lighter-weight materials and more efficient heat conductors. Pot-in-pot coolers, when filled with wet sand, can be extremely heavy. The use of these lighter-weight materials makes it easier to transport perishable goods without refrigeration.

Truong co-founded a company called, [Evaptainers](#), to provide affordable refrigeration in developing countries. The company's website explains the science of how evaporative cooling works.

3. Reconvene with your team of four from the first meeting. Take turns talking about the device you built during the last meeting. Share your sketches and the item itself, explaining why the chosen materials were used, and how they performed.

### EXTEND THE LEARNING

Many people in arid, or dry, climates of the western United States, such as Utah, Colorado, and parts of California, rely on [evaporative cooling](#) to cool their homes in the summer. Evaporative coolers, sometimes called "swamp coolers," are devices that pass air across a material that's saturated with water. As the air passes through this material, some of the water evaporates, cooling the air that is then blown with a fan, into a home.



**Part of the invention process is talking with teammates about what worked and what didn't.**

Credit: Sophie Landay



## HEAT TRANSFER AND ELECTRICITY

Three European physicists were separately exploring different aspects of electricity in the mid-1800s. Each independently discovered and described parts of a phenomenon often called the thermoelectric effect. The thermoelectric effect happens when electricity runs through a material, creating a temperature differential across its two sides. One side becomes hot and the other side becomes cold. Conversely, electricity can be generated from this temperature differential.

Harnessing the thermoelectric effect for use in consumer products is an emerging field of research. So is using the thermoelectric effect to convert waste heat, such as the heat generated by engines, to produce electricity. Small devices called Peltier tiles take advantage of this effect. These devices are named for Jean Charles Athanase Peltier, the French physicist who described the thermoelectric effect. Today, you are going to experiment with Peltier tiles. How quickly do they heat up? What temperatures do they reach on each side?

1. Answer the questions below, then discuss as a class. Today, you will begin to explore Peltier tiles in your team of four.
- How might you use a material that gets hot on one side and cold on the other in new products?

- What problem could materials like these help you solve?



Credit: Jennifer Cutraro

**Example of a Peltier tile. The white square tile gets hot on one side and cold on the other when the red and black wires are connected to a battery.**

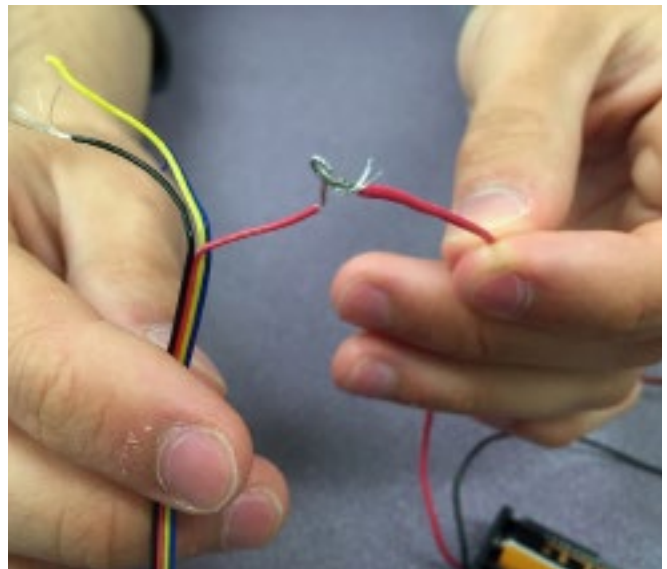
2. Gather with your team. Your instructor will give you:

- one AA battery holder
- one D-battery holder
- four AA batteries
- four D batteries
- one Peltier tile

Teams will share the classroom's two infrared thermometers.

Follow the steps below:

- Put on your safety glasses.
- Touch the Peltier tile and note what its temperature feels like. Does its temperature feel the same on each side?
- Have one member of the team use the infrared thermometer to measure the temperature of one side of the tile. Another team member should measure the temperature of the other side. A third team member should measure the temperature of the surface of the desk.
- Record these data in your guide.
- Have the fourth group member connect the wires on the tile to the wires on the AA battery holder. Be sure to connect red to red and black to black. To do so, twist the metal part of the wires together, as you can see in the photo below.
- Place the AA batteries inside the battery holder.
- Have each team member feel both surfaces of the tile. How do the sides differ?

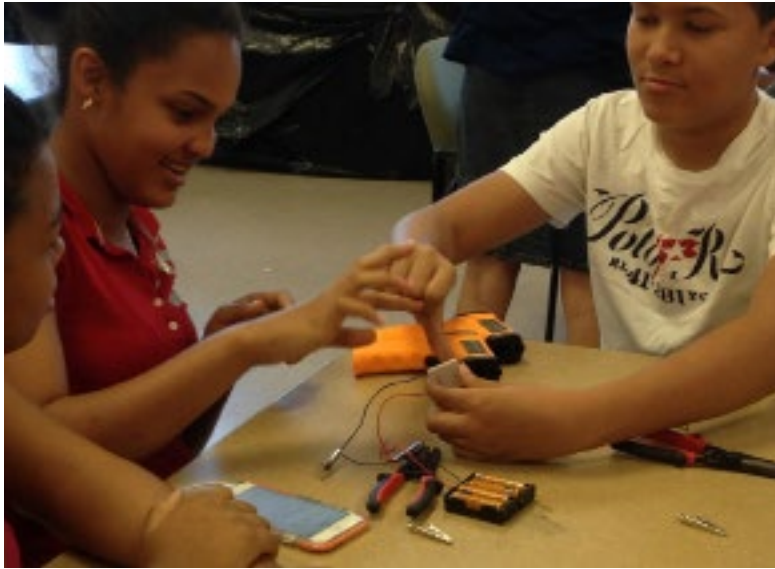


**Twist together the exposed metal part of each lead to connect two devices, such as a battery holder and Peltier tile. Be sure you only connect wires of the SAME color.**

Credit: Jennifer Cutraro



- Record the temperature of the two sides again after one minute. Compare with the initial readings.



Credit: Sophie Landay

**You should quickly feel a temperature differential when you connect the Peltier tile to the battery holder.**

- Repeat after five minutes. How do the temperatures compare now?
- Remove the batteries from the battery holder and then disconnect the wires.

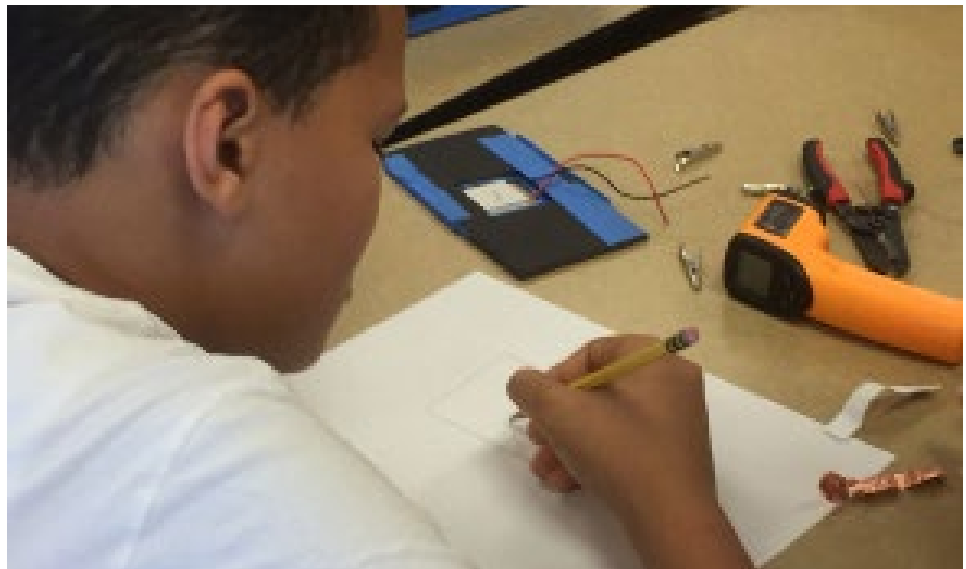
## PELTIER BRAINSTORMING

- Return to the questions you answered earlier, in the section
- “Keeping Hot, Keeping Cool.” What were some of the ideas you proposed for improving your product?
- Review some of the technologies and inventions you have learned about that help to remove heat from systems.
- Think about some of the challenges in keeping foods and beverages cool, especially on a hot day. What are some mechanisms you can think of for removing heat from a system?
- A Peltier tile can act as a heat pump, or a device that moves heat from one side of the device to the other. Talk with your team about how you might use this property of a Peltier tile in a lunchbox or cooler.
- Write about and sketch some ways in which you might design a portable cooler that uses a Peltier tile in an innovative way. You will build upon these ideas in your next meeting.

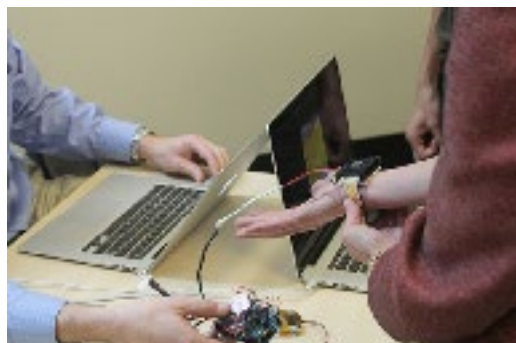
## WRAP UP

Work with your team to answer the questions below.  
Discuss your answers and record ideas in your guide.

- Revisit your list of potential users from Meeting 2.  
Are there other users or unmet needs you can think of that you might add to this list?
- How do you think a cooler using Peltier tiles might help meet some of the unmet needs for this user, or others you think of?

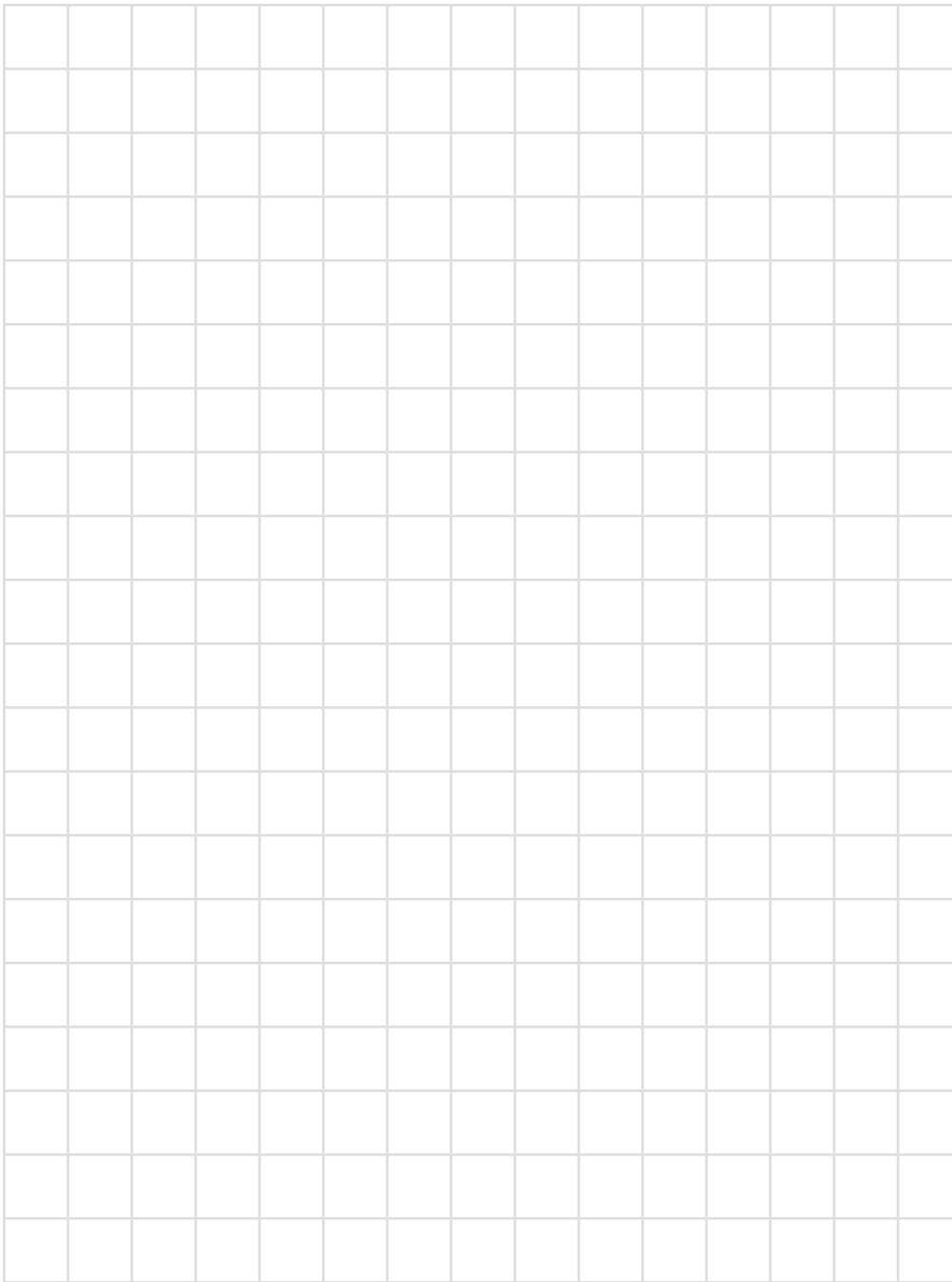


**Sometimes it helps to write and sketch ideas independently and then share them with the members of your team.**



**This image shows an early prototype of the temperature-regulating bracelet invented by a team of MIT students.**

Credit: Franklin Hobbs

**EXTEND THE LEARNING**

A team of MIT students took home first prize at the MIT and Dow Materials Engineering Contest (MADMEC), a materials science design competition held at MIT each year. They invented a bracelet that helps people maintain an ideal body temperature. It relies on a thermoelectric tile that transfers heat from one side to the other when you apply a current to it. As a result, one side feels cold to the touch; the other feels warm. Read more about this cool invention—[Wristify](#).

# CHILL OUT

## MEETING 5: PELTIER PROTOTYPING

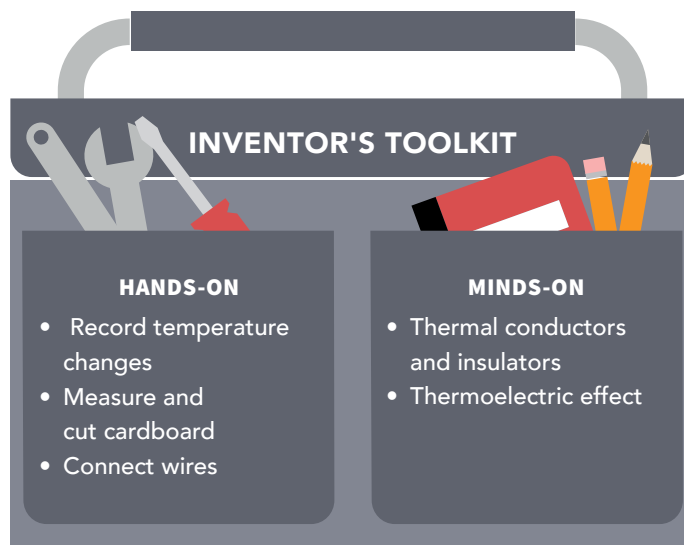
### KEY TERMS

**Alternator (n):** A device that converts mechanical energy into electrical energy.

**Ambient (adj):** Of the surrounding environment.

**Condensation (n):** The process by which water vapor in the air changes into a liquid.

**Heat sink (n):** A device or material that absorbs or stores excess heat.



### Tools

#### Whole Group

- Student Guides
- Computer and projector to show videos
- Infrared thermometers (2 to share among teams)

#### Per Team

- Writing utensils
- Indoor/outdoor digital thermometers with wired temperature probe
- Clock, watch, cell phone, or other device for recording time
- Safety glasses
- Ruler
- Masonite board
- Wire cutter/stripper
- Utility knife

### Materials

#### Entire Class

- Masking tape

#### Per Team

- 2 empty 16-ounce plastic bottles (check the recycling bins)
- Battery pack for four D-cell batteries
- 4 D-cell batteries
- 2 20-inch x 20-inch sheets of cardboard
- 2 Arctic Alpine 11 Plus CPU fans
- Peltier tile
- Alligator clamps (optional)

### Procedure

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

## Procedure

- Building a Better Lunchbox
- Product Development and Prototyping
- Building a Peltier Cooling Unit
- Designing and Building the Lunchbox
- Testing the Peltier Cooling Unit
- Assembling the Lunchbox
- Prototyping with Peltier Tiles
- Wrap Up
- Self Assessment

## BUILDING A BETTER LUNCH BOX

Look back to the end of the last meeting. You might have noticed that your Peltier tile (when connected to the battery holder) initially got cold on one side and hot on the other. However, after several minutes, the cold side began to warm back up. Why might that be?

Think back to what you have already learned about heat transfer. Heat moves from areas where there is more heat to areas where there is less. A Peltier tile works as a heat pump, using electricity to help move heat from one side to the other. But, this only works over time if the heat is somehow removed from the hot side.

Today, you are going to explore how to remove the heat from a Peltier tile and then use what you learn to build a cooling device that you can place inside of a lunchbox. This will not just keep things cool, but also remove the heat that enters the system. You will also explore whether it is feasible to use the heat removed from the tile to keep other things warm.

## PRODUCT DEVELOPMENT AND PROTOTYPING

Today you will build a two-compartment lunchbox in your teams. You will test whether you can use a Peltier tile to cool one compartment below **ambient** room temperature and use the heat removed from the tile to warm another compartment. You will build a prototype of a lunchbox out of cardboard. You will build a prototype of a Peltier cooling unit—a device made from a Peltier tile and two **heat sink** cooling fans—and test its performance in the prototype lunchbox.

## BUILDING A PELTIER COOLING UNIT

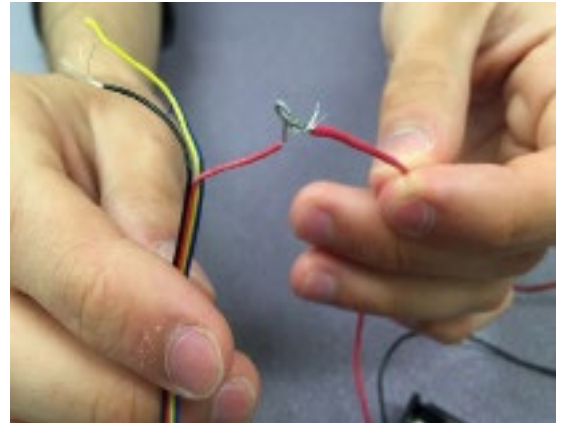
Read the instructions below and review them as a class. You will make a Peltier cooling unit—a unit composed of a Peltier tile sandwiched between two **heat sink** fans. These types of fans are used inside of computers (the CPU in the materials list stands for “central processing unit”). They help to remove the heat generated by the processor inside of a computer. The computer may shut down unexpectedly, and parts of the computer may even become damaged, if the processor overheats.

Watch the five-minute video

**“What Is a Heat Sink, as Fast as Possible?”**

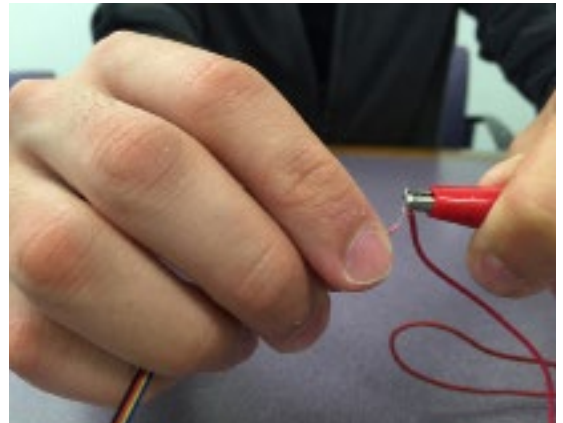
### PELTIER TILES

- Put on your safety glasses.
- Place the batteries inside the battery holder. Connect the wires (also called leads) on the battery holder to those on the Peltier tile by twisting the metal part of the leads together, as you see in the photo below. You can also connect the leads with small alligator clamps, as shown in the second photo. Be sure to connect red to red and black to black.
- Feel both sides of the tile after a few seconds. Write “cold” on the cold side and “hot” on the hot side.



Credit: Jennifer Cutraro

**Twist together the exposed metal part of each lead. Be sure you only connect leads of the SAME color.**



Credit: Jennifer Cutraro

**You also may connect the devices by placing the metal parts of each lead inside of a small alligator clamp.**

**The tiles quickly become cold on one side and hot on the other.**

- Disconnect the wires and allow the tile to return to room temperature.

## HEAT SINKS

- Open both boxes containing the cooling fans. Remove the fans and place them fan-side-down on the table.
- Pull on the plastic connector (the plastic cap with holes in it) with one hand while holding onto the thick black wire with the other. You will see that inside there are four narrow wires in four different colors.
- Your fan may have one of two types of wiring scheme. Please see the table below to identify the wiring scheme for your fan.



Credit: Sophie Landay

**This student has placed her heat sink fan fan-side-down on the table. The gray square in the middle of the flat surface of the fan is adhesive material.**



Credit: Jennifer Cutraro

**Pulling on the connector exposes the wires inside.**

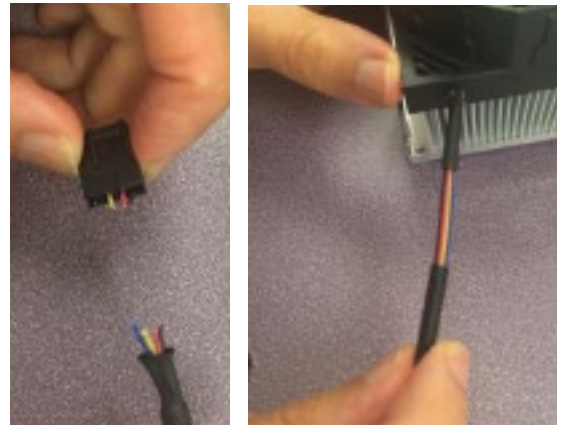
Type 1	Type 2	Function
Black	Black	Ground
Red	Yellow	VDC+12V
Yellow	Green	RPM Signal
Blue	Blue	PWM Signal



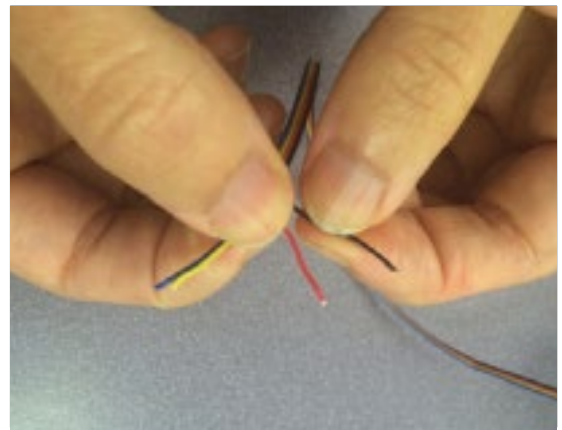
- Use wire cutters to cut off the plastic connector, working with a partner.
- Pull gently on the outer coating that covers the wires. It should pull off in one piece, exposing the four colored wires.
- Separate the red and black wires from the blue and yellow ones by inserting a thumbnail between them and gently pulling apart. Then, separate the red from the black in the same manner. You will not need to use the yellow or blue wires in this project.
- Strip, or remove, about one inch (about half the length of your thumb) of the insulating plastic coating from both the red and the black wires. To do this, place the wire inside the opening of the wire cutter that fits snugly. Squeeze the handle of the wire cutters, and pull the wire directly away from



**These teammates are working together to expose the colored wires and cut off the cap.**



**Removing the connector exposes the four colored wires inside. The outer covering should pull off in one piece with a gentle tug.**



**The colored wires can easily be separated with a fingernail.**

Credit for all photos: Jennifer Cutraro



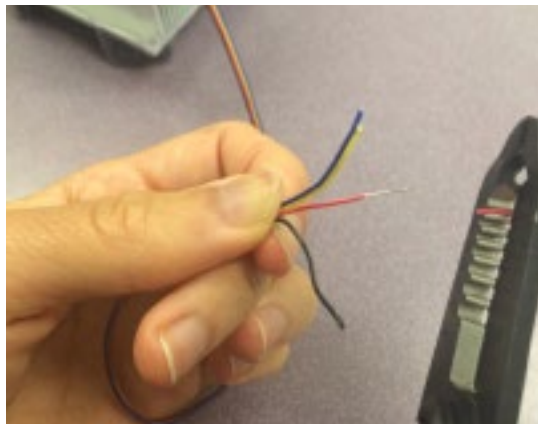
# MEETING 5

the wire strippers (don't bend the wire up or down as you pull it away). The wire stripper should cut through the plastic insulation and the insulation should pull off the wire. You might want to practice a few times with an extra piece of wire.

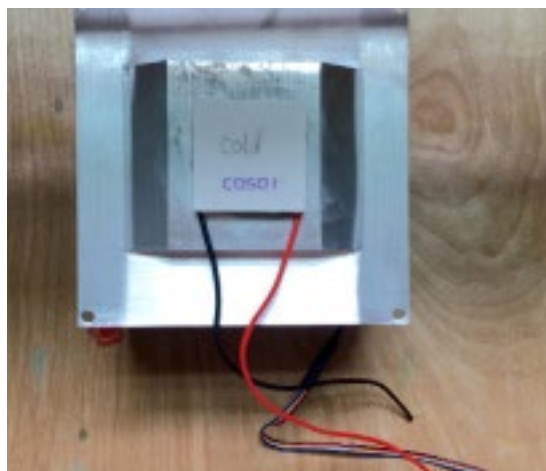
- Place the Peltier tile on the flat surface of the fan with the hot side down. Align it so that the wires coming from the tile are pointed in the same direction as the wires coming from the fan; this makes it easier to connect all of the components to the battery holder. The fan has a small patch of adhesive on its flat surface; press the tile firmly to attach to the flat surface of the fan, and then rotate the fan onto its side.
- Connect the wires from the tile and the wires from the fan to the battery holder. Remember to connect the red wire to the red wire and the black to the black by twisting



**Wire strippers should snugly enclose the wire without nicking the wire.**



**Stripping the colored insulation exposes the wire interior.**



**The Peltier tile has been placed on top of the heat sink fan with its wires facing the same direction as the wires coming from the fan.**

## PATENT SPOTLIGHT

Why does your heat sink fan have four different colored wires? Heat sink fans are typically used to cool components inside of a computer. They are powered by the computer and also communicate with the computer to provide feedback about the fan's operation. The red and black wires connect to the computer's power supply, giving power to the fan. The yellow wire is called the "tacho," and it communicates with the computer to let it know how quickly the fan is spinning. The blue wire is called the PWM control; this wire governs the fan's operation. Read more about PC fans [here](#).

together the exposed metal wires, or by connecting them with an alligator clamp. The cold side of the tile should immediately begin to feel cool, and the fan should begin spinning.

- Shine the beam from the infrared thermometer directly onto the Peltier tile on top of the **heat sink** fan to record its temperature. Note the time on a clock, cell phone, or watch. Record the data below:
  - Tile temperature: °C
  - **Heat sink** temperature: °C
  - Time: min sec
- Record both temperatures again after one minute. Record the data below:
  - Tile temperature: °C
  - **Heat sink** temperature: °C
- Time: min sec



Credit: Liza Goldstein

**Power the fan by connecting the red leads on the fan and the battery holder, and connecting the black leads on the fan and battery holder. This creates a closed circuit.**

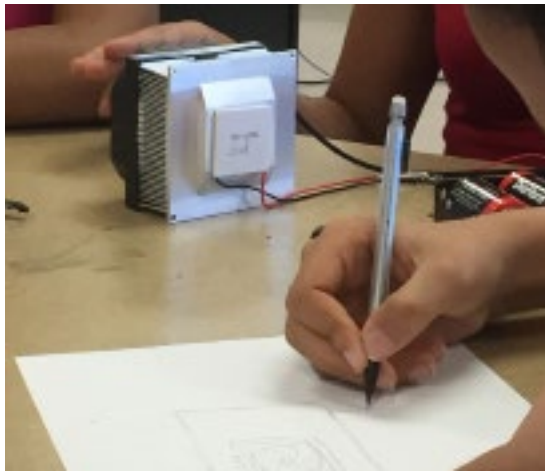


Credit: Ross Bloomfield

**Shine the beam from the infrared thermometer directly onto the Peltier tile atop the heat sink fan to record its temperature.**

# MEETING 5

- Leave the cooling unit connected to the battery holder, but remove one of the batteries from the battery holder to turn off the fan and cooling unit. You will return to this setup later in this meeting.



Credit: Ross Bloomfield

**Sketching the components of an invention is one part of the process.**

## EXTEND THE LEARNING

The electricity that cars and other vehicles use to power the lights, radio, power windows, and instrument panels comes from the vehicle's battery, which is recharged by a component called an alternator. The motion from the vehicle's engine—which uses gas—spins the alternator, which creates electricity to recharge the vehicle's battery.

MIT professor Gang Chen's invention has paved the way for vehicles to produce electricity from the engine's waste heat—bypassing the need for the alternator all together, and possibly boosting the vehicle's fuel efficiency. [Read more](#) about his invention.

## SAFETY

## DESIGNING AND BUILDING A LUNCHBOX

### How to Cut Cardboard with a Utility Knife

[Watch a video on MIT's Josh Ramos](#) as he shows you how to cut cardboard.



- Wear safety glasses.
- Always cut cardboard on top of masonite board in order to protect the tables.
- Hold the utility knife with thumb near the front, and pinky near the back.
- Stand up to get better leverage on your work when cutting.
- Keep your other hand on the material to stabilize it, but above and away from where you're going to cut. Don't cut toward your hand.

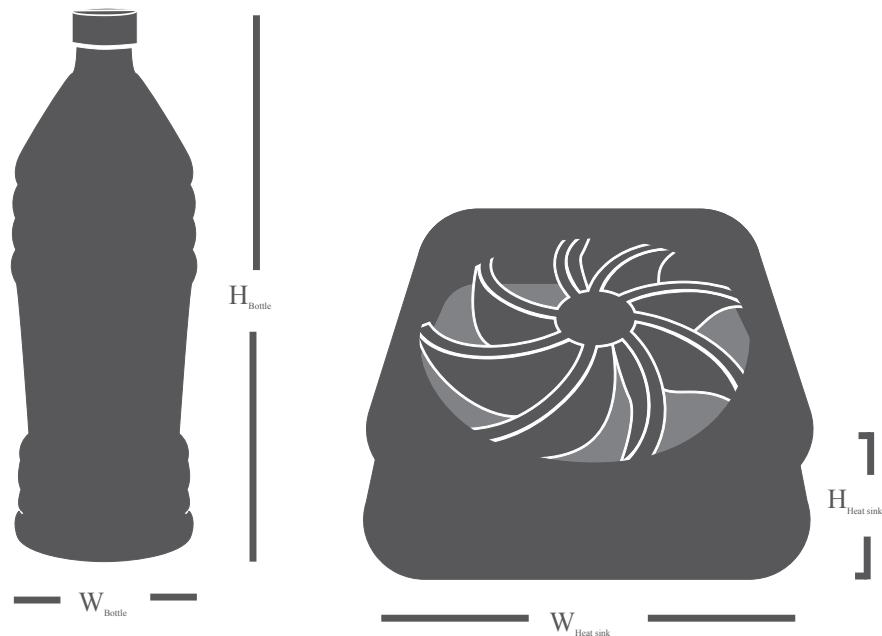
- Make a shallow cut first along the line, slowly and easily.
  - Make a few more cuts along the same line until you cut all the way through.
  - Cut against a ruler for precision.
  - Close the blade when not in use.
1. You will be making a prototype for a lunchbox that will keep a non-insulated bottle of water cold. Your finished lunchbox probably won't be pretty, but it will provide insulation. Experiment with variables such as how large to make the cooling compartment and how best to fit the Peltier cooling unit into the lunchbox.

2. Review the instructions below:

- Roughly measure the height and width of the bottle that you want to keep cool (or warm). A typical water bottle is about nine inches high and three inches wide. Enter those values below:

H (bottle) =

W (bottle) =



Roughly measure the height and width of your **heat sinks**. The Alpine 11 Plus fan is about three inches high and four inches wide.

H (**heat sink**) = \_\_\_\_\_ W (**heat sink**) = \_\_\_\_\_

- Determine the height of your box. The bottle will need to lie on its side in the box. The box also will contain the **heat sink** fans, standing on their sides. Thus, the box needs to be at least as high as the larger of either the width of the **heat sink** fan or the width of the bottle. Determine the largest of W (bottle) or W (**heat sink**) from above, and add 1 inch or more.

H (box) = [largest of W (bottle) or W (**heat sink**)] + 1 inch

H (box) = \_\_\_\_\_

- Determine the width (long side) of the box. The box is going to have two sides of equal size, and each should be able to fit a **heat sink** and a bottle. We'll add two inches on each side to make sure you have room.

W (box) = 2 x [W (bottle) + H (**heat sink**) + 2 inches]

W (box) = \_\_\_\_\_

- Calculate the depth of the box. The box will need to be deep enough for the water bottle to lie down in. Use the height of the water bottle and add two inches.

D (box) = H (bottle) + 2 inches D (box) = \_\_\_\_\_

- Make the sides and middle divider by measuring and then cutting three pieces of cardboard with the dimensions H (box) x D (box). Fill in the blanks below with the measurements you will use, based on the size of your water bottle.

D (box) = \_\_\_\_\_ H (box) = \_\_\_\_\_

- Make the front and back by measuring and cutting two pieces of cardboard of dimension H (box) x W (box). Fill in the blanks with the measurements you will use.

H (box) = \_\_\_\_\_ W (box) = \_\_\_\_\_

- Make the top and bottom by cutting two pieces of cardboard with the dimensions W (box) x D (box).

W (box) = \_\_\_\_\_ D (box) = \_\_\_\_\_

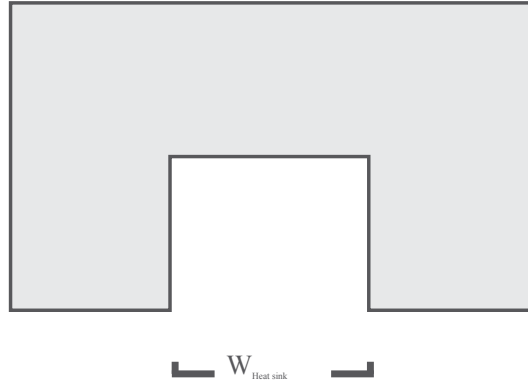


Credit: Lemelson-MIT

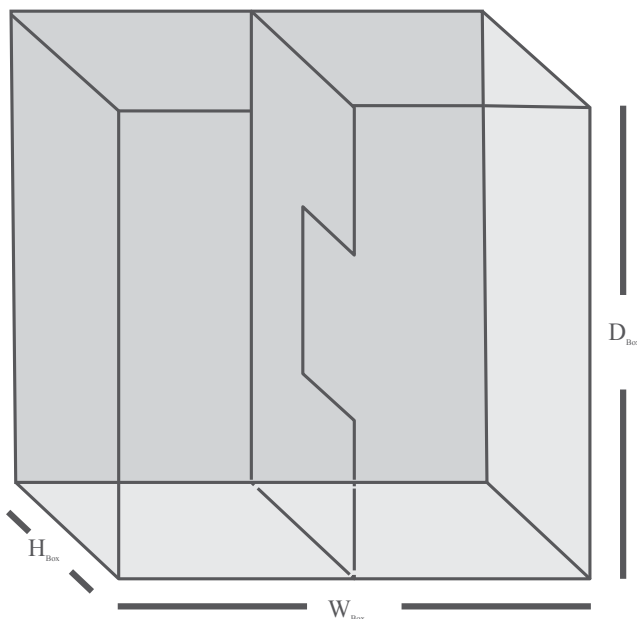
## INVENTION SPOTLIGHT

Frederick McKinley Jones was an African American inventor who taught himself mechanical and electrical engineering. In the mid-1930s, he noticed that truck drivers were frustrated with the spoiling of food stemming from melting ice in their trucks. He designed and patented a portable air-cooling unit for trucks carrying perishable food. Jones founded the U.S. Thermo Control Company, which grew substantially during World War II, helping to preserve blood, medicine and food. Jones earned over 60 patents during his lifetime. [Learn more here.](#)

- Cut a hole in the middle divider (which you cut already) that a **heat sink** can fit into. It will be easiest if the **heat sink** is resting on the bottom of the box, so the hole should be on the bottom of the board. Use the **W (heat sink)** dimension from above to cut the hole. It should look something like this:



- Tape the pieces together, but keep the top off. (Tip: Instead of tearing off pieces of tape one at a time, tear off a two-foot section first, attach one end to the table, and tear off little pieces from that—things will go faster!)
- Use the diagram below as a reference. Place the middle piece in last to determine whether it fits snugly, but do not tape it in place yet; you will do this later when you fit the Peltier cooling unit in place.



July 12, 1949. F. M. JONES 2,475,841  
AIR CONDITIONING UNIT  
Filed June 15, 1944 3 Sheets-Sheet 1

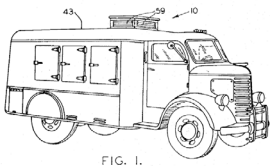
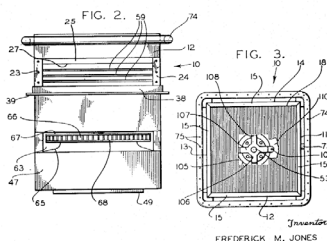


FIG. 1.



INVENTOR  
FREDERICK M. JONES  
BY *P. A. Whitely*  
ATTORNEY

Air conditioning unit for truck.

Credit: USPTO



## TESTING THE PELTIER COOLING UNIT

1. Return to the pages in this guide from the last meeting, when you tested the Peltier tiles. How long did the tiles resting on the table stay cold?  
Can you explain why they did not stay cold for very long?
2. Predict how your Peltier tiles will perform today, after being attached to the **heat sink** fan. You will compare the performance of the tile with and without the **heat sink**, to determine if adding a **heat sink** will lead to better performance inside the lunchbox.
  - Record the time. How much time has elapsed since you first connected your Peltier cooling unit to the power supply?
  - Lightly touch the surface of your Peltier cooling unit. How does it feel?
  - Lightly touch the surface of the **heat sink** fan. How does it feel?
  - Use the infrared thermometer and record the temperature of the surface of both the tile and the **heat sink**. If the tile has **condensation** beading up on it, wipe it away first with a paper towel.

Tile temperature: °C **Heat sink** temperature: °C

Time: \_\_\_\_\_min\_\_\_\_\_sec

- Record the final temperature of the tile after X minutes, with X being the number of minutes that have passed. Final tile temperature: °C

Number of minutes that have passed:

- Record the final temperature of the **heat sink** fan. Final **heat sink** temperature: °C

- Compare the final temperature of the Peltier tile today with the final temperature of the Peltier tile during the last meeting. How do they differ? Final tile temperature today: °C

Final tile temperature last meeting: °C

- Compare the beginning and final temperatures of the **heat sink** today. How do they differ? Beginning **heat sink** temperature: °C

Final **heat sink** temperature: °C

You should observe a dramatic increase in the length of time the tile remains cold, and quite cold at that, compared to the Peltier tile alone that you tested in Meeting 4. You should also notice that the **heat sink** feels warmer at the end of this time period than it did at the beginning. If you were to remove the Peltier tile at this time, the hot side would not be nearly as hot as it was during the last meeting. That's because the heat from the tile moved into the **heat sink**.

The **heat sink** fan is made of metal, a thermally conductive material. This **heat sink** helps heat transfer from one side of the Peltier tile to the other side, allowing heat to continually move from a high temperature surface to a lower temperature surface. The shape of the **heat sink** contributes to this function; it is made of numerous fins, much like a radiator. This increases the surface area the heat can flow to, and ultimately the fan transfers heat to the air by thermal conduction and convection.

## ASSEMBLING THE LUNCHBOX

1. Fit the Peltier cooling unit (the fans connected to the Peltier tile) into the middle divider you cut out earlier, so that the tile roughly lines up with the cardboard and both of the fans face outwards.



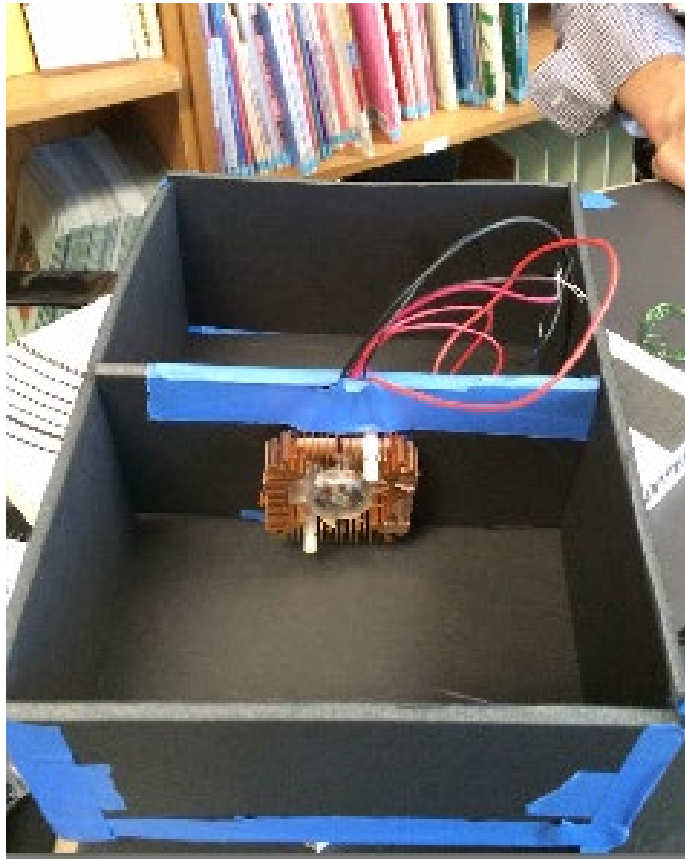
Credit: Ross Bloomfield

**This student is aligning a Peltier cooling unit inside the cardboard divider.**

**Note:** Students in this photo and photos on the subsequent pages used foam core for their box instead of cardboard.



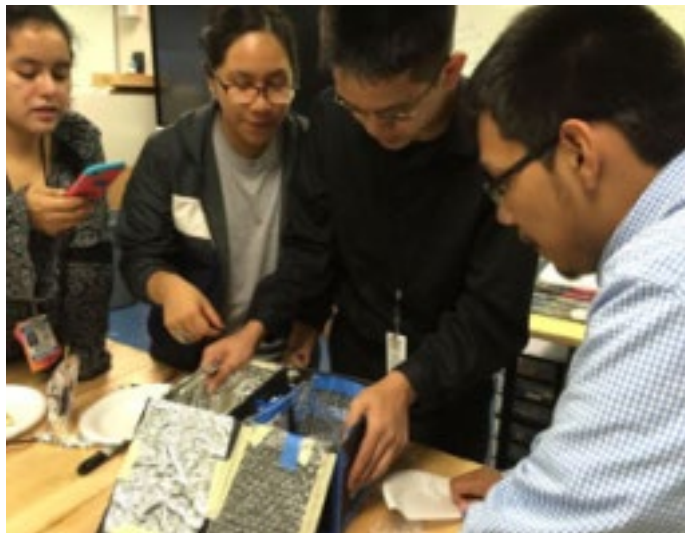
- Place the divider with the Peltier cooling unit inside the box. Your battery holder should be connected to the Peltier cooling unit. If you notice gaps where the cardboard divider meets the walls of the box, seal them off with tape. It should look something like this (right):



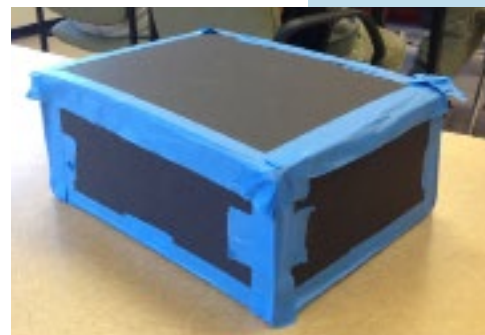
Credit: Jennifer Cutraro

**A proof-of-concept lunchbox, showing a Peltier cooling unit situated so that cooled air circulates on one side and warmed air circulates on the other.**

- Place the base of the indoor/outdoor thermometer inside the warm side of the lunchbox and the probe on the cool side. Record the initial temperature of each side.
- Warm side temperature: °C
- Cool side temperature: °C
- Place the top on the box and seal all the sides with tape when you have confirmed that the fans are on and the tile is cooling (you should be able to feel the **heat sink** on the cold side cooling down fairly quickly). It should look like this:



Credit: Energy Institute



Credit: Sophie Landay

## PROTOTYPING WITH PELTIER TILES

1. You will watch a short video about another potential use for Peltier tiles. Read the text below before you watch the video.

Peltier tiles hold promise for cooling applications in portable devices—or in places where there might not be electricity—because of their small size and solid construction. Inventor and tinkerer Eric William shows one such application in [this video](#):

- What problem did Eric identify?
  - What solution did he propose?
  - How did he prototype and test his idea?
  - Did his device work? Why or why not?
  - How does he suggest he might improve on this prototype?
  - Eric subtitles his video “Fail.” What does he mean, and how does he use this “fail” as a way to improve his design?
2. Inventors embrace failure and learn from failure. Often they also try to “break” a design to test its failure limits. How does this example show how we can learn from failure?

## WRAP UP

Reconvene with your team. Review the following steps:

- With your team, return to your lunchbox. Open the lid, and immediately record the temperatures shown on the indoor/ outdoor thermometer.

Warm side final temperature:      °C

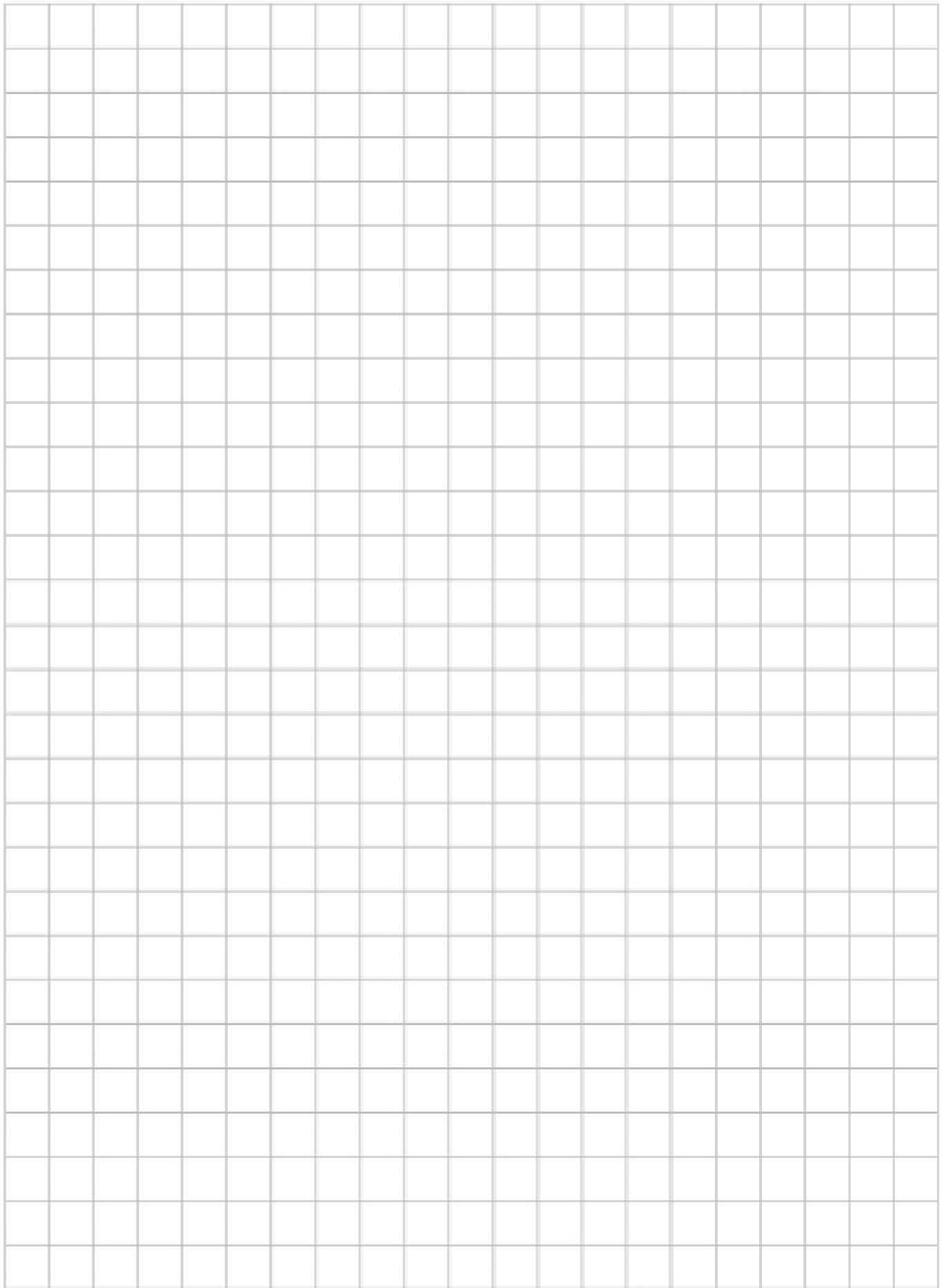
Cool side final temperature:      °C

- How do these temperatures compare to the initial temperatures?
- Is this what you expected to see? Why or why not?
- If not, what might be some reasons?

Refer back to the video and answer the following questions:

- What are some of the ideas Eric proposed for why his invention didn't work as he expected?
- How does he plan to troubleshoot these problems?
- Can you use any of his suggestions to improve on your invention? How?

## MY THOUGHTS

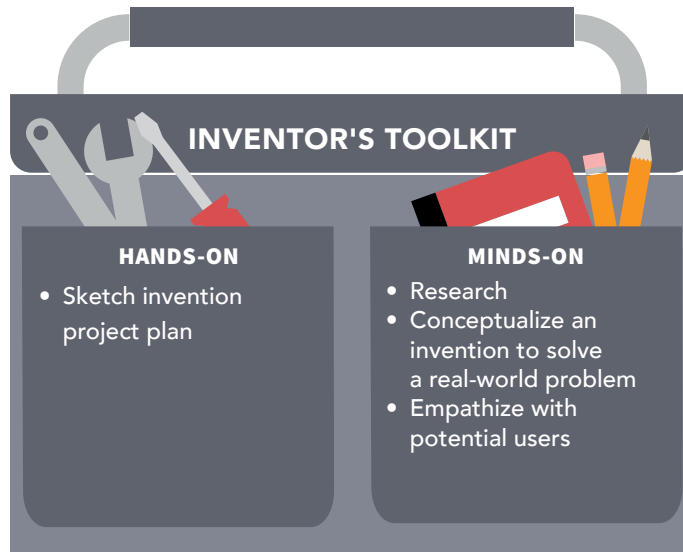


# U CONTROL

## MEETING 6: INVENTION EXTENSION

### KEY TERMS

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



### Tools

- Writing utensils

### Materials

- Student Guides
- Computer for research
- Self-Assessments

### Procedure

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

## INTRODUCTION TO INVENTION CHALLENGE

Sit back and reflect on the new toolkit of skills you have acquired in this unit. You have new minds-on skills such as working in teams and understanding the design process, the prototyping process, heat transfer, heat conductors and insulators, and the role of heat in everyday life. You have gained hands-on skills such as making circuits, cutting and stripping wire, cutting cardboard, and wiring together a Peltier tile, a battery holder, and heat sink fans.

Invention is centered on **empathy** and fulfilling people's needs. How could you use your new skills to solve a real problem? Your challenge is to select a person or group of people with a need and apply your skills to invent a solution.

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

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

For additional information on problems/needs in other countries, explore the [World Bank](#) website.

## REVIEW REAL-WORLD EXAMPLES

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

### Example 1

Product designer Ian Tansley was working on sustainable development projects in Africa and Asia when he saw the need for better technologies to cool vaccines and other medicines in places lacking electricity. A walk around a frozen lake got him thinking about a seeming puzzle: If hot water rises and cold air sinks, why is there ice at the top of a lake and not the bottom? The phenomenon is explained by some of the unique physical properties of water, which he applied to invent a new type of cooling technology.



He teamed up with entrepreneur Peter Saunders to start the company [Sure Chill, Ltd.](#), which specializes in solar-powered refrigerators that use this technology.

Read more about his invention [here](#).

### Discuss as a Class

What are some of the problems of conventional refrigeration highlighted in this article? Can you think of any other low-cost solutions for transporting goods that need to be refrigerated or otherwise cooled? What would the product do? How would it meet a user's needs? Who might benefit from this solution?

### Example 2

High school student Ann Makosinski came up with an innovative application for Peltier tiles. She used one to convert heat from the body into electricity to power a flashlight. Her invention, the hollow flashlight, won the 2013 Google Science Fair competition for her age category.

Read her full Google Science Fair entry [here](#).

### Discuss as a Class

What are some of the future applications of Peltier tiles that Makosinski describes in her science fair entry? What were some challenges she faced while working on this project, and how did she address those challenges? In what ways could you use her idea to improve upon your Peltier-cooled lunchbox?

### Example 3

Do you ever notice how, when you get out of bed in the morning, the spot where you'd been sleeping feels warmer than the rest of your bed? That's because your body produces heat as a byproduct of metabolism, all of the chemical processes that keep your body running. Inspired by this simple fact, engineers Klas Johansson and Karl Sundholm invented a system to capture that heat and use it to heat a nearby office building.

Read more about using body heat to keep buildings warm [here](#).

## Discuss as a Class

How did Sundholm and Johansson come up with their idea? How does their invention expand on the people-powered heating used at Minnesota's Mall of America, which recycles the body heat given off by the mall's shoppers? Can you think of other ways to capture, store, and reuse body heat? How would you use this heat?

## BRAINSTORM INVENTION IDEAS

1. As you brainstorm invention ideas, you need to think first about WHO your invention will help.
2. The most successful brainstorms are the ones in which all ideas, even wacky ones, are proposed, and all ideas are accepted. You never know when a wacky idea will inspire a great invention! Take a few minutes to brainstorm invention ideas using the blank pages in your student guide. After you've come up with ideas, rejoin as a team and share your ideas. Brainstorm new ideas together. Remember to think of ways to apply the new minds-on and hands-on skills you have learned, such as building circuits and understanding heat transfer, and think of specific users and their needs. For example, could you build a cooler that uses fans and **evaporative cooling**? Could you create a low-cost, battery-operated cooler for aid workers in developing countries to keep vaccines or other medications cool during transport by harnessing and using the heat generated by Peltier tiles?

## BRAINSTORM SOLUTIONS

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

**S = Substitute** (*playing basketball with a softball*)

**C = Combine** (*toothbrush combined with a pencil to create a new product*)

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

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

**P = Put to Other Uses** (*could your fork be used as a comb?*)

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

**R = Rearrange** (*what if the laces of a shoe were placed on the bottom and not the top?*)

2. To use the SCAMPER technique, you should first state the problem you would like to solve. Then, ask questions about it using the SCAMPER checklist.
3. Use SCAMPER to do some personal brainstorming in your guide.
4. Gather with your team to discuss ideas and streamline them. Select one idea to take to the next step.

## MAKE A PLAN

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

3. Use the invention worksheet in your guide to document and sketch your idea. This is a version of what high school InvenTeams use in their project proposals.
4. Share your ideas with the class in a culminating celebration of your work. If you are interested in continuing this work, consider [\*\*applying for InvenTeams grants!\*\*](#)

## 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: \_\_\_\_\_

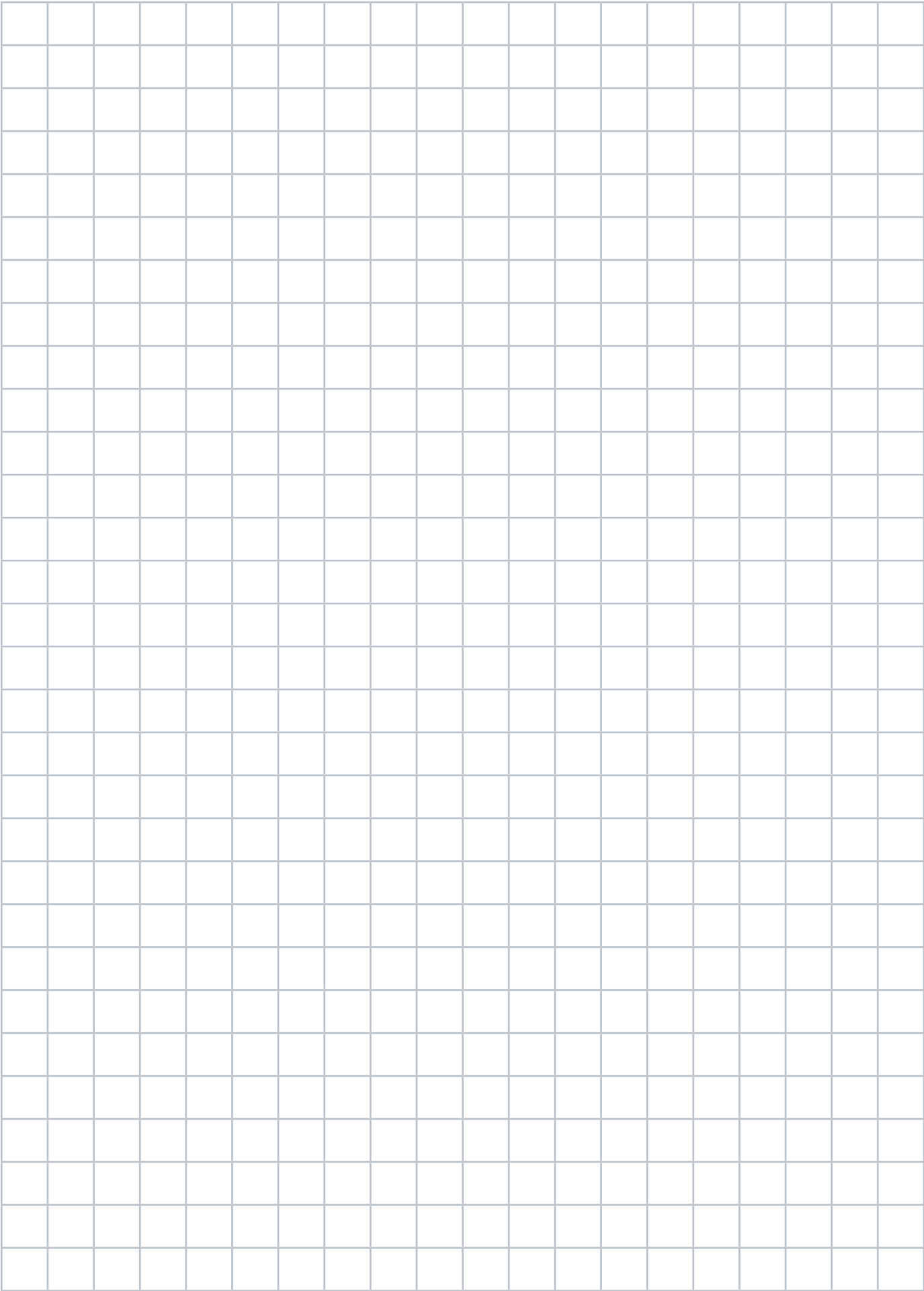
It functions by: \_\_\_\_\_

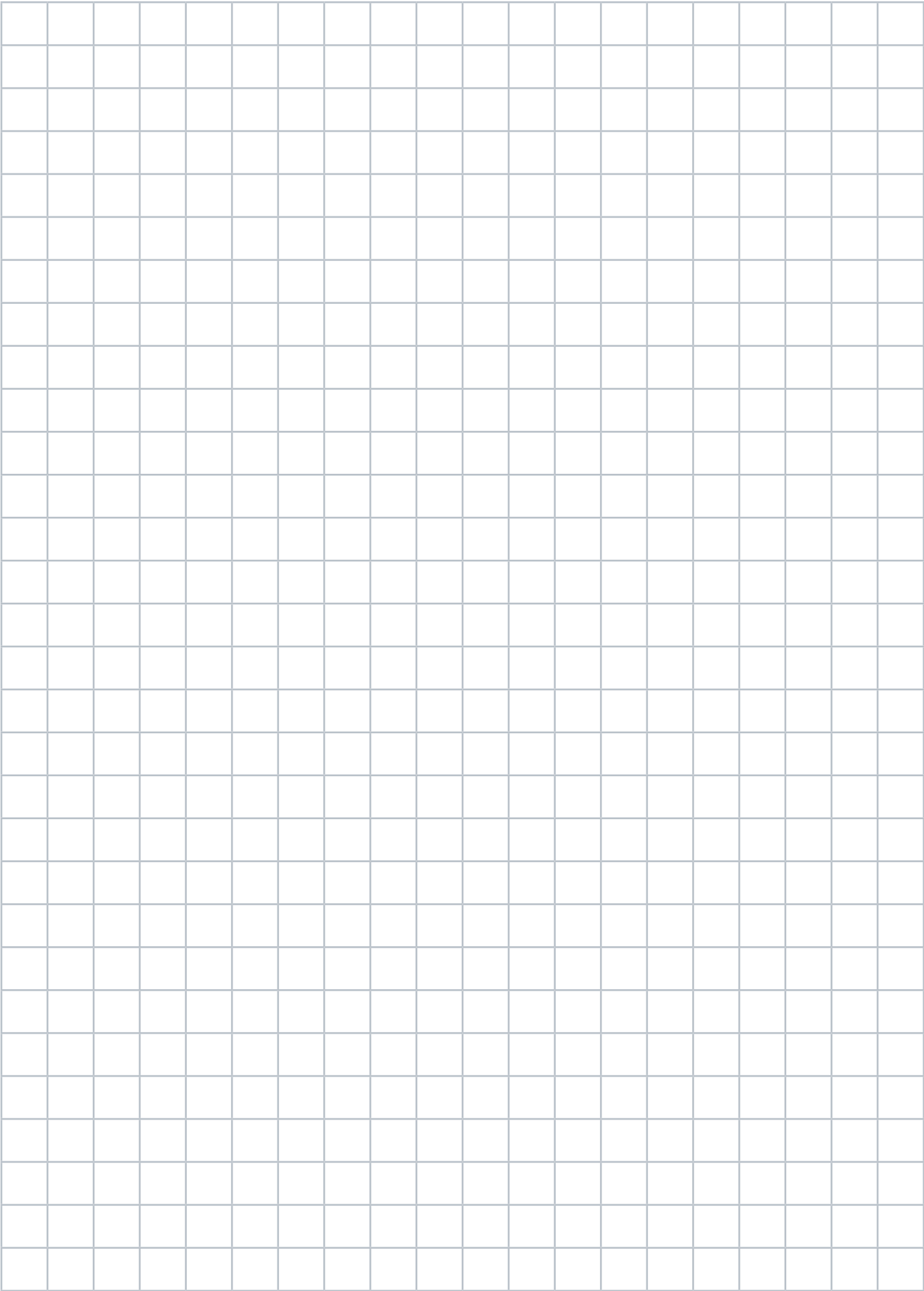
The tools we need are: \_\_\_\_\_

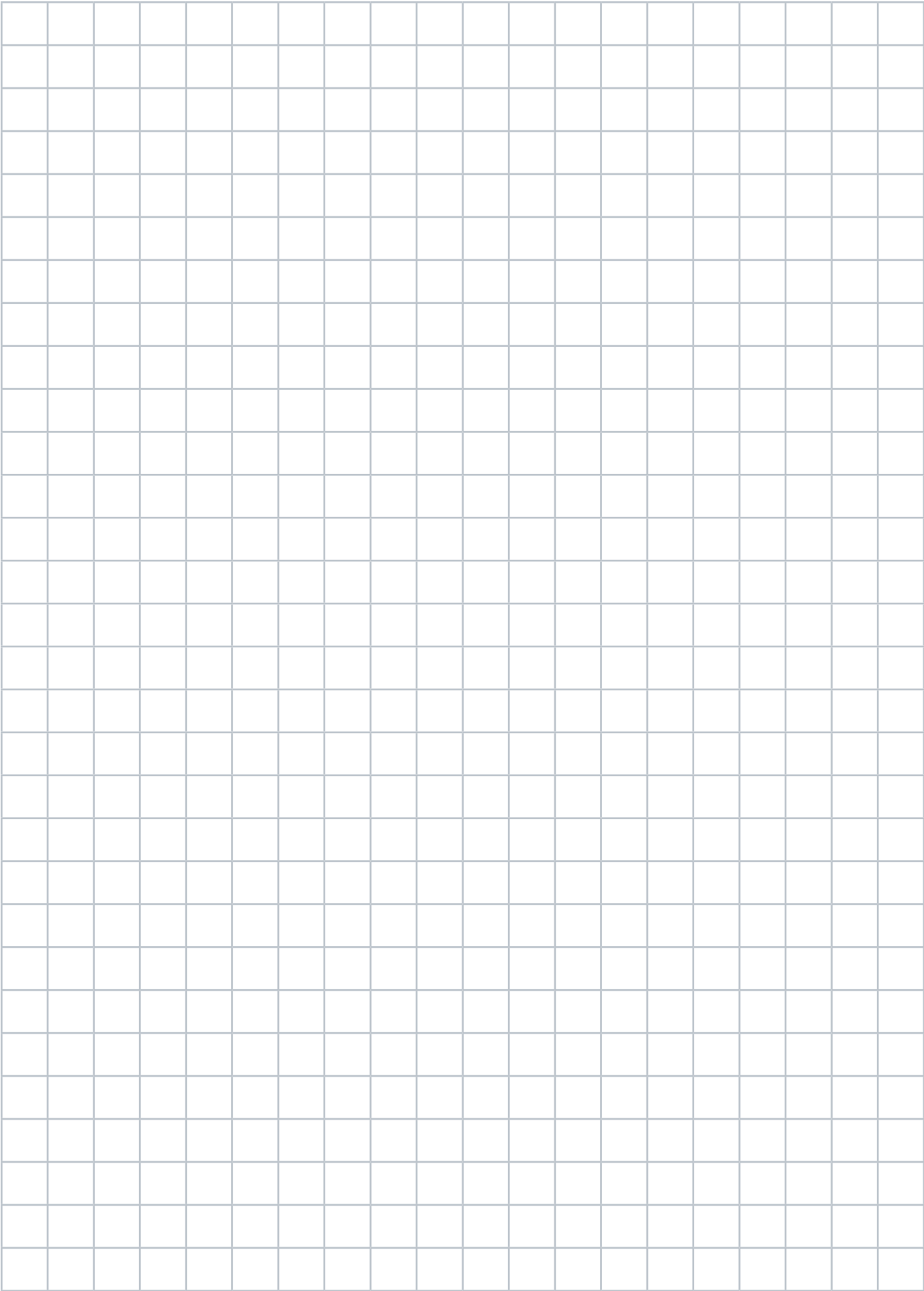
The materials we need are: \_\_\_\_\_

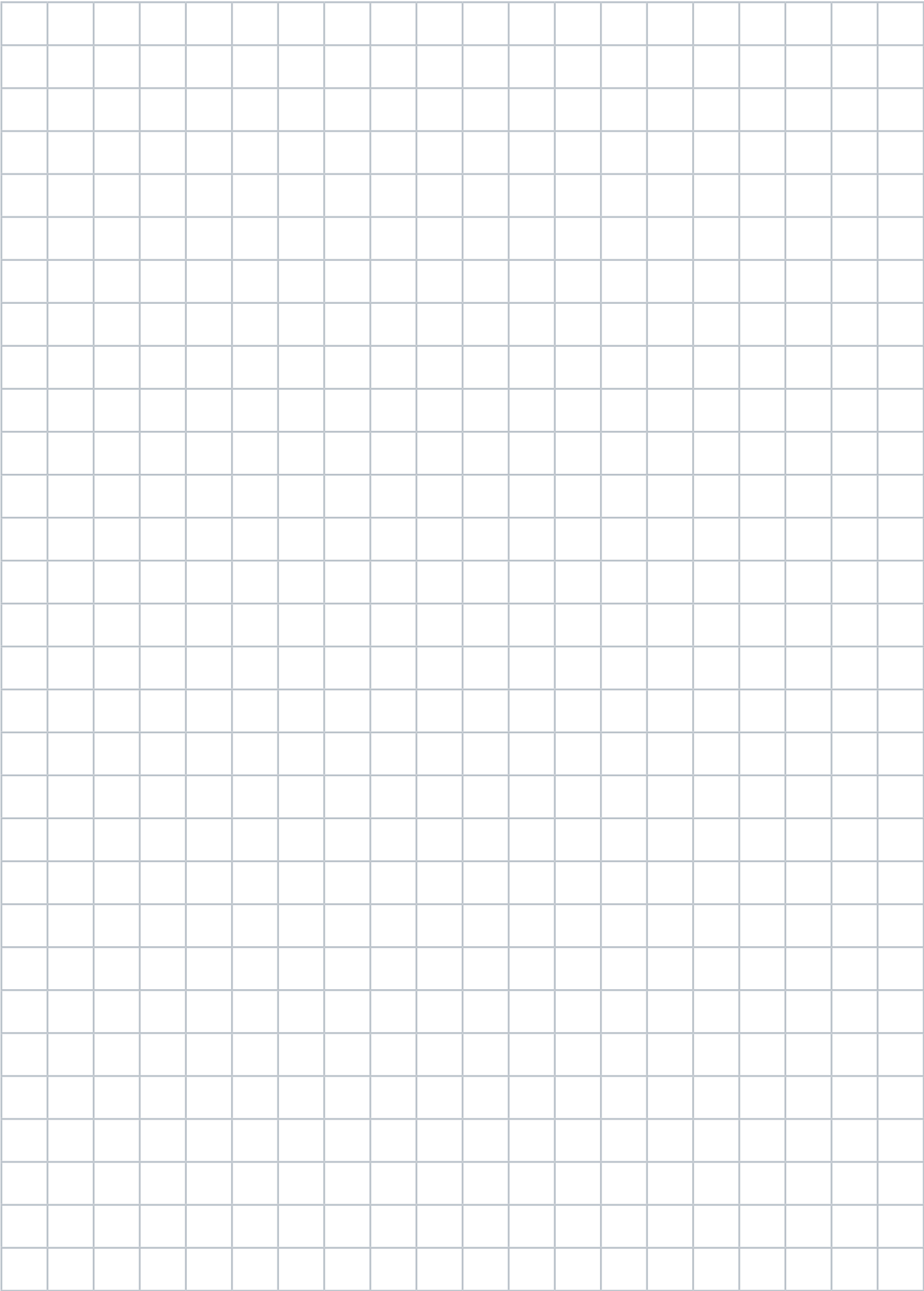
The estimated total cost of our invention is: \_\_\_\_\_

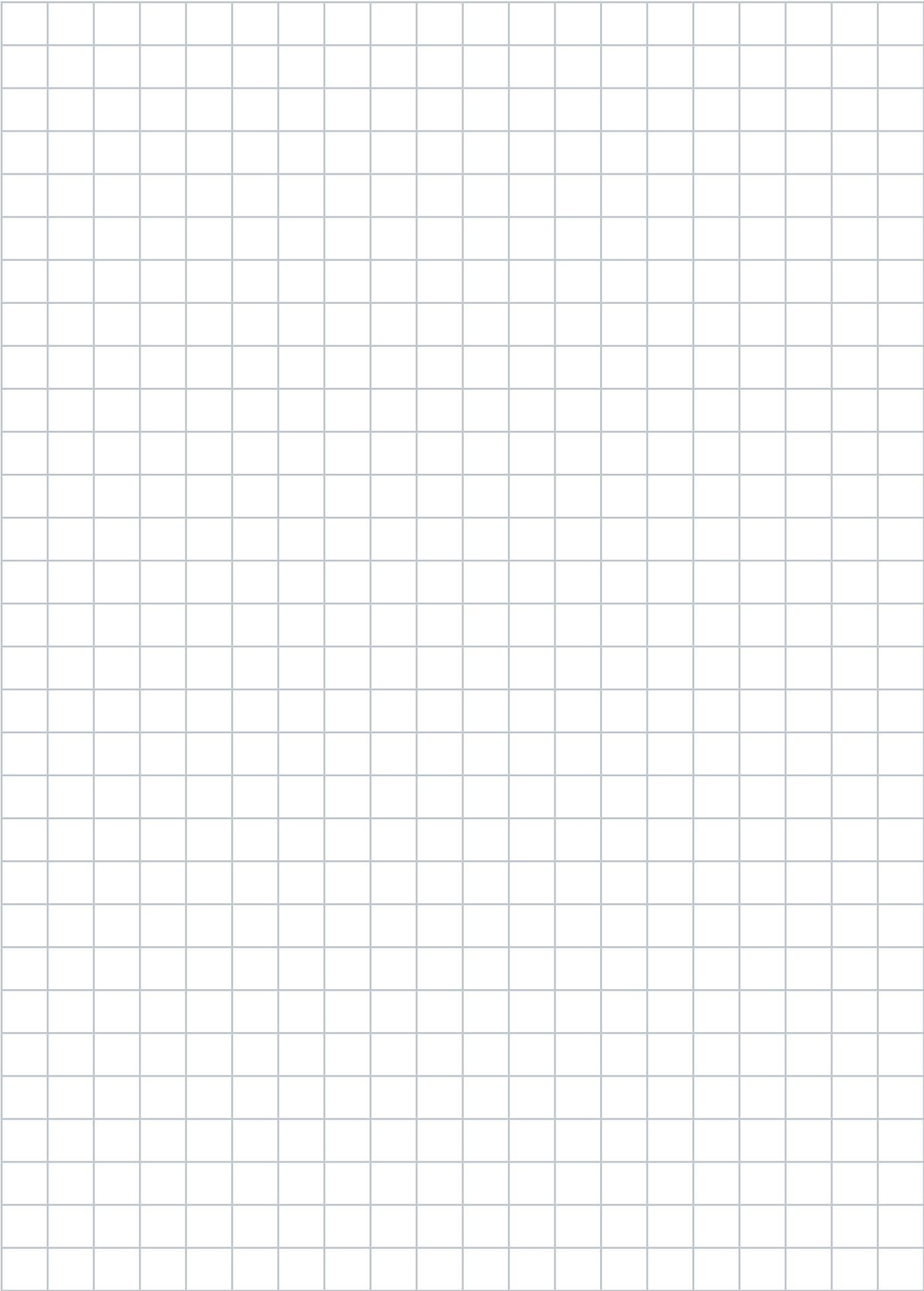


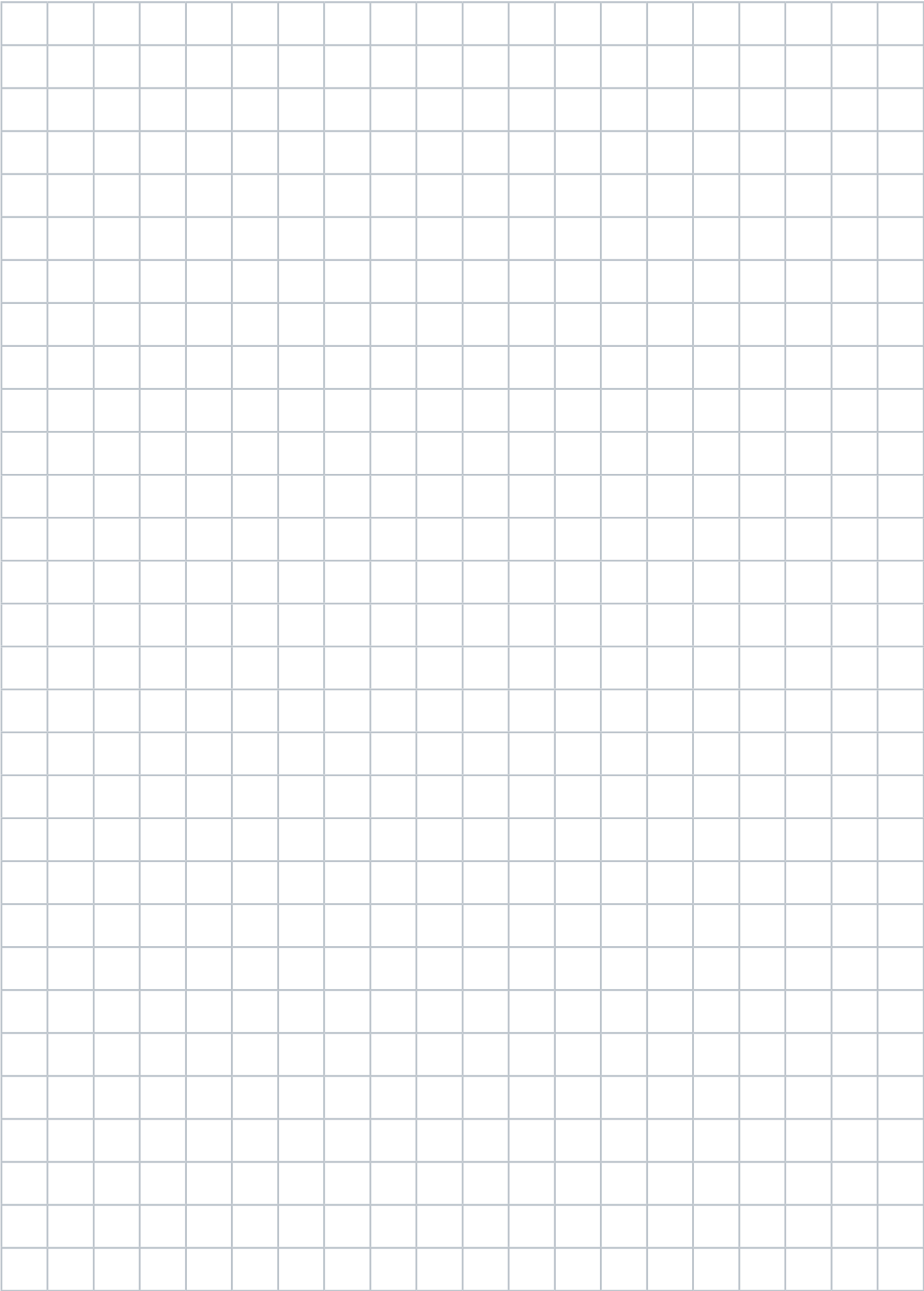


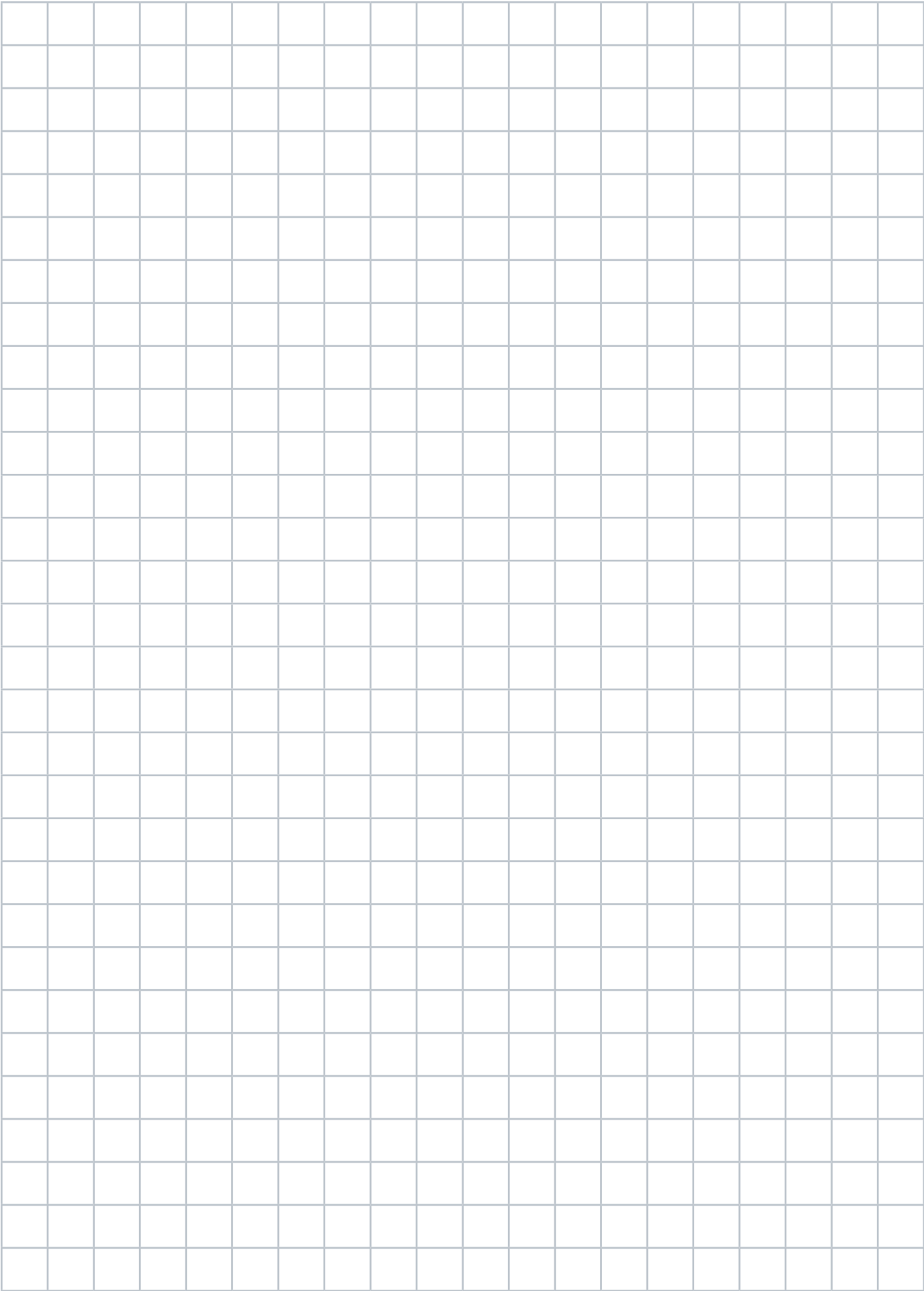




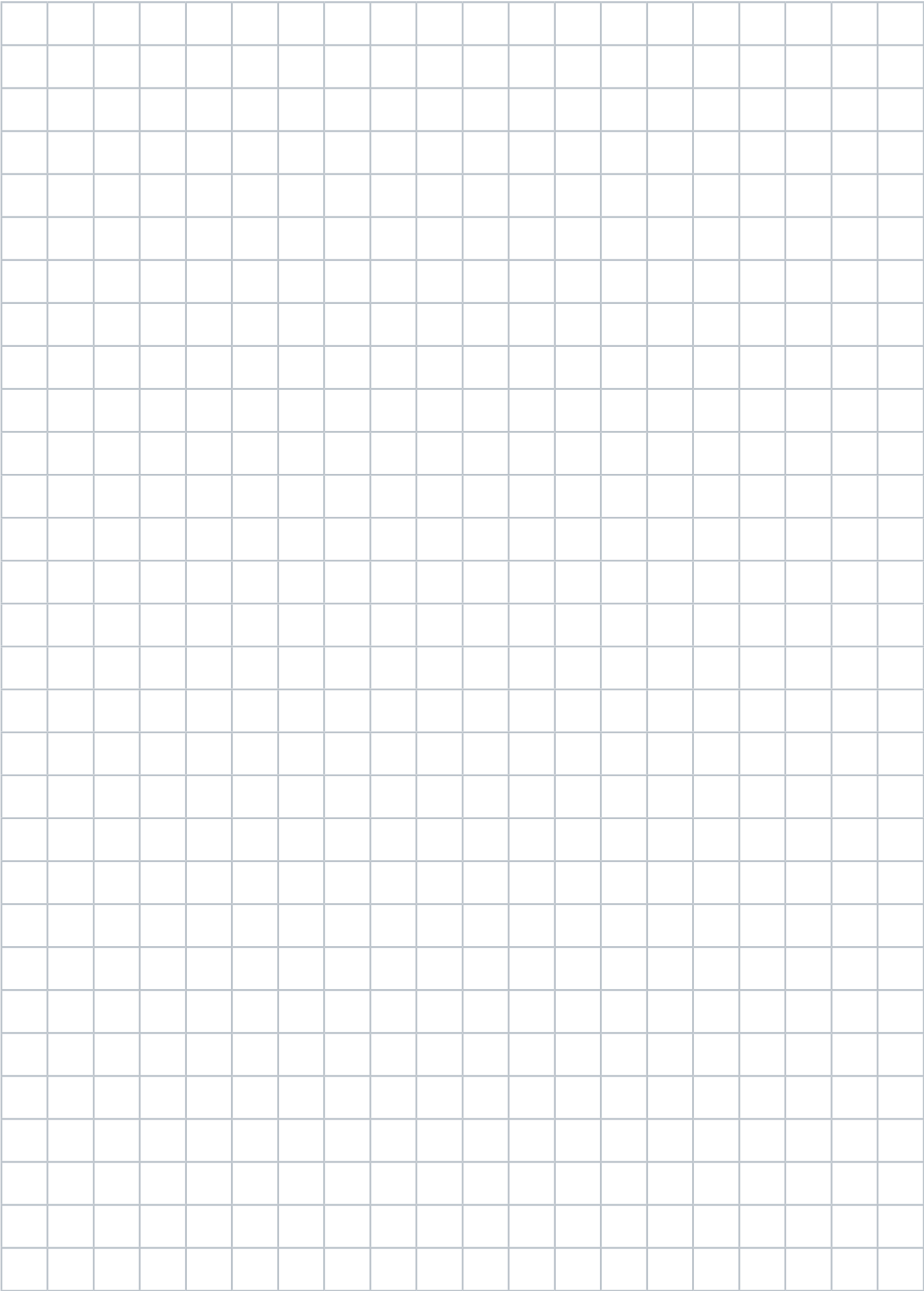


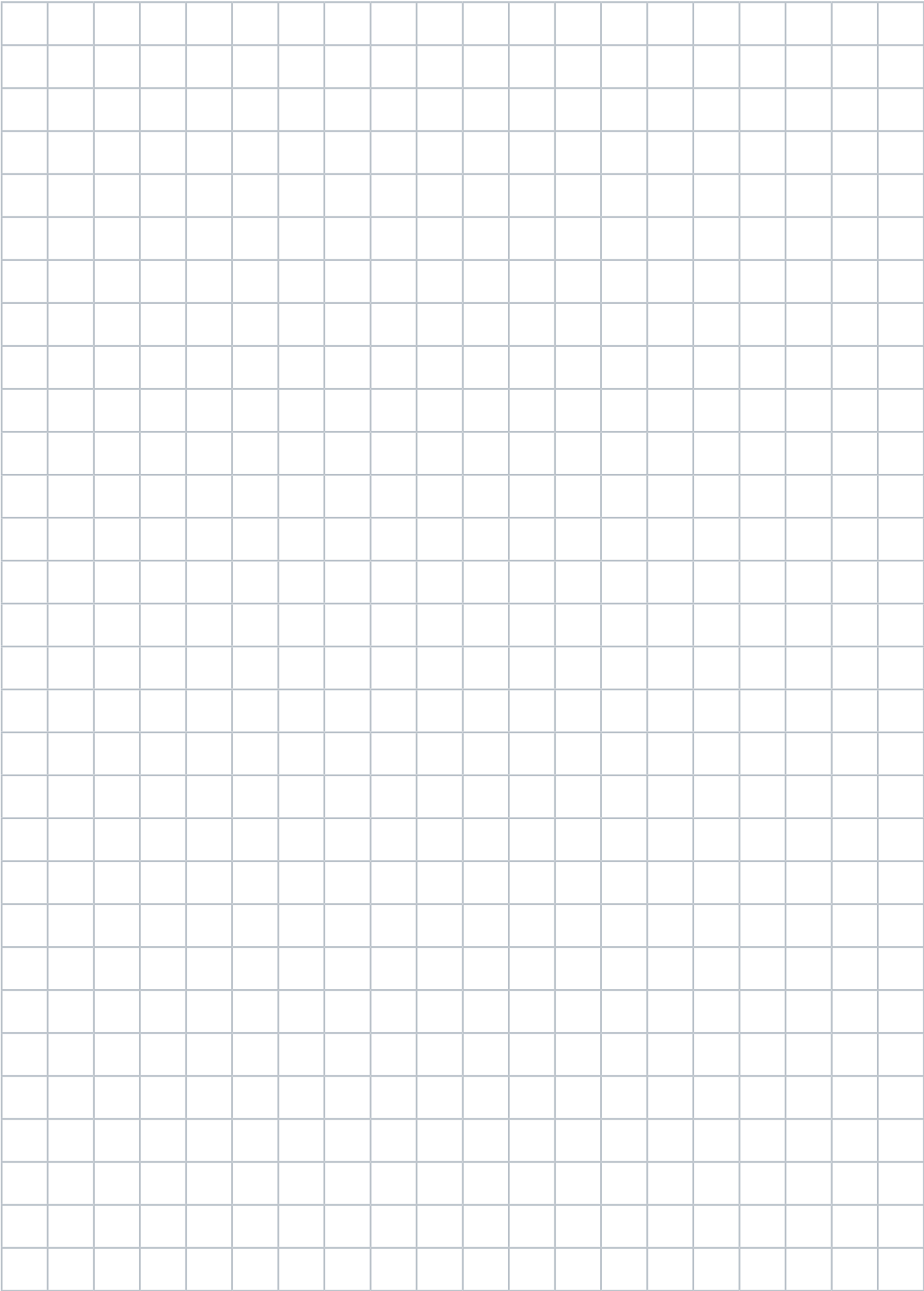












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