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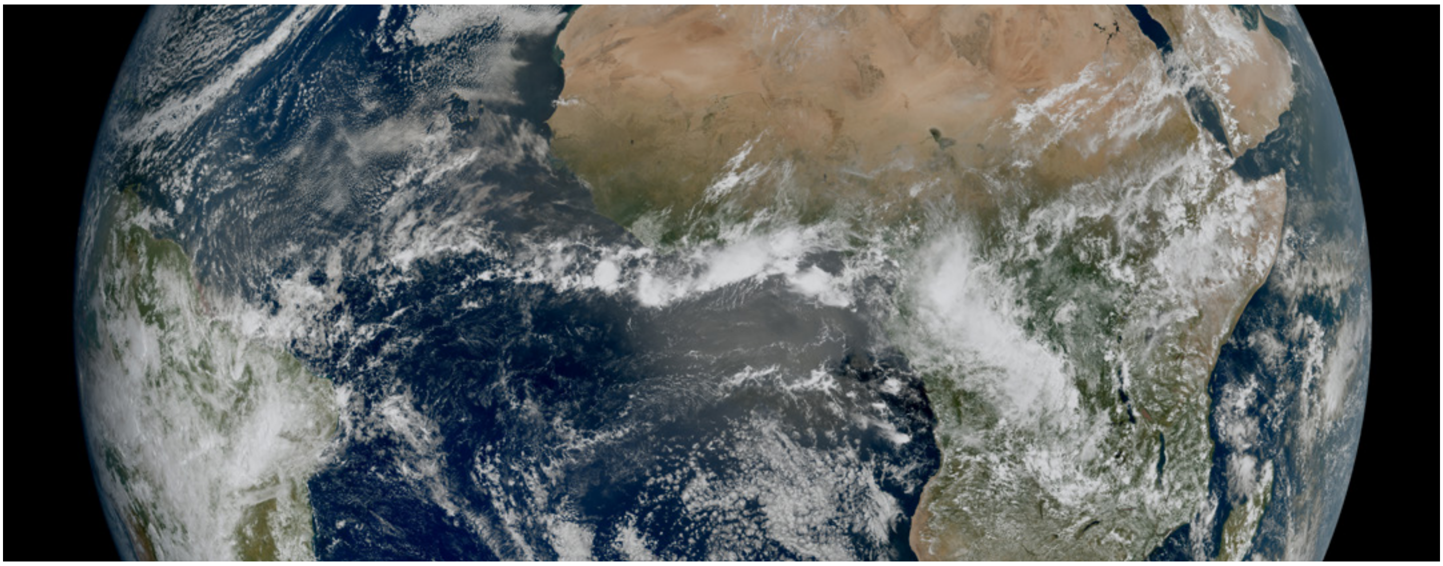


Image: ESA

The Eratosthenes experiment: calculating the Earth's circumference

Sevasti Malamou, Vasileios Kitsakis

On the shoulders of giants: follow in the footsteps of Eratosthenes and measure the circumference of the Earth like he did 2300 years ago.

The following learning scenario is made for secondary school students that are familiar with the concepts of equal angles, from geometry, and tangents, from trigonometry. Moreover, it can also be adjusted for primary school students not familiar with trigonometry: they can make measurements like Eratosthenes did and leave advanced calculations for the teacher.

Brief description

Students can measure the Earth's circumference like Eratosthenes did approximately 2300 years ago using simple materials and a stick's shadow made by the Sun. Even though there is a high probability that the measurement will not approximate the true value of the Earth's circumference, like we know it today, the measuring itself provides a basis for simple mathematical reasoning and scientific thinking.

Ideally, the experiment should take place on the March or September equinoxes on a sunny, or almost sunny, day. Before starting to measure the Earth's circumference, students should learn about Eratosthenes, his life, work, and the way he calculated the circumference of the Earth.

Learning objectives

- Describe the geometry of sunlight towards Earth (sunrays are parallel when falling to Earth)
- Understand that equinoxes and solstices are due to the Earth's movement
- Realize the geographic coordinate system of Earth: latitude and longitude
- Describe how Eratosthenes measured the circumference of the Earth
- Measure angles and distances
- Compare angles and triangles
- Explain measurement errors and suggest ways to minimize them
- Collaborate with other schools on the same longitude

Optional introductory activity: Who was Eratosthenes? Why is his experiment so important nowadays?

Although it seems a simple and easy experiment, it takes time for students to really understand geometry, the direction of the Sun towards Earth on specific days, and the logical sequence of Eratosthenes' thoughts.

The goal is not simply to measure the length of the stick and its shadow, but to understand Eratosthenes' logic behind these simple measurements, and thus, highlight his ingenuity, since almost 2300 years ago he calculated the circumference of the Earth with relatively great accuracy.

We recommend carrying out the introductory activity, so that students understand the importance of Eratosthenes' experiment, the era during which he did his experiment, what helped him to reach to his conclusions, and the way he managed to accomplish his experiment.

Activity 1: Identify the exact time of the measurement

Before implementing the experiment, which is actually to measure distances and make calculations, we must first determine when the Sun reaches its highest point in the sky on the day of the equinox; what we call local noon (or zenith). This time differs for each school and depends on the school's position on the globe and should be determined with the best accuracy possible. At this specific time, sunrays fall perpendicularly on the equator, and they are parallel to the equatorial plane, so a vertical bar will have no shadow. On the other hand, in our place at this specific time, a vertical bar will have a shadow.

A calculator tool that can be used is SunCalc. The position and date have to be filled in for the Sun's culmination time to be calculated. At this exact time on the day of the equinox, students have to measure the stick's length and its shadow.

This activity only takes a few minutes, but it is also recommended to do the introductory activity to set the context. It should be possible to do the introductory activity and Activities 1 and 2 in one lesson; these should be completed a few days before the measurement lesson on the equinox (Activity 3).

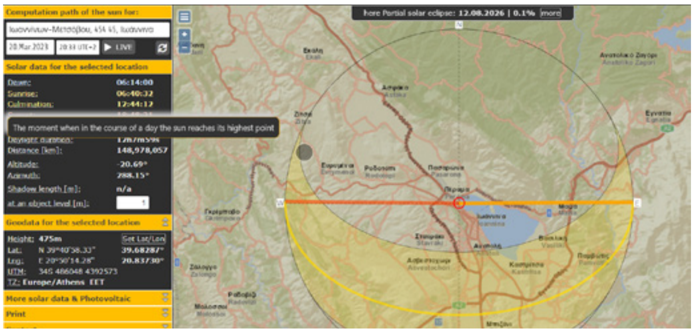
Materials

- Internet connection and a suitable device (PC, laptop, tablet, smartphone)

Procedure

At least 1–2 days before the equinox (when the measurements will be made), you should:

1. Explain the experiment (ideally using the introductory activity).
2. Tell your students that many schools are doing this experiment on this specific day.
3. Split your class into groups of two students and let them run the web tool SunCalc in the computer lab or use tablets.



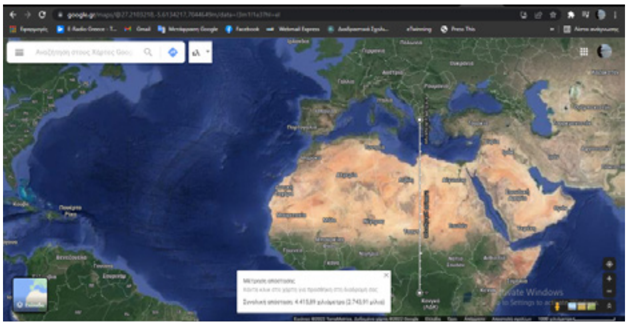
Determination of the exact time for the experiment using SunCalc. In the application, you can choose your location and date, and then it calculates the exact culmination time.
Image: SunCalc.org ©Torsten Hoffmann 2015–2023

4. Ask your students to:
    - Find their city/village and school on the map
    - Select the required date that the measurements are going to be made (equinoxes are preferred)
    - Write down the culmination time

Alternatively, if you don't have enough time or equipment, you can demonstrate the procedure.

Results

Finding the zenith time for the Sun should only take a few minutes. You can also use the application as a learning object for students and ask them to investigate different sundial characteristics. The tool gives the chance to understand the concept of noon during the year. Students can change the date, and then see the culmination time for each date. Solstices and equinoxes are dates that should be investigated. Local noon is in the midpoint between sunrise and sunset times, and it depends on the latitude and date during the year.



Measuring the distance between your school and the equator using the Google Earth application. Alternatively, it can be measured using Google Maps.

Activity 2: Identify the school's coordinates

At least one day before the experiment, students should identify the school's coordinates using online tools. What is to be measured is the distance in kilometres from the schoolyard to the equator along the school's meridian, which is going to be a curved line, following the Earth's curvature. All points along this meridian have the same longitude.

Eratosthenes knew the distance between Alexandria and Syene (nowadays Aswan) in stadia (an ancient unit of length). Nowadays, we can measure the distance using electronic applications. You could also get a distance estimate using a real map and a ruler, just like students used to calculate real distances years ago. Especially for younger students, it would be a great chance to refresh their knowledge of map scales. The measurement won't be as accurate as the one with online tools, but it is a simple estimation.

This activity should only take 10 min.

Materials

- Internet connection and a suitable device (PC, laptop, tablet, smartphone)
- Video on how to measure the distance from your school to the equator
- Alternatively, a map and a ruler

Procedure

1. Use a smartphone with a location function.
2. Write down the latitude and longitude of the schoolyard.
3. Measure the distance from your school to the equator. For this step, Google Maps or Google Earth can be used, as shown in the video.
4. Write down the distance in kilometres. This information is what students need for their calculations.

Activity 3: Measure like Eratosthenes on the equinox

The day that everyone was expecting has arrived. The teacher has to organize all the required materials before the time that the Sun reaches its highest point. Everything should be prepared in advance because, once the Sun reaches its zenith, there is no time to lose. Students have to act quickly, and they have to know exactly what to do.

Materials

- Linear sticks (approximately 1 m long is ideal)
- Right-angle triangles, plumb bobs, carpenter's levels, or an object that has a right angle to ensure verticality
- Metre sticks or tape measures
- Pencils
- Clock accurate to the minute (or a smartphone)
- Student worksheet

Procedure

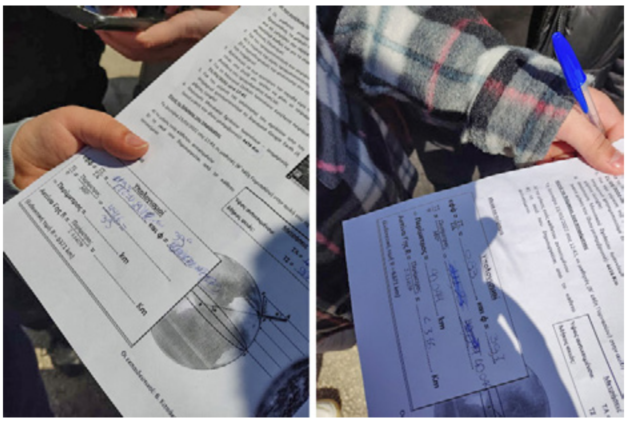
1. To measure the length of the sticks when the Sun is overhead, supply students with the necessary materials and worksheet a short time before the measurement time.
2. Go with your students into the schoolyard at least 10–15 min before the zenith time for your latitude.
3. Split the class into groups of four.
4. Ask each member of the group to take on a specific role. Student 1 will be responsible for the time, student 2 will act as a scribe and record the measurements, and students 3 and 4 will do the measurements.
5. Make sure that each group has a set of materials (a linear stick, a metre stick, a right-angle triangle, a pencil, a clock, and a worksheet).
6. Ask students to measure the length of the stick before the zenith time and write their measurements on the worksheet.
7. About 2–3 min before the zenith time, ask students to place and hold the sticks vertically.
8. Use the right-angle triangle to make sure that the sticks are vertical. Check that all groups achieve verticality.

9. When the Sun reaches its highest point in the sky, ask students to measure the stick's shadow on the ground and write its value on the worksheet.
10. If students don't manage to measure the stick's length before the zenith time, or if they want to be sure about it, they can measure it again after the local noon time.

Verticality and stick-shadow measurements
Image courtesy of Sevasti Malamou and Vasileios Kitsakis

Results

After measuring the two lengths (stick length and shadow length) and writing the values on the worksheet, data processing begins. Calculations can be done in the schoolyard, with students working in groups and comparing their results with their classmates. Alternatively, if there is a lack of time, calculations can be done in the classroom at another time. Students can use scientific calculators (or the one on their smartphones) to calculate the angle θ.



Student calculations
Image courtesy of Sevasti Malamou and Vasileios Kitsakis

Extension activities

There are several extension activities that can be done to make the learning experience more meaningful, such as calculating the radius of the Earth and collaborating with another school. These are described fully in the supporting material.

Discussion

When doing the calculations and exporting the results, you could use the following questions as the basis for a discussion:

- What could be the measurement errors during the experiment?
- What can be done to minimize errors?
- What errors could have been made by Eratosthenes when he performed his own experiment 2300 years ago? To answer this, the globe could be used, with pins on Alexandria and Syene. Alternatively, students can observe the two cities on Google Earth.
- Angle θ, calculated during the experiment, also represents what?
- If you do the experiment during the summer/winter solstice, what would you change? Explain.
- Why did Eratosthenes make his measurements during the summer solstice? Could he do it on the spring or autumn equinoxes? Explain.

As a conclusion, you can emphasize to your students that science often develops from a simple idea and an inquisitive mind. «

References

[1] Panhellenic Union of Heads of Laboratory Centers of Natural Sciences (Greek language): https://panekfe.gr/eratosthenes/

Resources

- Find more teaching resources relating to the Eratosthenes experiment on the Eratosthenes.eu website.
- Read more about the life and work of Eratosthenes of Cyrene.
- Watch a video about Eratosthenes by Carl Sagan.

- Explore data visualization by sketching graphs from story videos of everyday events: Reuterswärd E (2022) Graphing stories. *Science in School* **58**.
- Discover how physicists study very small and large objects that cannot be directly observed or measured: Akhobadze K (2021) Exploring the universe: from very small to very large. *Science in School* **55.**
- Get your students to use their smartphones for some hands-on astronomy: Rath G, Jeanjacquot P, Hayes E (2016) Smart measurements of the heavens. *Science in School* **36**: 37–42.
- Measure distances to the stars like real astronomers with this classroom activity: Pössel M (2017) Finding the scale of space. *Science in School* **40**: 40–45.
- Measure the distance between Earth and the Moon with the help of radio signals: Middelkoop R (2017) To the Moon and back: reflecting a radio signal to calculate the distance. *Science in School* **41**: 44–48.

AUTHOR BIOGRAPHY

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