Orienting & Asking questions

Orienting: Provide contact with the content and/or provoke curiosity:

- Did you ever wonder how huge Earth is compared to us?

- Since Earth is so big, do you think it is possible to measure the size of the Earth without using satellites?
- How about doing it here in our school by just using a stick, do you think it's possible?

Teacher Guideline

Use "Google Earth " to make a small demonstration to the children. The purpose of this demonstration is to impress children by showing them how small we are in comparison to Earth's size.

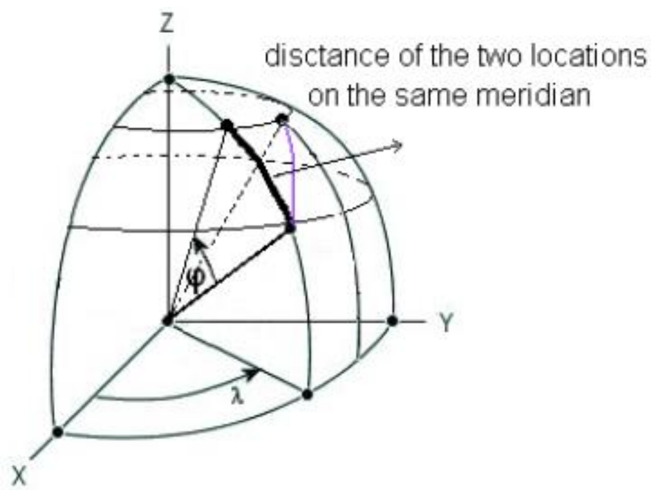
Inform the students that Eratosthenes measured the Earth's circumference 2,200 years ago by just using a stick and the Sun's location.

Define goals and/or questions from current knowledge

- So how do we know the Earth is round?

Since Earth is round, its perimeter corresponds to a circle.

- How many degrees are there in a full circle?
- What is the arc of a circle?
- Can we calculate the whole perimeter, if we know the length of the arc that corresponds to a given angle?
- If we have two locations on Earth, what does the angle between them correspond to
- How can we measure it?



- How many cars do you think are approximately required to circle the Earth at the equator? (1 car has approximately 4m length)
  a) 1 million
  b) 10 million
  c) 100 million
  d) 1 billion

  Note: All the knowledge questions provided here will be also available online

Teacher Guideline

Explain to the students, how Aristotle came to the conclusion that Earth is a sphere by looking at the shadow it casts on the moon.
Present how the angular distance between two locations can be measured. Students need to understand the main idea that if we now the angle and the arc corresponding to this angle, we can calculate the whole circumference.
Students need to understand that in order to do the calculation we need to define the angular distance between the two locations.

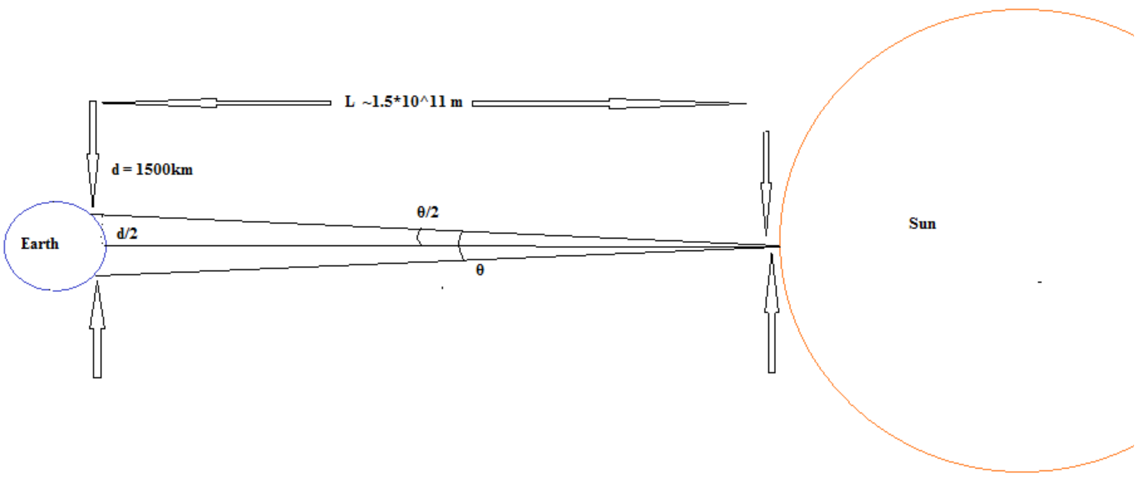
Eratosthenes assumed that sun rays are parallel. However, when we draw the sun we present it as a small yellow disk with divergent rays coming out of it. Which of the following is correct?

a) The rays are parallel, because the sun is very far from earth
b) The rays are divergent because the sun is considered as a point source

Teacher Guideline

The question is mainly Geometry and trigonometry oriented:

The earth- sun distance is 1 Astronomical Unit (). Also, the sun is an extended light source and not a point source.
Let's pick 2 places into earth's surface with distance ~1500 km (see picture)



We have :

$$\tan\left(\frac{\theta}{2}\right) = \frac{\frac{d}{2}}{L}$$

$$d << L \rightarrow \ : \tan\left(\frac{\theta}{2}\right) \sim \frac{\theta}{2} \quad \text{(measured in radians)}$$

$$\text{Thus: } \frac{\theta}{2} = \frac{d}{2L} \rightarrow \theta = \frac{d}{L} \rightarrow \theta = \frac{1.5*10^{3}}{1.5*10^{11}} \rightarrow \theta = 10^{-8} rad$$

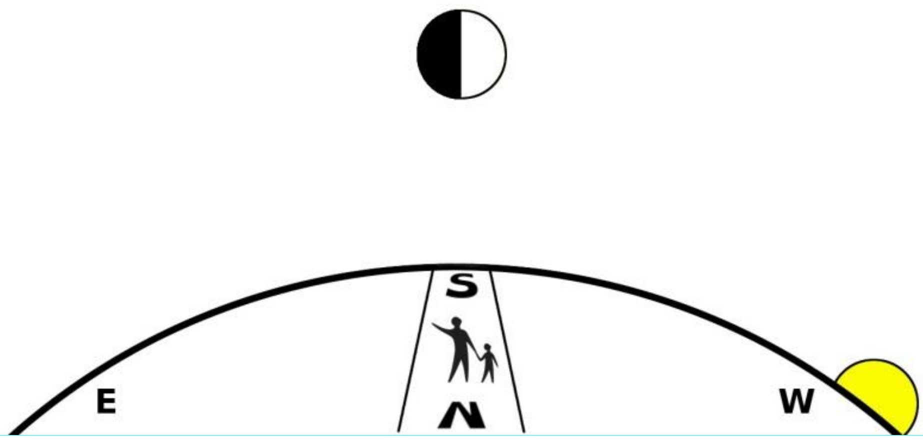
Since the angular opening of the rays is close to zero, we can consider them as parallel. This happens due to the great difference between the distances on earth compared to the earth-sun distance.

How did Eratosthenes know about the sun’s rays being parallel?

Eratosthenes famously observed that the sun’s rays were perpendicular to the ground in one location, yet non-perpendicular to the ground at a location some miles to the north. On the assumption that the sun's rays are all parallel, this means the earth is round (or at least not flat).

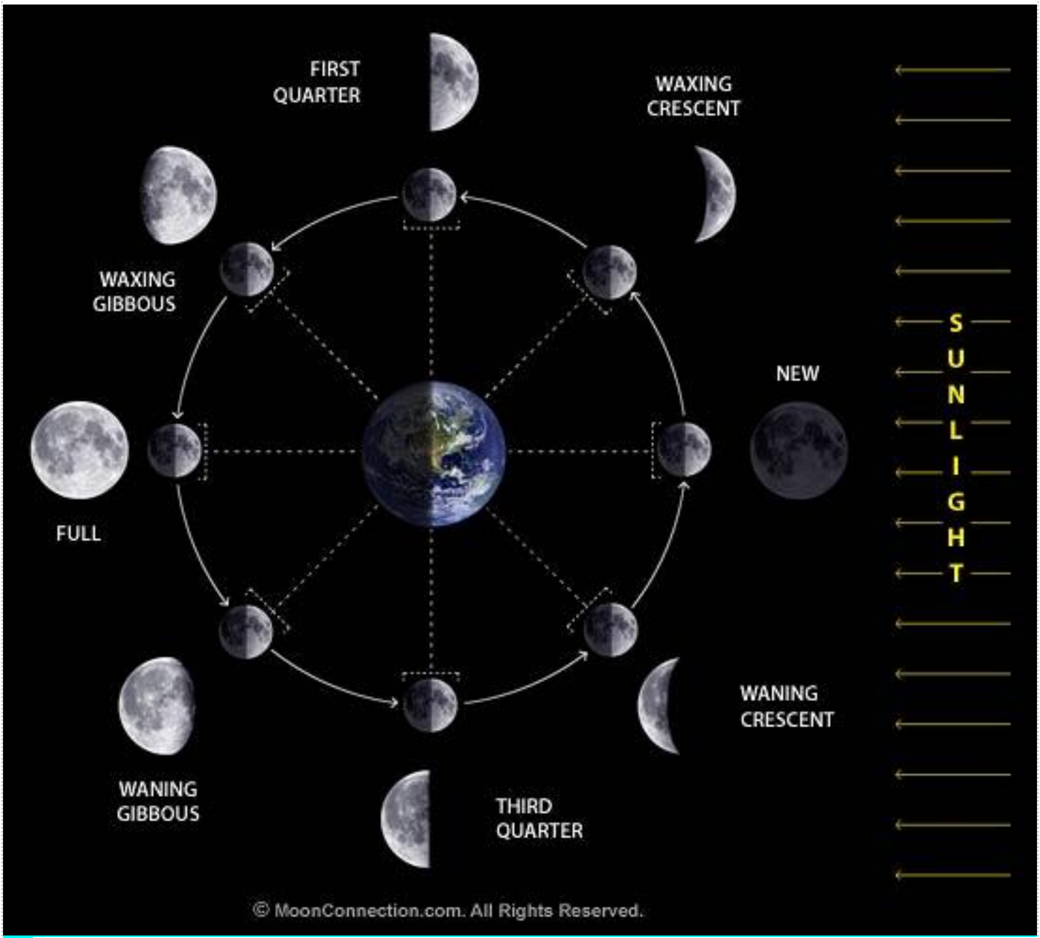
But how do we know the sun's rays are parallel? The rays of light from my desk lamp aren't parallel by the time they reach my desk. The spot directly below the lamp is hit perpendicularly, but the edge of the desk is hit obliquely. The issue is clearly determining whether or not the sun is far enough away that its rays can be assumed to be parallel. But how can we know that?

There's actually at least one very big clue that's been accessible to skygazers since the earliest times: the first quarter moon at dusk. Every child in the northern hemisphere going back to 30,000 BCE likely would have been familiar with how 1st-quarter moons always tend to rise at noon, reach its highest point at sunset (with an azimuth directly south), and set at midnight.



Form a triangle out the observer, the sun and the moon: ∆OSM. The only angle the observer can measure directly is of course the angle between the sun and moon, the observer forming the vertex. The sun is in the direction of the horizon, and the 1st-quarter moon is near zenith, hence $\angle SOM \approx 90°$.

The angle with vertex at the moon, $\angle OMS$, couldn't be measured in general, but it doesn't take too much imagination to infer that the shape of the sunlit portion of a 1st-quarter moon results whenever $\angle OMS \approx 90°$. Hence, ∆OSM is an acute, nearly isosceles right triangle, whose legs are practically parallel and much, much greater in length than the base. This small base length is the earth-moon distance $|OM|$ is itself much greater than any terrestrial distances we measure on the Earth's surface. Thus, with extremely little effort we can be reasonably confident that Eratosthenes' condition of parallel sunlight rays holds to good enough approximation for the purpose of his measurements (uncertainties in the measurements of distances between cities would have been the limiting factor towards overall precision anyway).



What is a local noon? How does it change over the year?

a) The local noon is at 12.00 local time . It doesn't change with respect to the location of a place.

b) The local noon is the mid-time between sunrise and sunset. As the duration of the day grows the local noon shifts to later hours.

Teacher Guideline

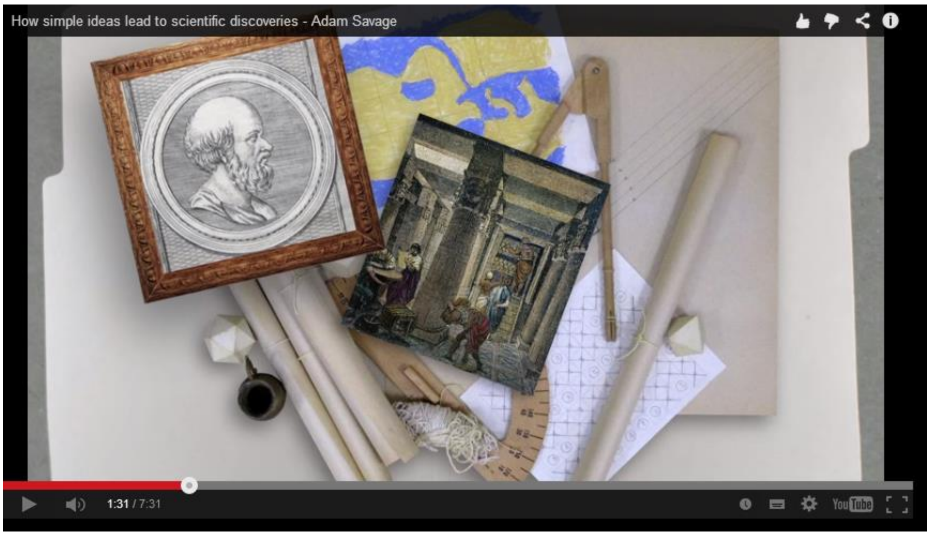
Local noon is the median between sunrise and sunset.
Latitude affects how up in the sky is the sun, whereas longitude affects the time of the local noon due to time zone difference.Moreover, to locate the local noon you can see at what time the shadow of the rod is the smallest during Eratosthenes's experiment.

Hypothesis generation & Design

Generation of Hypotheses or preliminary explanations

Following the ideas we discussed above, can you come up with a plan on how to measure Earth's circumference:

Let's see how Eratosthenes did it!



Eratosthenes` experiment was based on a chance observation that in Syene the sun was reflected on the surface of a deep well at midday, while at the same time an obelisk in Alexandria projected a small shadow.

Since Eratosthenes knew that Earth is a sphere, why was he puzzled by this observation?

Teacher Guideline

If the earth is a sphere, this observation could be possible becuauuse sunrays that reach the earth are parallel

Ask students to write down their ideas.

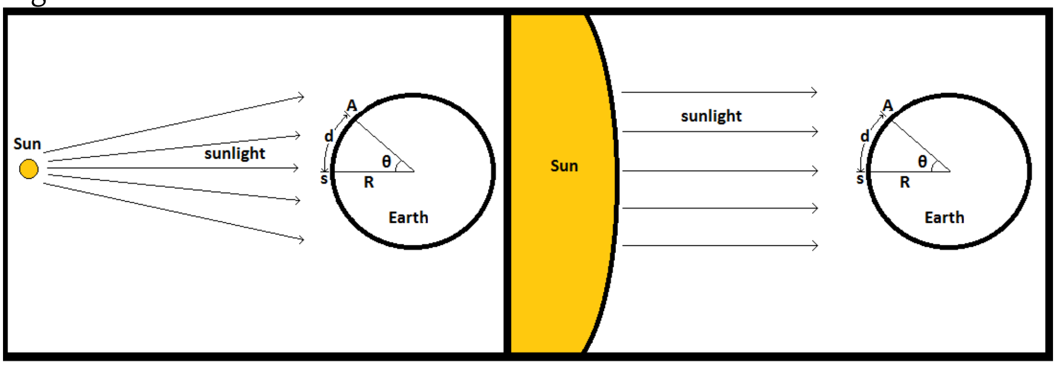
https://www.ted.com/talks/how_simple_ideas_lead_to_scientific_discoveries
01:31 - 03:40

Design/Model
Let's build some models to see how we can do the same observation.

The shape of the Earth:

The left model represents the case of a flat Earth. The model on the right represents the case of a round Earth.

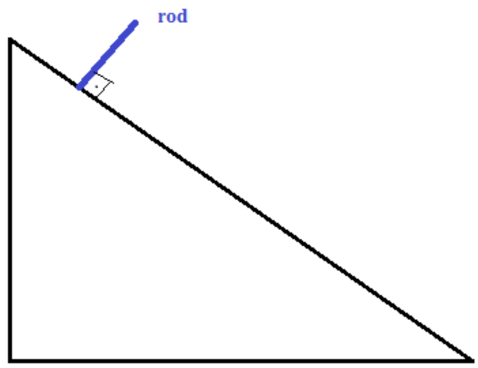
Sunlight:



The left model represents the case of non-parallel sunrays. The model on the right represents the case parallel sunrays. Which one do you think is correct?

After having observed the models, look back at the question and check your answer. Is your answer correct or do you wish to change it?

Look at the image below and answer the following question:



In the activity you have to fix the rod vertically to the ground.
If the location you choose to fix the rod is the slope of a hill and looks like the picture above, will your measurement be accurate?

a) Yes, because the rod is vertical to the ground.

b) No, because the axis of the rod must point to the center of the earth.

Teacher Guideline

This is a physics question. The true answer is the second one. The axis of the rod doesn't point to the center of the earth but is tilted with respect to it.

This is a nice opportunity to engage students in learning about the direction of gravitational force as well as the fact that every location has its own vertical. The vertical is the line that starts from the center of the earth and ends at the respective location. This is the direction of the gravitational force, starting from the place and pointing to the center of the earth as well.

You can use many ways to do this.
For example:
- You can use a simple pendulum. Its axis coincides with the vertical from the place to the earth's center (most common practice for builders), or else there would be torque which would set the pendulum in motion. Therefore the rod of your experiment must be placed parallel to the pendulum's axis.

Planning & Investigation

Plan investigation

Let's see what factors are important for our investigation.

For the time of the experiment we need to:

a) bear in mind the local time of the partner school and to carry out the experiment at the same time
b) bear in mind the local time of the partner school and carry out the experiment when the sun is on the same position at the sky for each school.
c) use sticks of the same length
d) the same number of students carry out the experiment

To measure the distance between the two schools we'll have to:

a) Measure the direct distance between two schools.
b) Measure the distance based on the road network
c) Measure the distance of the schools on the same meridian.

To get good results, the stick should be:

a) hold by hand
b) stick into ground
c) fixed into ground
d) lean on a wall

For the shadow of the stick we need to:

a) take many measurements and calculate the mean value to avoid errors
b) take the shortest value because it has the shortest error
c) take the shortest value because that is when the sun is at its zenith
d) take many measurements and calculate the mean value because I can't know when exactly the sun is at its zenith.

→ Use Google Earth to find out the distance between the two collaborating schools

Perform investigation

- Place the stick in the Sun and make sure it is vertical to the ground.
- Measure the length of the stick (H) and note down your measurement in the table below.
- At the time scheduled to conduct the experiment, measure the length of the stick's shadow. Repeat the measurement 5 times and write your values down in the table.

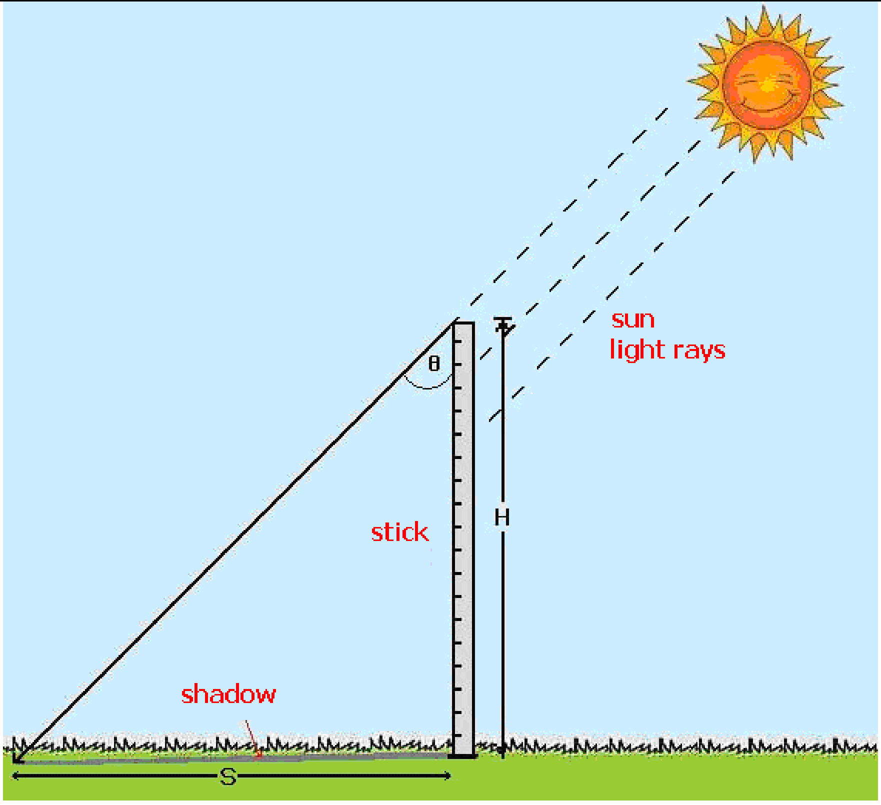


Table of measurement	
Stick length	
Shadow length (1st measurement)	
Shadow length (2nd measurement)	
Shadow length (3rd measurement)	
Shadow length (4th measurement)	
Shadow length (5th measurement)	
Mean shadow length	
Length of triangle's 3rd side	
Distance between schools	

Answer the following questions:

The primary assumptions of Eratosthenes's experiment were that: i) The earth is spherical and , ii) The sun's rays are parallel.
If the earth was flat and the sun's rays would reach the surface of the earth vertically, what would you expect to observe during local noon?

a) The rod would have no shadow no matter what place on earth we placed it.

b) The rod's shadow would be different in various locations.

Let's suppose that we provide you with a rod and ask you to observe the rod shadow during the day.
Can you identify the east-west (and therefore the north-south) orientations?

a) Yes we can, by observing the way the tip of the shadow moves during daytime.

b) No we can't because we don't have a compass.

Teacher Guideline

This question is used to test the spatial thinking of students.

The concept here is to engage them into understanding how a solar compass works.
For a full demonstration, look at this video:
https://www.youtube.com/watch?v=u3l49zQREcY

Analysis & Interpretation

Analysis and Interpretation: Gather result from data

1. Find the shortest value for the length of the shadow.

2. Divide the length of the stick's length, the length of the stick's shadow and the length of the triangle's 3rd side (see table above) with 10.

3. Using the value you calculated at the previous step draw a triangle like the one depicted in the figure above.

4. Using a protractor measure angle θ (see figure above) in the triangle you drew.

Angle (θ): ___________________

5. Note down the angle measured by your fellow students at the other school.

Angle (φ): ___________________

6. Subtract the two angles. The value you'll find corresponds to the angular distance of the two schools.

7. Using proportions calculate the Earth's circumference.

$$\frac{\text{distance between the schools}}{\text{angular distance between the schools}} = \frac{\text{Earth's circumference}}{360^0}$$

Earth's circumference:_____________________________

Conclusion & Evaluation

<u>Conclude and communicate result/explanation:</u>

- What is the Earth's circumference according to your calculations?
- Compare your measurement to the real value for Earth's circumference. Did you get it right?
- Do you think your experiment was successful?

Answer the following questions:

1. Eratosthenes assumed that sun rays are parallel. However, when we draw the sun we present it as a small yellow disk with divergent rays coming out of it. Which of the following is correct?

a) The rays are parallel, because the sun is very far from earth
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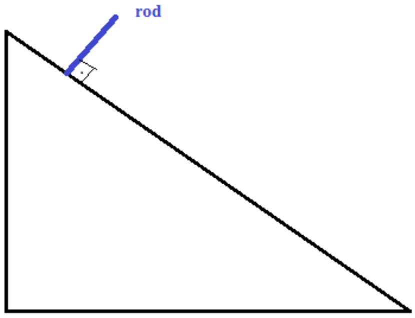
2.What is a local noon? How does it change over the year?

a) The local noon is at 12.00 local time . It doesn't change with respect to the location of a place.

b) The local noon is the mid-time between sunrise and sunset. As the duration of the day grows the local noon shifts to later hours.

**3. In the activity you have to fix the rod vertically to the ground.
If the location you choose to fix the rod is a hill and looks like the following picture, will your measurement be accurate?**



a) Yes, because the rod is vertical to the ground.

b) No, because the axis of the rod must point to the center of the earth.

Evaluation/reflection:

- What sources of error are there? Have they been taken into consideration?
- Is Eratosthenes method accurate?
- If you could repeat the experiment, what would you change?

Consider other explanations

If the Eratosthenes experiment is carried out from one school in Greece and one in Finland whose longitudes are very close, the result would be better than from two schools only in Greece. This is:

a) correct, because the weather in Greece is much better
b) correct, because the greater the distance between the two schools the better the measurement.
c) not correct, because the mountains in between will interfere with the measurement
d) not correct, because the accuracy of the measurement is not affected.

Assessment using provided assessment questions

After students finished the last learning activity they answer a set of multiple choice assessment questions. These questions measure the problem solving skills of the students.

According to the ‘Big Idea’ that is focused in the Demonstrator it is possible to pick at least one matching Assessment Question out of the official catalogue of ISE assessment questions and to create up to three (minimum two) Assessment Questions by your own in order to investigate the problem solving competency of your students. It is possible to immediately compare the results of the students with average PISA results.

There are several ways to assess students’ performance in the Eratosthenes project.

a) Students can prepare a written or oral presentation to a younger student on Eratosthenes’ measurement of the circumference of Earth.
b) Students can prepare a written or oral presentation to a younger student on Eratosthenes’ measurement of the circumference of Earth.
c) Students can prepare a written or oral presentation to a younger student on Eratosthenes’ measurement of the circumference of Earth.