Pendulum Time

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Lesson Focus

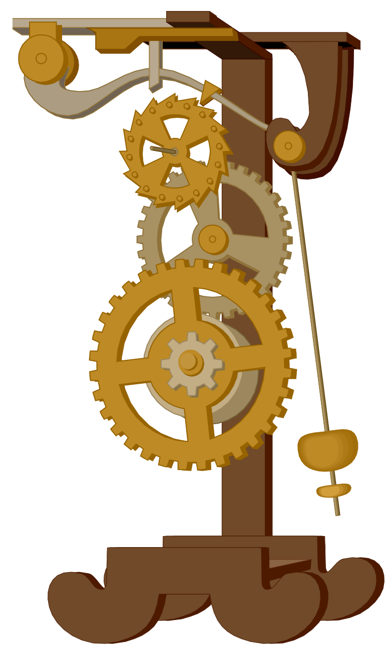
Lesson focuses on how pendulums have been used to measure time and how mechanical mechanism pendulum clocks operate. Students work in teams to develop a pendulum out of everyday objects that can reliably measure time and operate at two different speeds. They will determine the materials, the optimal length of swing or size of weight to adjust speed, and then develop their designs on paper. Next, they will build and test their mechanism, compare their results with other student teams, and share observations with their class.

Lesson Synopsis

The "Pendulum Time" lesson explores how the pendulum has been a reliable way to keep time for centuries. Students work in teams to build their own working clock using a pendulum out of every day materials. They will need to be able to speed up and slow down the motion of the pendulum clock. They sketch their plans, consider what materials they will need, build the clock, test it, reflect on the assignment, and present to their class.

Age Levels

8-18.



Objectives

- Learn about timekeeping and engineering.
- Learn about engineering design and redesign.
- Learn how engineering can help solve society's challenges.
- Learn about teamwork and problem solving.

Anticipated Learner Outcomes

As a result of this activity, students should develop an understanding of:

- timekeeping
- engineering design
- teamwork

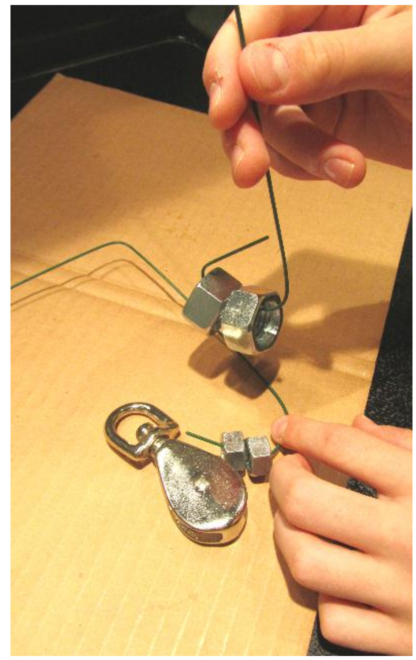
Lesson Activities

Students explore how the pendulum clock has proved to be a very accurate way of measuring time over the centuries. Students work in teams to build their own pendulum clock out of everyday items. They conduct research, determine and draw a design, gather parts, build the clock, test it, complete a reflection sheet, and share their experiences with the class.

Resources/Materials

- Teacher Resource Documents (attached)
- Student Resource Sheet (attached)
- Student Worksheet (attached)

Alignment to Curriculum Frameworks



See curriculum alignment sheet at end of lesson.

Internet Connections

- TryEngineering (www.tryengineering.org)
- A Walk Through Time (www.nist.gov/pml/general/time/)
- Clockworks -- from Sundials to the Atomic Second (www.britannica.com/clockworks/startpage.html)
- National Science Education Standards (www.nsta.org/publications/nses.aspx)
- ITEA Standards for Technological Literacy (www.iteaconnect.org/TAA)

Recommended Reading

- Time's Pendulum: From Sundials to Atomic Clocks, the Fascinating History of Timekeeping and How Our Discoveries Changed the World (ISBN: 978-0156006491)
- The Pendulum: A Case Study in Physics (ISBN: 978-0199557684)
- Make Your Own Working Paper Clock (ISBN: 978-0060910662)

Optional Writing Activity

- Write an essay or a paragraph about whether you think a pendulum clock would work on the moon.

Optional Extension Activity

- Have students build a working metronome that can keep a beat at equal time intervals. Have students explore the concept of isochronism.

Pendulum Time

For Teachers:
Teacher Resources

◆ **Lesson Goal**

The "Pendulum Time" lesson focuses on how pendulums have been used to measure time and how mechanical mechanism pendulum clocks operate. Students work in teams to develop a pendulum out of everyday objects that can reliably measure time and operate at two different speeds. They will determine the materials, the optimal length of swing or size of weight to adjust speed, and then develop their designs on paper. Next, they will build and test their mechanism, compare their results with other student teams, and share observations with their class.

◆ **Lesson Objectives**

- Learn about timekeeping and engineering.
- Learn about engineering design and redesign.
- Learn how engineering can help solve society's challenges.
- Learn about teamwork and problem solving.

◆ **Materials**

- Student Resource Sheets
- Student Worksheets
- Student Team Materials: stopwatch or clock with a second hand, string, rubber balls, golf balls, pingpong balls --or ball or weight with knob in it, pencil, tape, foil, paper cups, paper clips, wire, plastic or paper plates, glue, pipecleaners, pvc piping, cardboard, paper, Velcro tape, or other materials. (Note: the weight could be fishing weight or another object with a knob on it or students will have to devise a way to have a attach the ball to the string such as holding it in a paper cup)

◆ **Procedure**

1. Show students the student reference sheets. These may be read in class or provided as reading material for the prior night's homework.
2. To introduce the lesson, consider asking the students how important it is to have a way to accurately measure time. Ask them to observe all the different types of clocks and time measuring devices they have at school and at home.
3. Teams of 3-4 students will consider their challenge, conduct research into how pendulums operate.
4. Teams then consider available materials and develop a detailed drawing showing their pendulum clock including a list of materials they will need to build it.
5. Students build their clock, and test it, and also observe the clocks developed and tested by other student teams.
6. Teams reflect on the challenge, and present their experiences to the class.

◆ **Time Needed**

Two to three 45 minute sessions.

◆ **Notes:**

- For younger students, simplify the lesson by having the string/wire taped or tied to a chair frame, and just have them observe and record with a stopwatch the constancy of the pendulum motion.
- For older students, require a gear system or escapement, so the pendulum is a working part of a larger mechanism.

Pendulum Time

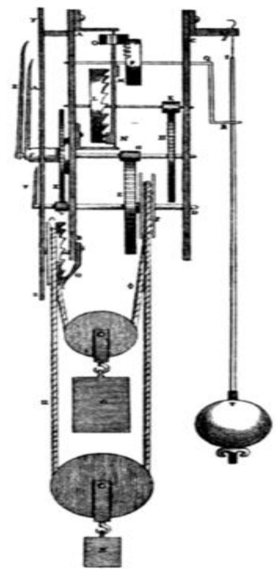
Student Resource: History of Pendulums

◆ What is a Clock?

All clocks must have two basic components:

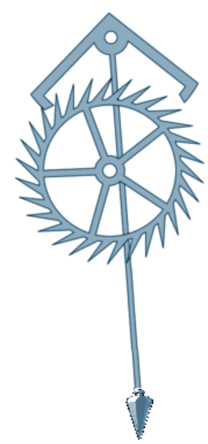
- a regular, constant or repetitive process or action to mark off equal increments of time. Early examples of such processes included the movement of the sun across the sky, candles marked in increments, oil lamps with marked reservoirs, sand glasses (hourglasses), and in the Orient, knotted cords and small stone or metal mazes filled with incense that would burn at a certain pace. Modern clocks use a balance wheel, pendulum, vibrating crystal, or electromagnetic waves associated with the internal workings of atoms as their regulators.
- a means of keeping track of the increments of time and displaying the result. Our ways of keeping track of the passage of time include the position of clock hands and digital time displays.

◆ Pendulum History



In 1656, Christiaan Huygens, a Dutch scientist, made the first pendulum clock, regulated by a mechanism with a "natural" period of oscillation. (Galileo Galilei is credited with inventing the pendulum-clock concept, and he studied the motion of the pendulum as early as 1582. He even sketched out a design for a pendulum clock, but he never actually constructed one before his death in 1642.) Huygens' early pendulum clock had an error of less than 1 minute a day, the first time such accuracy had been achieved. His later refinements reduced his clock's error to less than 10 seconds a day. In 1721, George Graham improved the pendulum clock's accuracy to 1 second per day by compensating for changes in the pendulum's length due to temperature variations.

◆ Escapement



In mechanical watches and clocks, an escapement is a device which converts continuous rotational motion into an oscillating or back and forth motion. It is the source of the "ticking" sound you hear from some clocks. An escapement drives the timekeeping element, usually a pendulum or balance wheel, in a clock or watch. It is powered by a coiled spring or a suspended weight that rotates a gear train. The escapement, controlled by the periodic swing of the pendulum or balance wheel, regulates the motion of the pendulum and allows the gears to advance or "escape" a fixed amount with each swing -- this moves the timepiece's hands forward at a steady rate. A second function of the escapement is to keep the pendulum or balance wheel moving by giving it a small push with each swing. With each swing of the pendulum, one of its arms releases one tooth of a gear and then another tooth on the gear strikes the opposite arm of the pendulum, which stops the gear again.

(Note: some source on this page is from National Institute of Standards and Technology (NIST), an agency of the U.S. Department of Commerce)

Student Resource: Advances in Timekeeping

◆ **Quartz Clocks**

Quartz crystal oscillators and clocks, developed in the 1920s and onward, eventually improved timekeeping performance far beyond that achieved using pendulum and balance-wheel escapements. Quartz clock operation is based on the piezoelectric property of quartz crystals. If you apply an electric field to the crystal, it changes its shape, and if you squeeze it or bend it, it generates an electric field. When put in a suitable electronic circuit, this interaction between mechanical stress and electric field causes the crystal to vibrate and generate an electric signal of relatively constant frequency that can be used to operate an electronic clock display.

Quartz crystal clocks were better because they had no gears or escapements to disturb their regular frequency. Even so, they still relied on a mechanical vibration whose frequency depended critically on the crystal's size, shape and temperature. Thus, no two crystals can be exactly alike, with just the same frequency. Such quartz clocks and watches continue to dominate the market in numbers because their performance is excellent for their price. But the timekeeping performance of quartz clocks has been substantially surpassed by atomic clocks.

◆ **Atomic Clocks**

Each chemical element and compound absorbs and emits electromagnetic radiation at its own characteristic frequencies. These resonances are inherently stable over time and space. An atom of hydrogen or cesium here today is (so far as we know) exactly like one a million years ago or in another galaxy. Thus atoms constitute a potential "pendulum" with a reproducible rate that can form the basis for more accurate clocks. In 1949, NIST built the first atomic clock, which was based on ammonia. However, its performance wasn't much better than the existing standards, and attention shifted almost immediately to more promising atomic-beam devices based on cesium. The cesium atom's natural frequency was formally recognized as the new international unit of time in 1967: the second was defined as exactly 9,192,631,770 oscillations or cycles of the cesium atom's resonant frequency, replacing the old second that was defined in terms of the Earth's motions. The second quickly became the physical quantity most accurately measured by scientists.

Other kinds of atomic clocks have also been developed for various applications; those based on hydrogen offer exceptional stability, for example, and those based on microwave absorption in rubidium vapor are more compact, lower in cost, and require less power.

Much of modern life has come to depend on precise time. The day is long past when we could get by with a timepiece accurate to the nearest quarter-hour. Transportation, communication, financial transactions, manufacturing, electric power and many other technologies have become dependent on accurate clocks. Scientific research and the demands of modern technology continue to drive our search for ever more accurate clocks.

(Source: National Institute of Standards and Technology (NIST), an agency of the U.S. Department of Commerce)

Student Resource: All About Patents

◆ **What Is a Patent?**
A patent for an invention is the grant of a property right to the inventor, issued by a country's Patent and Trademark Office. The procedure for granting patents, the requirements placed on the patentee, and the extent of the exclusive rights vary widely between countries according to national laws and international agreements. In the United States, the term of a new patent is 20 years from the date on which the application for the patent was filed or, in special cases, from the date an earlier related application was filed, subject to the payment of maintenance fees. *Utility patents* protect useful processes, machines, articles of manufacture, and compositions of matter. Some examples: fiber optics, computer hardware, medications. *Design patents* guard the unauthorized use of new, original, and ornamental designs for articles of manufacture. The look of a specific athletic shoe or a bicycle helmet are protected by design patents. *Plant patents* are the way we protect invented or discovered asexually reproduced plant varieties. Hybrid tea roses, Silver Queen corn, and Better Boy tomatoes are all types of plant patents.

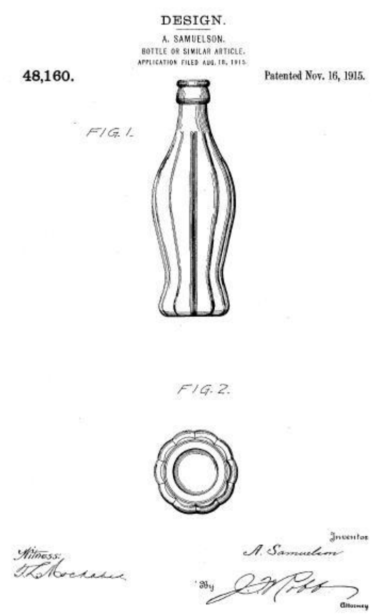
◆ **Famous Patents**

Safety Pin: The patent for the "safety pin" was issued on April 10, 1849 to Walter Hunt, of New York. Hunt's pin was made from one piece of wire, which was coiled into a spring at one end and a separate clasp and point at the other end, allowing the point of the wire to be forced by the spring into the clasp.

Dishwasher: A patent for the first practical dish washing machine was issued December 28, 1886 to Josephine Garis Cochran of Shelbyville, Illinois. She was wealthy, entertained often, and wanted a machine that could wash dishes quickly, and without breaking them. When she couldn't find one, she built it herself.

◆ **How to Register a Patent**

Each country, or sometimes a region has its own patent procedures. For example, in Europe, there is the European Patent Office; in the United States, the U.S. Patent and Trademark Office manages the patent process. Wherever you are, you have to design your product on paper or on a computer and specifically show why your design is different from others. On the left is one of the first drawings of the Coca Cola bottle, and on the right, is a copy of the patent design. You also need to check to see if someone else has already invented what you think you did! Try searching for a trademark at www.uspto.gov/patents.



Pendulum Time

Student Worksheet: Build a Pendulum Clock

◆ Research and Planning

You are part of a team of engineers who have been given the challenge of building a working clock based on a pendulum. You'll need to be able to set the clock at two speeds, and will have to figure out how to adjust the materials you are using to make the clock run faster and slower. You'll use every day items such as string attached to a rubber ball to serve as your pendulum. How you design your clock and what materials you use are up to you!

Read the handouts provided to you by your teacher, and if you also have access to the internet visit one of these sites to gain more understanding in the history and operations of pendulum clocks:

- A Walk Through Time (www.nist.gov/pml/general/time/)
- Clockworks -- from Sundials to the Atomic Second (www.britannica.com/clockworks/startpage.html)

◆ Parts of a Pendulum

A pendulum is relatively simple, and consists of only a few components: a length of string or wire, a bob or some type of weight, and a fixed point where it is attached to a solid object. Remember that a string may swing in various directions, but for the clock, you'd want to fix it to something, or use another material to keep the motion along a single plane -- back and forth, not wobbling.

◆ Design Phase

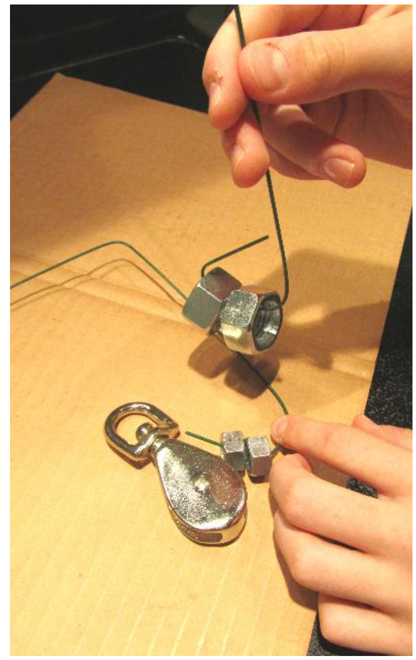
You have been provided with many materials from which to design and build your own pendulum clock. Remember that your clock doesn't need to be perfect, but does need to be able to measure time fairly consistently. You can keep a chart or measurements of the "period of the pendulum" -- which is the amount of time that it takes a pendulum to complete one full back-and-forth swing. Consider which materials you would like to use, and list them in the box below. On a separate piece of paper, draw a diagram of the clock you intend to build.

Parts Required:

Student Worksheet: Build a Pendulum Clock

◆ **Measurement Phase**
Measure the length of string you plan to use to attach your weight to in order to form a pendulum. You'll need to keep track of this when you are adjusting the speed at which your pendulum moves. You may wish to weigh your pendulum weight as well to help you set your clock to work at two different speeds

◆ **Build it! Test it!**
Next build your clock and test it. You'll need to be able to record time with your clock and set up your own scale or chart to keep track of the pendulum movements. Use a stop watch to see how many swings of the pendulum occur in 10 seconds. You'll also need to speed up or slow down your clock. (Hint: adjusting the length of string attached to the pendulum might assist with this task.) You may share unused building materials with other teams -- and trade materials too. Be sure to watch what other teams are doing and consider the aspects of different designs that might be an improvement on your team's plan.



◆ **Reflection**
Complete the reflection questions below:

1. How similar was your original design to the actual clock your team built?

2. If you found you needed to make changes during the construction phase, describe why your team decided to make revisions.

3. Was your clock able to measure time at two different speeds? What measurement scale did you devise to measure time with your clock?

4. Which clock that another team made was the most effective or interesting to you? Why?

5. Do you think that this activity was more rewarding to do as a team, or would you have preferred to work alone on it? Why?

6. If you could have used one additional material (tape, glue, wood sticks, foil -- as examples) which would you choose and why?

For Teachers:
Alignment to Curriculum Frameworks

Note: All lesson plans in this series are aligned to the National Science Education Standards which were produced by the National Research Council and endorsed by the National Science Teachers Association, and if applicable, also to the International Technology Education Association's Standards for Technological Literacy or the National Council of Teachers of Mathematics' Principles and Standards for School Mathematics.

◆National Science Education Standards Grades K-4 (ages 4-9)

CONTENT STANDARD A: Science as Inquiry
As a result of activities, all students should develop
- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

CONTENT STANDARD B: Physical Science
As a result of the activities, all students should develop an understanding of
- Properties of objects and materials
- Position and motion of objects

CONTENT STANDARD E: Science and Technology
As a result of activities, all students should develop
- Abilities of technological design
- Understanding about science and technology

CONTENT STANDARD F: Science in Personal and Social Perspectives
As a result of activities, all students should develop understanding of
- Science and technology in local challenges

CONTENT STANDARD G: History and Nature of Science
As a result of activities, all students should develop understanding of
- Science as a human endeavor

◆National Science Education Standards Grades 5-8 (ages 10-14)

CONTENT STANDARD A: Science as Inquiry
As a result of activities, all students should develop
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

CONTENT STANDARD B: Physical Science
As a result of their activities, all students should develop an understanding of
- Properties and changes of properties in matter
- Motions and forces
- Transfer of energy

CONTENT STANDARD E: Science and Technology
As a result of activities in grades 5-8, all students should develop
- Abilities of technological design
- Understandings about science and technology

CONTENT STANDARD F: Science in Personal and Social Perspectives
As a result of activities, all students should develop understanding of
- Science and technology in society

CONTENT STANDARD G: History and Nature of Science
As a result of activities, all students should develop understanding of
- History of science

For Teachers:
Alignment to Curriculum Frameworks (cont.)

◆National Science Education Standards Grades 9-12 (ages 14-18)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- Abilities necessary to do scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop understanding of

- Motions and forces
- Conservation of energy and increase in disorder
- Interactions of energy and matter

CONTENT STANDARD E: Science and Technology

As a result of activities, all students should develop

- Abilities of technological design
- Understandings about science and technology

CONTENT STANDARD F: Science in Personal and Social Perspectives

As a result of activities, all students should develop understanding of

- Personal and community health
- Science and technology in local, national, and global challenges

CONTENT STANDARD G: History and Nature of Science

As a result of activities, all students should develop understanding of

- Historical perspectives

◆Standards for Technological Literacy - All Ages

The Nature of Technology

- Standard 1: Students will develop an understanding of the characteristics and scope of technology.
- Standard 3: Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

Technology and Society

- Standard 4: Students will develop an understanding of the cultural, social, economic, and political effects of technology.
- Standard 6: Students will develop an understanding of the role of society in the development and use of technology.
- Standard 7: Students will develop an understanding of the influence of technology on history.

Design

- Standard 8: Students will develop an understanding of the attributes of design.
- Standard 9: Students will develop an understanding of engineering design.
- Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

Abilities for a Technological World

- Standard 11: Students will develop abilities to apply the design process.
- Standard 12: Students will develop abilities to use and maintain technological products and systems.
- Standard 13: Students will develop abilities to assess the impact of products and systems.