ASTROEDU

Peer-reviewed Astronomy Education Activities

# The Quest for Longitude

## How to navigate at sea like an explorer?

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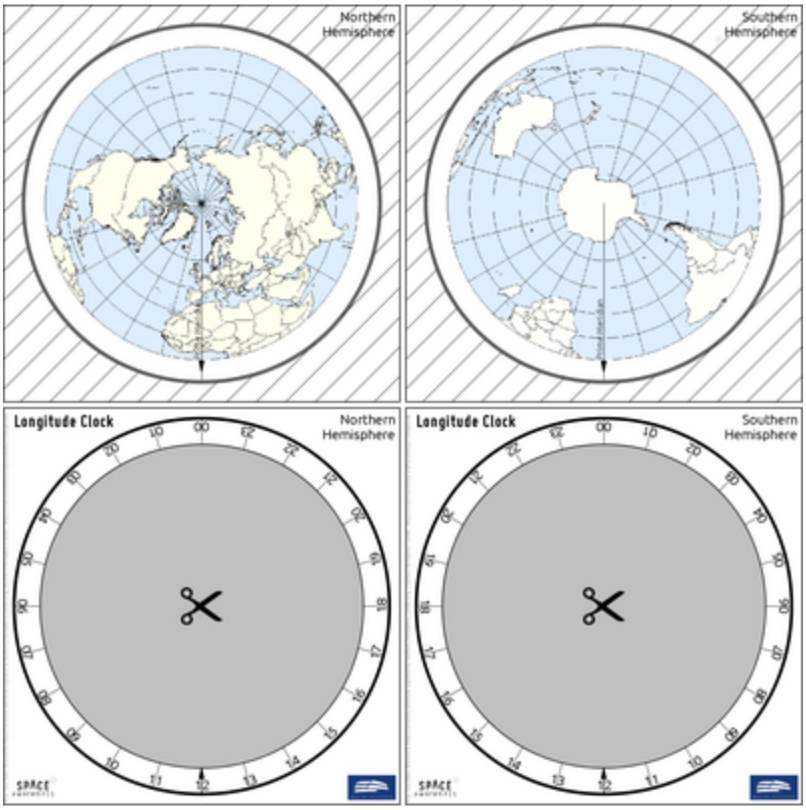



KEYWORDS

Meridian, Longitude, Earth, Geography, Latitude, Celestial Navigation, Astronomy, History, Equator, Countries, Sun, Clocks, John Harrison, Navigation, James Cook, Exploration

CATEGORY

Astrometry and celestial mechanics

LOCATION

Small Indoor Setting (e.g. classroom)

AGE

16 - 19 14 - 16

LEVEL

Middle School

### TIME

2h

### GROUP

Group

### SUPERVISED

Yes

### COST

Low Cost

### SKILLS

Asking questions, Developing and using models, Planning and carrying out investigations, Analysing and interpreting data, Using mathematics and computational thinking, Communicating information

### TYPE OF LEARNING

Structured-inquiry learning, Discussion Groups, Modelling

## GOALS

With this activity, the students will learn that - determining longitude reliably was a serious problem in marine navigation in the 17th and 18th centuries, during which time a large number of ships were lost at sea. - longitude can be derived from time measurements. - the astronomical (local) noon does not coincide with noon on the clock. - with John Harrison as a role model, persistence and conviction toward achieving a goal can lead to great achievements.

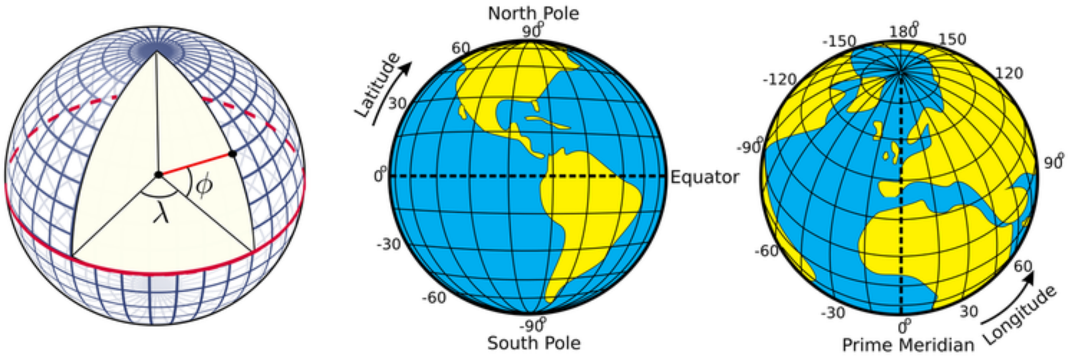
## LEARNING OBJECTIVES

Students will be able to - explain how time is related to the rotation of the Earth. - explain why determining the longitude on the open sea had been difficult for centuries. - determine the longitude based on time measurements. - describe basic navigational skills used during the Age of Exploration. - name the English clockmaker who managed to build the first reliable marine chronometer.

## BACKGROUND

### Latitude and longitude

**Figure 1:** Illustration of how the latitudes and longitudes of the Earth are defined (Credits: Peter Mercator, djexplo, CC0).




Any location in an area is defined by two coordinates. The surface of a sphere is a curved area, but using coordinates like up and down does not make much sense, because the surface of a sphere has neither a beginning nor an ending. Instead, we can use spherical polar coordinates originating from the centre of the sphere, where the radius is fixed by its size (Figure 1). Two angular coordinates remain. Applied to the Earth, they are called the latitude and longitude. Its rotation provides the symmetry axis. The North Pole is defined as the point where the theoretical axis of rotation meets the surface of the sphere, and the rotation is counter-clockwise when looking at the pole from above. The opposite point is the South Pole. The equator is defined as the great circle halfway between the poles.

The latitudes are circles parallel to the equator. They are counted from 0° at the equator to 390° at the poles. The longitudes are great circles connecting the two poles of the Earth. For a given position on Earth, the longitude going through the zenith, the point directly above, is called the meridian. This is the line the Sun apparently crosses at local noon. The origin of longitudes is defined as the Prime Meridian, and passes Greenwich, where the Royal Observatory of England is located. From there, longitudes are counted from 0° to +180° (eastward) and -180° (westward).

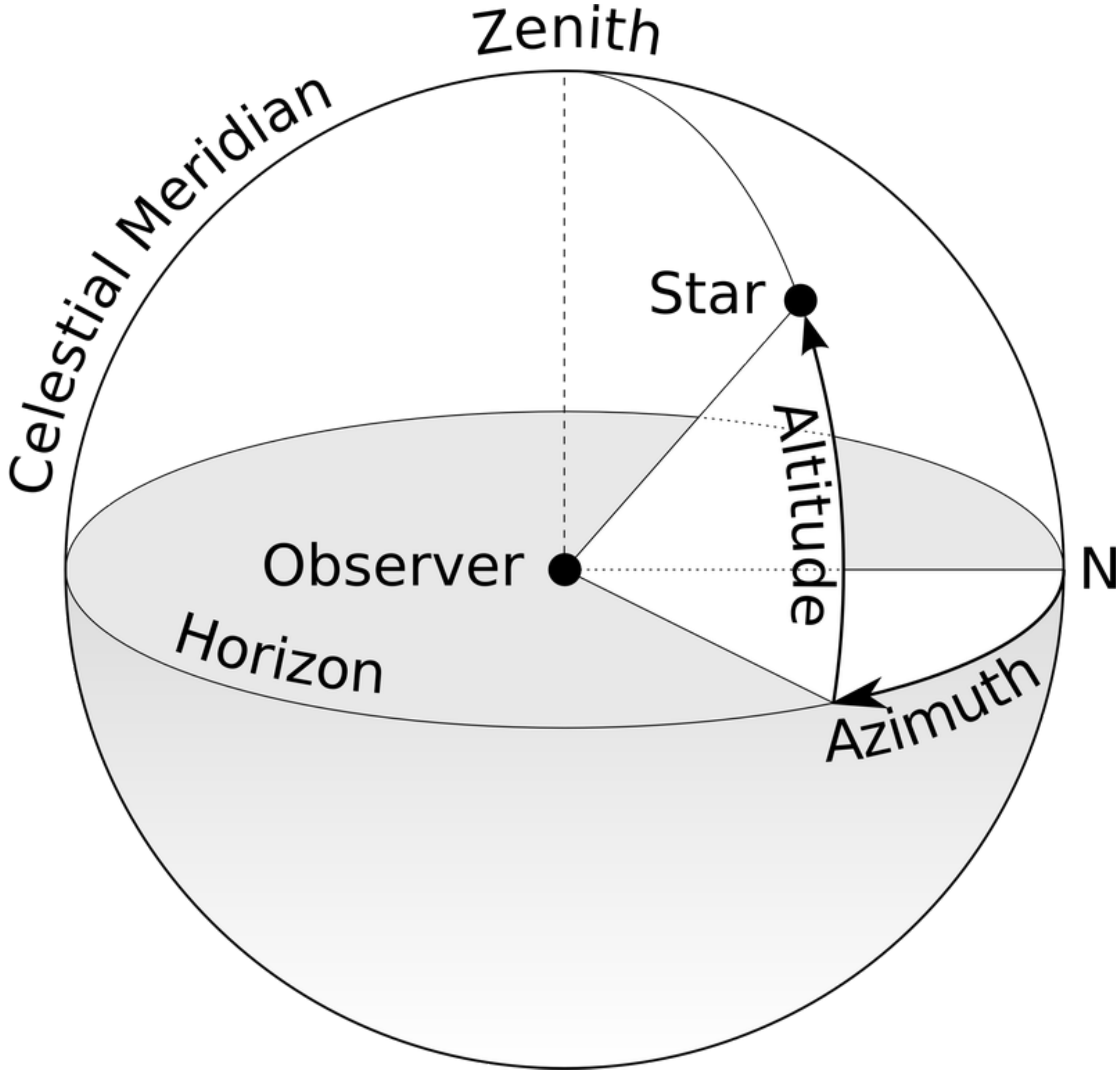
Example: Heidelberg in Germany is located at 49.4° North and 8.7° East.

### Elevation of the pole (pole height)

**Figure 2:** Trails of stars at the sky after an exposure time of approximately 2 hours (Credit: Ralph Arvesen, Live Oak star trails, https://www.flickr.com/photos/rarvesen/9494908143, https://creativecommons.org/licenses/by/2.0/legalcode)

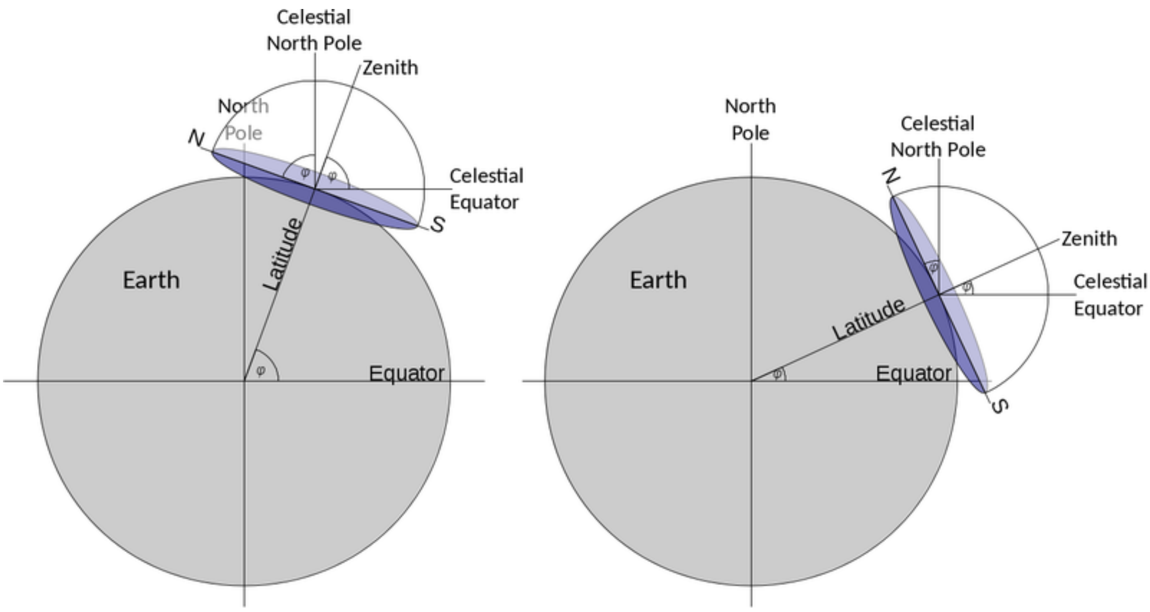
If we project the terrestrial coordinate system of latitudes and longitudes on the sky, we get the celestial equatorial coordinate system. The Earth's equator becomes the celestial equator and the geographical poles are extrapolated to build the celestial poles. If we were to take a photograph with a long exposure of the northern sky, we would see from the trails of the stars that they all revolve about a common point, i.e. the northern celestial pole (Figure 2). In the northern hemisphere, there is a moderately bright star near the celestial pole, namely, the North Star or Polaris. At the southern celestial pole, there is no such star that can be observed with the naked eye. Other methods must be used to find it. If we stood exactly at the geographical North Pole, Polaris would always be directly overhead. We can say that its elevation would be (almost) 90°. This information already introduces the horizontal coordinate system (Figure 3).

Figure 3: Illustration of the horizontal coordinate system. The observer is the origin of the coordinates assigned as azimuth and altitude or elevation (Credit: TWCarlson, https://commons.wikimedia.org/wiki/File:Azimuth-Altitude_schematic.svg, 'Azimuth-Altitude schematic', https://creativecommons.org/licenses/by-sa/3.0/legalcode).




It is the natural reference we use every day. We, the observers, are the origin of the coordinate system located on a flat plane whose edge is the horizon. The sky is imagined as the hemisphere above. The angle between an object in the sky and the horizon is the altitude or elevation. The direction within the plane is given as an angle between 0° and 360°, the azimuth, which is usually measured clockwise from north. In navigation, this is also called the 'bearing'. The meridian is the line that connects north and south at the horizon and passes the zenith.

Figure 4: When combining the three coordinate systems (terrestrial spherical, celestial equatorial and local horizontal), it becomes clear that the latitude of the observer is exactly the elevation of the celestial pole, also known as the 'pole height' (Credit: own work).



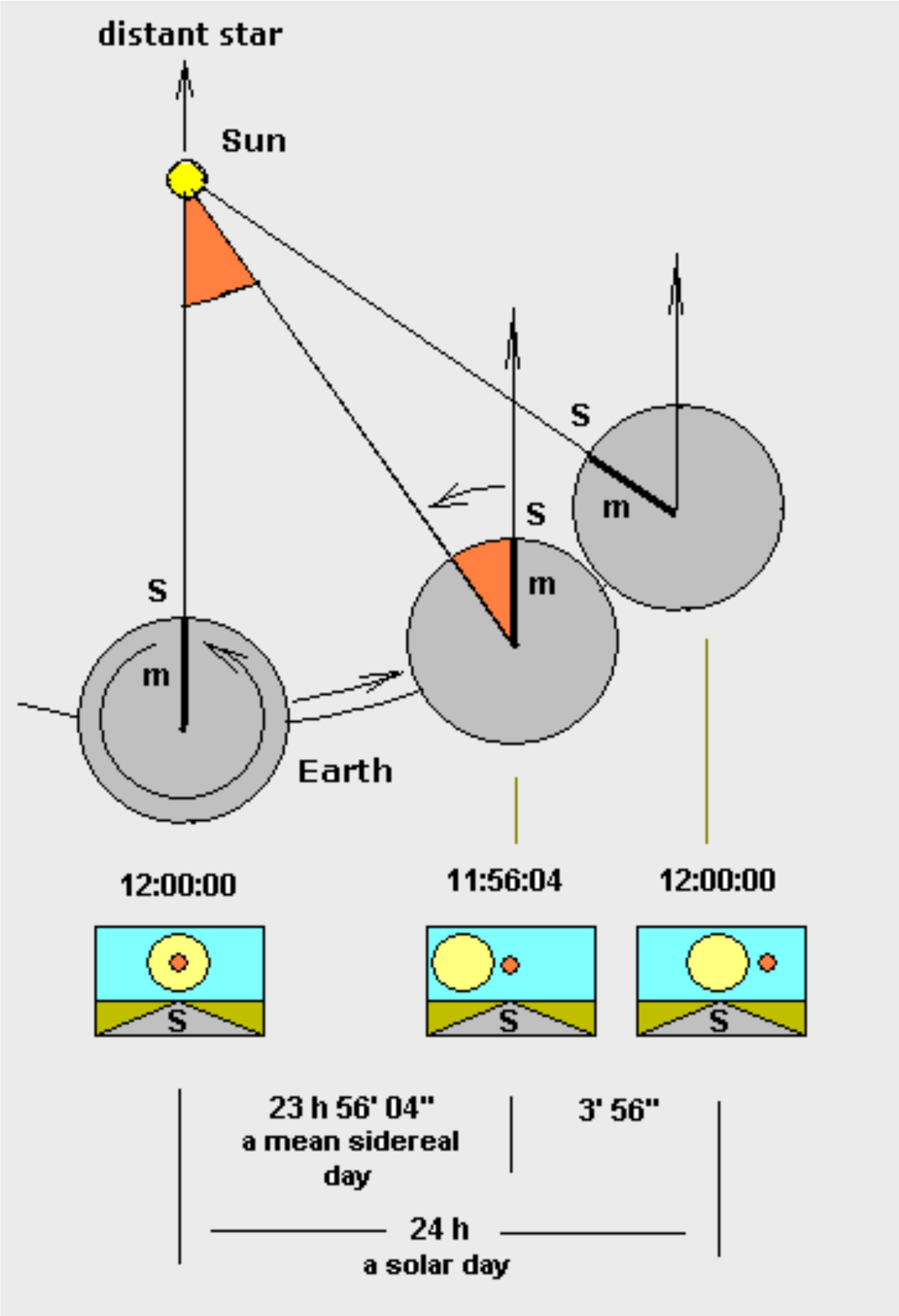

For any other position on Earth, the celestial pole or Polaris would appear at an elevation less than 90°. At the equator, it would just graze the horizon, i.e. be at an elevation of 0°. The correlation between the latitude (North Pole = 90°, equator = 0°) and the elevation of the celestial poles is no coincidence. Figure 4 combines all three mentioned coordinate systems. For a given observer at any latitude on Earth, the local horizontal coordinate system touches the terrestrial spherical polar coordinate system at a single tangent point. The image demonstrates that the elevation of the celestial north pole, called the pole height, is exactly the northern latitude of the observer on Earth.

### Mean and true solar time

Figure 5 demonstrates the Earth's rotation and its orbit around the Sun. The Sun illuminates the Earth, which leads to day and night. Within nearly 24 hours, the Earth rotates once around its own axis. As a result, the orientation relative to the sky at position 2 is the same as that at position 1.

In addition to its own rotation, the Earth also revolves around the Sun. At position 1, the Sun indicates local noon. This means, in the northern hemisphere, the Sun is due south. However, at position 2, i.e. after one full rotation, the Sun does not align with that point in the sky anymore, in that it indicates a time before local noon. In order to have the Sun at the same spot in the sky again (next local noon), the Earth has to revolve and rotate for a little longer (position 3). As a result, a solar day lasts a few minutes longer than it takes the Earth to rotate around its own axis. The solar day takes almost exactly 24 hours.

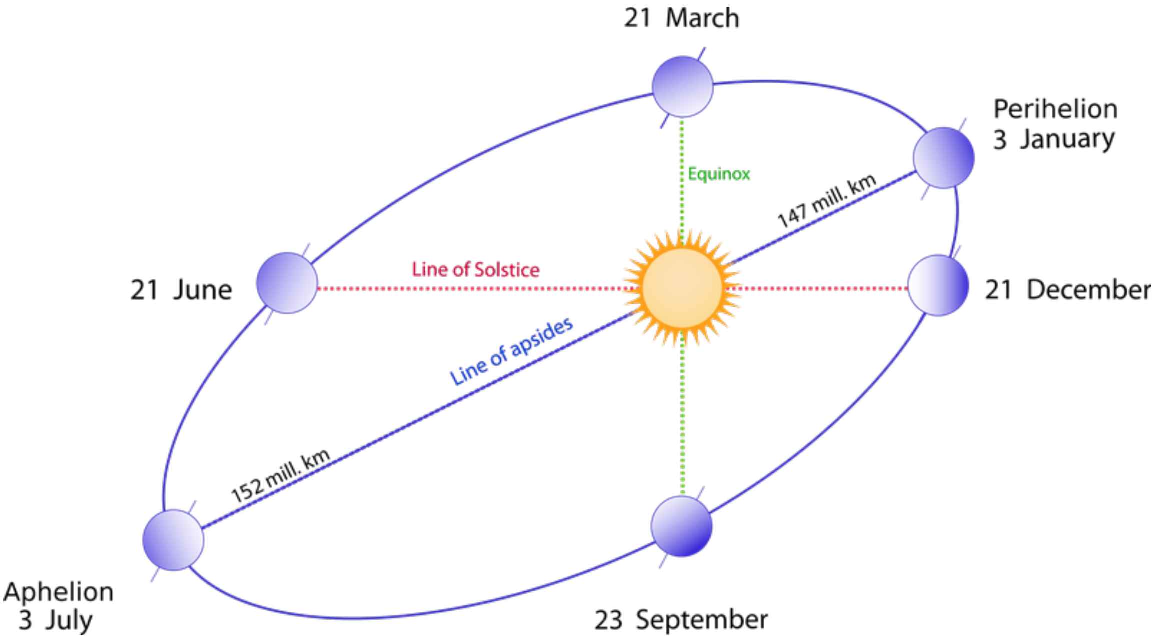
**Figure 5:** Illustration of the difference between solar and sidereal day (Credit: Francisco Javier Blanco González, https://commons.wikimedia.org/wiki/File:Tiempo_sidéreo.en.png, https://creativecommons.org/licenses/by-sa/2.5/legalcode).




However, the orbital speed of the Earth around the Sun is not constant throughout the year. It is faster near perihelion and slower near aphelion.

Figure 6: Schematic view of the Earth's elliptical orbit around the Sun throughout a year. The position closest to the Sun is the perihelion, while the most distant point is the aphelion (Credits: following Duoduoduo's advice, vector image:

Gothika, https://commons.wikimedia.org/wiki/File:Seasons1.svg, 'Seasons1', annotations updated by Markus Nielbock, https://creativecommons.org/licenses/by-sa/3.0/legalcode).




Consequently, the duration of a true solar day changes constantly. This is reflected by the apparent solar time (AST) or true solar time (TST), which corresponds to the true apparent path of the Sun across the sky. Therefore, 12:00 noon TST is exactly when the Sun is due south.

On average, the solar day lasts 24 hours, which corresponds to a full apparent revolution of the Sun in the sky, i.e. 360°. Based on this average, we can also assume that on average every day is equally long, i.e. the Sun returns to the same position exactly every 24 hours. We have seen that in reality this is not the case, but it simplifies measuring time. This timescale is called the mean solar time (MST). This means that the angular speed $\omega$ of the Earth relative to the Sun's apparent position for a solar day is, on average, 360° divided by 24 hours (h), or 15 degrees per hour:

$\omega = 360°/ 24h = 15°/ h$

**Determining longitude**

With this rotational rate, one can determine longitude if both the time at the Prime Meridian and the local time are known. If one calculates the difference between those times, the longitude is derived by simply multiplying this number with 15.

$\Delta t = 12h - TST$

The longitude in degrees is then $\lambda = \Delta t \cdot 15\ °/ h = (12h - TST) \cdot 15°/ h$

**Glossary**

*Aphelion*
The point of the Earth's orbit that is most distant from the Sun

*Apparent movement*
Movement of celestial objects that is in fact caused by the rotation of the Earth

*Cardinal directions*
Main directions, i.e. north, south, west, east

*Culmination*
Passing of the meridian by celestial objects. These objects attain their highest or lowest elevation there.

*Diurnal*
Concerning a period that is caused by the daily rotation of the Earth around its axis

*Elevation*
Angular distance between a celestial object and the horizon

*Galilean moons*
The four of more than 60 known moons of Jupiter (Io, Europa, Callisto and Ganymede) that Galileo Galilei discovered in 1610 with one of the first astronomical telescopes used in human history

*Great circle*
A circle on a sphere whose radius is identical to the radius of the sphere

*Mean solar time*
The annual average of the duration of the Sun reaching the same azimuthal direction (e.g. between noons), which is almost exactly 24 hours. The time measured according to these astronomical events is called the mean solar time. In general, this differs from the time displayed by common contemporary clocks.

*Meridian*
A line that connects north and south at the horizon via the zenith

*Perihelion*
The point of the Earth's orbit that is closest to the Sun

*Pole height*
Elevation of a celestial pole. Its value is identical to the latitude of the observer on Earth.

*Precession*
As a spinning body rotates, the rotation axis often also moves in space. This is called 'precession'. As a result, the rotation axis constantly changes its orientation and points to different points in space. The full cycle of the precession of the Earth's axis takes roughly 26,000 years.

*Sextant*
Navigational tool invented during the 18th century used to measure the angular altitude of celestial objects to determine latitude

*Spherical polar coordinates*
The natural coordinate system of a flat plane is Cartesian and measures distances in two perpendicular directions (ahead, back, left, right). For a sphere, this is not very useful, because it has neither beginning nor ending. Instead, the fixed point is the centre of the sphere. When projected outside from the central position, any point on the surface of the sphere can be determined by two angles, one of which is related to the symmetry axis. This axis defines two poles. In addition, the radius represents the third dimension in space, whereby each point within a sphere can be determined. This defines the spherical polar coordinates. When defining points on the surface of a sphere, the radius stays constant.

*Time zone*
Before mass transportation across large distances by train became possible, each town had its own local time that followed the solar time. This situation became impractical, as time tables for trains had to consider the shifts in time between stations. Therefore, in the 1840s, a standard time that would be valid throughout Britain was decided on. Later, the concept was implemented all over the world, with 24 zones of local standard times, namely, the time zones. This is what we still use today.

*True solar time (apparent solar time)*
The duration of a true solar day – the period between two meridian passages of the Sun – changes throughout the year. This is caused by the eccentric orbit of the Earth around the Sun. While the rotational speed of the Earth itself remains constant, the orbital velocity around the Sun does not. Consequently, a true solar day can be off from the mean value of 24 hours between about 20 to 30 seconds. This leads to differences between the true and mean solar times of up to approximately 15 minutes in either direction. In this time frame, noon is when the Sun is exactly on the meridian, i.e. south in the northern hemisphere and north in the southern hemisphere.

*Zenith*
Point in the sky directly above

**FULL DESCRIPTION**

## PREPARATIONS

This activity only briefly introduces the concept of deriving latitude from the angular measurements of celestial objects. A more detailed approach is provided by other activities from the educational package focused on celestial navigation called 'Navigation Through the Ages'. The teacher might want to have a look at those first.

There are two versions of a longitude clock available. One is a computer app written in Java, because of which it is independent of the operating system. However, please check whether it runs on your local computers. For details, see the instructions for the app below.

The other version is a hands-on cardboard dial, similar to a planisphere. The students will have to build it first. The instructions are included.

## INTRODUCTION

It would be beneficial if the activity were discussed in the larger context of seafaring, e.g. in geography, history and literature.

Tip: This activity could be combined with other forms of acquiring knowledge like giving oral presentations in history, literature or geography highlighting navigation. This would prepare the field in a much more interactive way than what a teacher can achieve by summarising the facts. This topic is also well suited for acting classes.

Tip: There are good documentaries available highlighting the works of John Harrison and the history of finding the longitude.

This is a suggested collection:

'Longitude and latitude explained', Australian National Maritime Museum (Duration: 2:33) https://www.youtube.com/watch?v=-8gg98ws2Eo

'Determine Longitude', Science Online (Duration 11:10) https://www.youtube.com/watch?v=b7yoXhbOQ3Y

'The Clock That Changed the World (BBC History of the World)', Leeds Museums (Duration 29:01) https://www.youtube.com/watch?v=T-g27KS0yiY

Let the students watch these during a preparatory lesson or at home.

## QUESTIONS, ANSWERS AND DISCUSSION

Ask the students if they had an idea about how long mankind had been using ships to navigate the oceans. One may point out the spread of Homo sapiens to islands and isolated continents like Australia.

Possible answers: We know for sure that ships have been used to cross large distances since 3,000 BCE or earlier. However, the early settlers of Australia must have found a way to cross the oceans around 50,000 BCE.

Ask the students what the benefits of trying to explore the seas could have been. Perhaps someone knows historic cultures or peoples that were famous sailors. The teacher can support this with a few examples of ancient seafaring peoples, e.g. from the Mediterranean, and the art of navigation.

Possible answers: Finding new resources and food, trade, the spirit of exploration and curiosity.

Ask the students how they find their way to school every day. What supports their orientation and prevents them from getting lost? As soon as reference points (buildings, traffic lights, bus stops, etc.) are mentioned, ask them how navigators were able to find their way on the seas. In early times, they used sailing directions in connection to landmarks that could be recognised. But for this, the ships would have to stay close to the coast. Lighthouses improved the situation. But what could be used as reference points in the open sea? The students will probably soon mention celestial objects like the Sun, the Moon and stars.

*Additional suggested questions and answers*
Q: From the documentary, what were the major obstacles for building a marine timekeeper?
A: They were too inaccurate and unreliable at sea. The main reasons for this were that the rolling movements of the ships interfering with the pendulums and there were great differences in the temperature and humidity in the open sea.

Q: What triggered the Longitude Act--the call for finding an accurate method to determine longitude?
A: The naval disaster of 1707 at the Scilly Islands.

Q: How are time and the rotation of the Earth connected?
A: The solar time, as we use it, is connected to the apparent diurnal movement of the Sun. Every two noons are separated by 24 hours during which the Earth rotates (approximately) once around its own axis. The rotation of the Earth apparently moves the Sun around the sky. The longitude above which the Sun shines changes in time.

Q: How long is one day in hours? How many degrees of one rotation are within one hour?
A: 1 day = 24 hours; 360 degrees = 1 full rotation; 15 degrees per hour

Q: How would measuring time permit determining longitude?
A: The difference in time between the current position on Earth and a longitude reference (the Prime Meridian at Greenwich) is directly proportional to the longitude of an unknown position.

Q: Who solved the longitude problem with a novel clock?
A: The clockmaker John Harrison.

Q: What was the clockwork of John Harrison's H1 clock made of?
A: Wood.

Q: What is the main difference in design between H1 and H4?
A: The H1 is a large and heavy clock, while the H4 is similar to a pocket watch and is easier to operate.

Q: Where are these clocks displayed now?
A: The Greenwich Observatory Museum.

Q: Which great explorer tested and used a copy of the H4 during his voyages around the world?
A: James Cook.

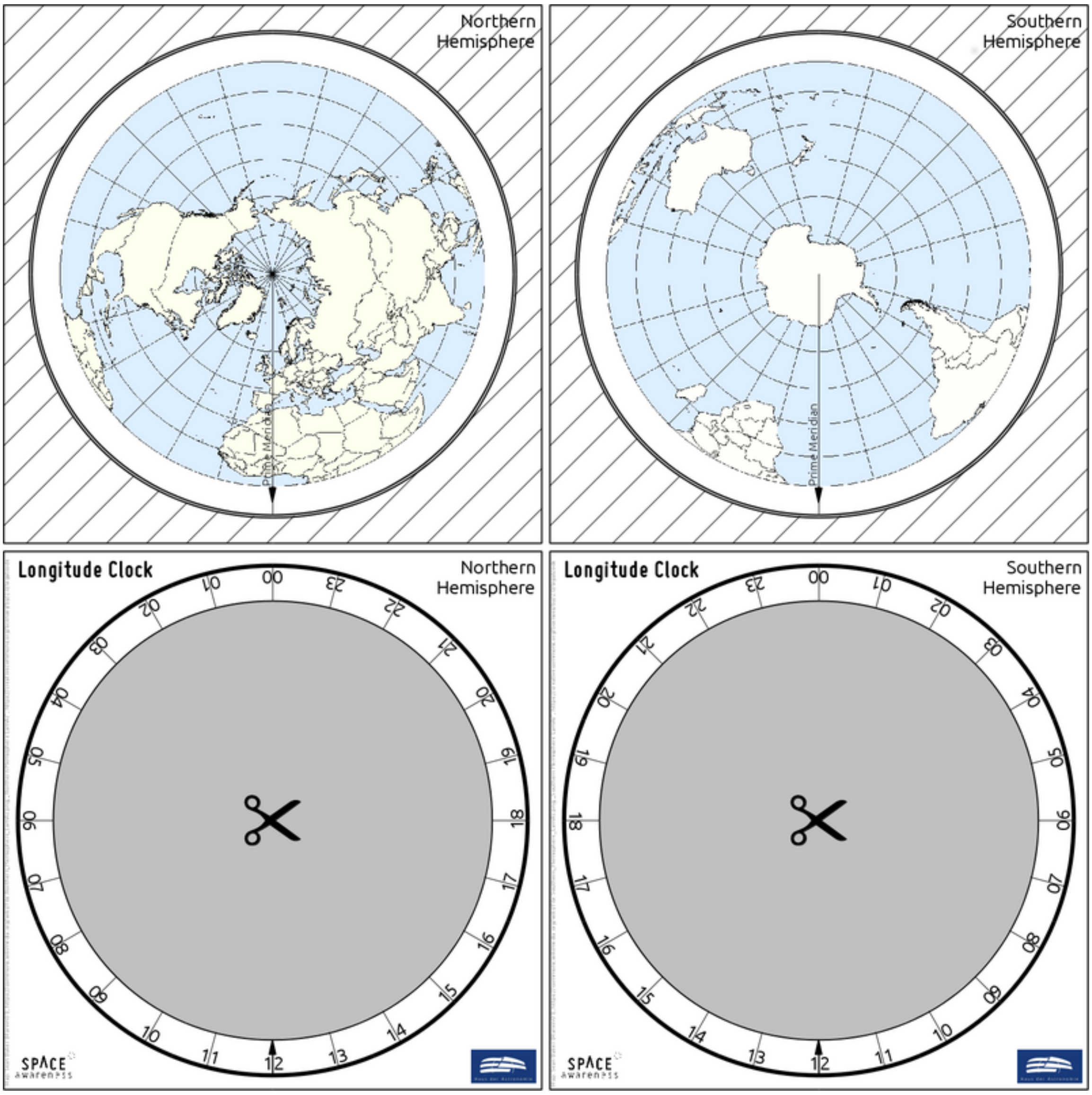
*Remark*
The following activity can either be done with a cardboard version of the longitude clock or the computer app. Teachers can choose one. Please check if the app runs on local computers. For details, see the instructions for the app below.

## BUILDING THE LONGITUDE CLOCK (Available as separate document)

Items needed: - Template printed on heavy paper or thin cardboard - Instructions - Crafting knife - Scissors - Glue

The template of the longitude clock consists of four pages. 1. Print the template on extra heavy paper or cardboard to provide stability. 2. Cut out the square areas. 3. Glue the squares with the maps back to back. Make sure the glue is well distributed and the arrow on the Prime Meridian points in the same direction on both sides. 4. Cut out the grey area inside the face of the clock (labelled 'Longitude Clock'). 5. After the glue has dried, cut off the hatched area around the maps, but do not destroy the hatched part. It will be needed later. 6. Remove the grey area in between the hatched area and the maps. You may cut into the black borders surrounding it. Scissors can be used to trim the edges. 7. Glue the part with the hatched area to the back of one of the faces of the longitude clock. Make sure the glue is well distributed on the hatched side. Let it dry. 8. Put the disk with the maps inside the hatched area and check that it rotates smoothly. If needed, trim the edge some more. Then remove the disk again. 9. Put glue on the remaining visible side of the hatched page. 10. Carefully put the disk with the maps inside. It must not receive any glue. Be sure that the correct side of the map disk is facing up. Double-check with the labelling of the clock face. 11. Place the back of the remaining face of the longitude clock on the glued hatched part. 12. Let it dry and check that the disk rotates.

Figure 7: Template for building the longitude clock. A printable version is available as a separate file (own work).




## THE LONGITUDE CLOCK APP

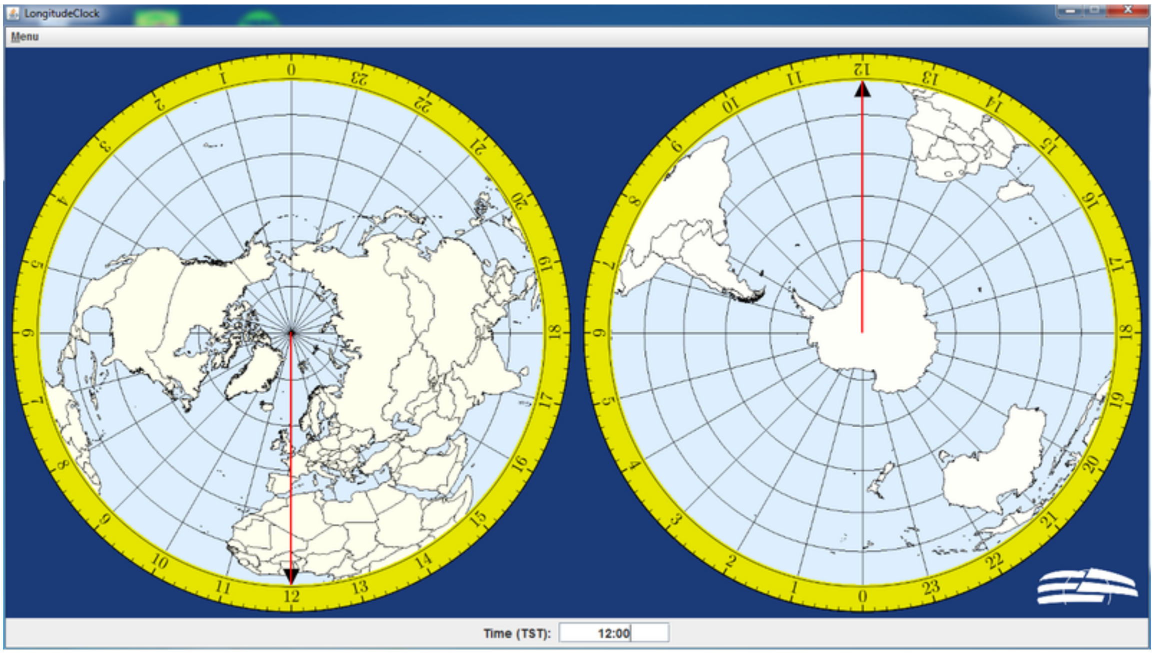
There is a Java application attached to this unit that works in the same way as the longitude clock built by the students. After the software is started, the northern and southern hemispheres appear side by side. The time can be set by dragging with a computer mouse or typing. The software contains a readme file with further instructions.

*Minimum requirements:* - Java version 7 or higher - Graphic board that supports at least OpenGL 3.3 When the application is started, the OpenGL version that is currently supported will be shown in a separate console.

*Important Remark:*
Since the graphical standard mentioned above (OpenGL 3.3) was only introduced in 2010, it is possible that the app will not run on all computers, especially those that are older or only possess a simple graphic card. It is recommended that the teacher test the application beforehand.

*Instructions:*
Unzip the file astroedu1646-LongitudeQuest-LongitudeClock.zip anywhere on a computer that has either Windows or Linux installed. A new folder called LongitudeClock is created. Go to this folder and run either the Windows or Linux launcher script. Detailed information about its usage is included.

**Figure 8:** Screen shot of the longitude clock application.




## ACTIVITY 1: FIND THE LONGITUDE

Materials needed: - Worksheet - Longitude clock or/and longitude clock application - Pencil - Calculator - Computer, if the longitude clock app is used

Students will learn the concept of determining the longitude using the longitude clock. Its precision is good enough to illustrate the procedure by visualising the underlying mathematical concept. However, the time resolution is too small to determine the longitude with very high precision as is needed for navigation.

The worksheets contain a summary of the most important concepts needed to understand and carry out this activity.

*Using the longitude clock*
When navigating using a sextant and clock, the local time on board a ship is compared to the time measured at the Prime Meridian. For this purpose, ships used to carry along a highly accurate clock that was set to the time at 0° longitude, i.e. the time at the Greenwich Observatory. The measurements were usually made at local noon, i.e. when the Sun attains its highest elevation.

The Prime Meridian is indicated on the longitude clock. To determine longitude, simply turn the marker of the Prime Meridian to the time displayed by the clock, which is set to the time at the 0° longitude. The local longitude is then indicated at the time marker of 12 o’clock (local noon). The longitudes are indicated in steps of 15° west and east of the Prime Meridian. The teacher may choose to project the longitude clock app and demonstrate its usage to the students.

Note that for our exercises, we assume the clocks are showing the True Solar Time, but we calculate assuming the mean duration of a solar day of 24 hours.

*Exercise*
The worksheet contains a table with five examples of time readings (time at the Prime Meridian) for local noon (TST). The students calculate the time difference and the resulting longitude by applying the equations below. The results are then crosschecked with the longitude clock (paper or app version).

If TST is the true solar time at Greenwich (Prime Meridian), the time difference in hours between local noon and TST is

$\Delta t = 12h - TST$

The longitude corresponds to the angle the Earth has rotated between noon at the Prime Meridian and the local noon. Since the mean solar day lasts 24 hours, one hour corresponds to 15° in longitude. The local longitude in degrees is then

$\lambda = \Delta t \bullet 15°/h = (12h - TST) \bullet 15°/h$

Negative values indicate western longitudes while positive values represent eastern longitudes.

**Table 1: List of Greenwich times for which the students are asked to calculate the longitudes, if local noon is assumed. The solutions (not provided to the students) are added in italics.**

True Solar Time at Greenwich (hh:mm) | Δt (h) | λ (°) --- | --- 08:00 | +4 | 60 East 23:00 | -11 | 165 West 18:00 | -6 | 90 West 00:00 | +12 | 180 West/ East 14:30 | -2.5 | 37.5 West

If the students have difficulties applying the equations, the teacher may want to demonstrate the solution for the first example.

Note: The teacher may want to change the focus of the exercise by starting with the longitude clock and using the calculations as a crosscheck instead.

## ACTIVITY 2: CAPTAIN COOK'S SECOND VOYAGE

Materials needed: - Worksheet - Pencil - Calculator - Computer/tablet/smartphone with internet connection

Using the worksheet, the students follow up on Cook's second voyage. They determine latitude and longitude of seven locations during the three-year journey and locate each position on an online map.

Q: How many minutes and seconds are in one hour?
A: 1 hour = 60 minutes = 3600 seconds

The latitude can be calculated on the basis of any observable celestial object. If its position in the sky is known, the angle between the horizon and that object, the elevation, leads to the latitude. Celestial objects have coordinates of their own. It is important to note here the angle towards the equator. This angle is called 'declination' and corresponds to the latitude on Earth. Only at the terrestrial poles, the equator aligns with the horizon.

The latitude ϕ is calculated from the declination δ and elevation η using the following equation.

$\phi = 3\ (90° - \eta) + \delta$

The plus sign in front of the bracket is chosen if the Sun attains its highest elevation to the south. It is minus if the Sun is to the north. The sign of ϕ is positive for northern latitudes and negative for southern latitudes. Unfortunately, the Sun changes its declination all the time. However, it can be calculated. For the seven measurements, its value is added to the table.

*Story*
Captain James Cook began his second voyage on 13 July 1772. His fleet consisted of two ships, the HMS Resolution and the HMS Adventure, the latter commanded by Captain Tobias Furneaux. Before setting sail, Cook took the first set of measurements.

After stopping in the Madeira and Cape Verde Islands, the expedition anchored on 30 October 1772 at their first major southern port. They navigated around the Cape of Good Hope and after manoeuvring the ships through pack ice, they reached the Antarctic Circle on 17 January 1773. Both ships rendezvoused on 17 May 1773. From there, they explored the Pacific, and on 15 August reached an island, where the first pacific islander ever to visit Europe embarked on the HMS Adventure.

The Adventure returned to England early, while Cook with the Resolution continued to roam the seas. After several attempts to venture south of the Antarctic Circle, he reached the most southern point on 30 January 1774, where ice blocked the passage. Cook continued to explore the Pacific but finally decided to steer a course home. Cook headed east and his crew sighted land on 17 December 1774. They spent Christmas in a bay that Cook later named Christmas Sound.

He continued exploring the South Atlantic and discovered South Georgia and the South Sandwich Islands. After a stopover in southern Africa, the ship returned home on 30 July 1775.

**Table 2: List of navigational measurements made on Cook's flagship HMS Resolution on seven dates during his second voyage. The measurements were all obtained at local noon, i.e. at the highest elevation of the Sun on that day. The times were obtained from the K1 watch James Cook took with him.**

| Date | Solar declination (°) | Sun direction | Solar elevation (°) | True Solar Time (hh:mm:ss) |
| --- | --- | --- | --- | --- |
| 13 July 1772 | 21. 7 | South | 61.3 | 12:16:24 |
| 30 October 1772 | -14.1 | North | 70.2 | 10:46:24 |
| 17 May 1773 | 19.3 | North | 29.7 | 00:22:48 |
| 15 August 1773 | 14.0 | North | 58.5 | 02:01:36 |
| 30 January 1774 | -18.6 | North | 37.4 | 19:07:36 |
| 17 December 1774 | -23.4 | North | 60.0 | 17:05:14 |
| 30 July 1775 | 18.5 | South | 58.1 | 12:06:00 |

For the seven destinations mentioned here, the table above lists measurements from which the students should determine the latitude and the longitude and add them to the table with the results below.

For the longitudes, use the equations in Activity 1. The times listed in the table have to be converted into hours, with decimals representing the minutes and seconds.

*Example:*
The first measurement is at Cook's home port. It was taken on 13 July 1772 at 12:16:24. So, it is 12 hours, 16 minutes, and 24 seconds. To convert this into hours with decimals, simply add up the following numbers:

12 hours 16/60 hours 24/3600 hours

The sum is rounded to 12.2733 hours.

Following the equation mentioned above, you get (rounded to the first decimal):

$$\lambda = (12h - 12.2733h) \cdot 15°/ h = -4.1°$$

Thus, the longitude is -4.1° or 4.1° west.

To get the latitude, calculate (northern hemisphere, i.e. the Sun is in the south):

$$\phi = (90° - \eta) + \delta = (90° - 61.3°) + 21.7°$$

**Table 3: A table prepared for the students to fill in the solutions. The results (not provided to the students) are added in italics.**

| Date | Latitude (°) | Longitude (°) | Location on map |
| --- | --- | --- | --- |
| 13 July 1772 | *50.4 N* | *4.1 W* | *Plymouth* |
| 30 October 1772 | *33.9 S* | *18.4 E* | *Cape Hope/Table Bay* |
| 17 May 1773 | *41.0 S* | *174.3 E* | *Queen Charlotte Sound (NZ)* |
| 15 August 1773 | *17.5 S* | *149.6 E* | |

| *Tahiti* 30 January 1774 | *71.2 S* | *106.9 W* | *Most southern point, close to Antarctica* 17 December 1774 | *53.4 S* | *76.3 W* | *West of Patagonia Strait of Magellan* 30 July 1775 | *50.4 N* | *1.5 W* | *English Channel, close to Isle of Wight*

If possible, check a map in an atlas or via a map service online where these positions are on Earth. In Google Maps, simply enter the latitude followed by the longitude, both separated by a comma.

## FINAL DISCUSSION

The students are invited to discuss how accurate this method is. The discussion may be guided along these lines. The answers are suggestions of where the discussion may lead.

Q: Which steps are needed to plot a ship's position on the open sea?
A: Either course and speed or solar elevation at local noon and Greenwich time.

Q: How does weather interfere with this?
A: The Sun must be visible for latitude and the time of local noon to be determined. Winds and storms make measurements difficult.

Q: What knowledge and skills are needed to navigate in the way you did?
A: Simple math, the meaning of latitude and longitude, measuring angles of celestial objects, etc.

Q: What skills and knowledge are needed to navigate with GPS?
A: Very little.

## EVALUATION

- When introducing the topic, ask the students what defines a day. Using an Earth globe helps visualising the situation. After realising that it is the period of one full apparent revolution of the Sun around the Earth (i.e. passage of the meridian), let them work on activity 1.
- Try to address methods of how to determine the time synchronously at two locations on the Earth. The time difference corresponds to the difference in longitude relative to a reference position.
- Activity 2 is especially suited to understanding how navigating with the Sun and a clock works. Guide the students through this task and check the results.
- Let the students research the life and the achievements of John Harrison. There are suggested videos mentioned in the description of the activity.

## CURRICULUM

## ADDITIONAL INFORMATION

## CONCLUSION

This module highlights the navigational challenges in determining longitude from time measurements. Along with getting an insight into the historic events that led to the invention of the first maritime timekeeper, the students use the method in two consecutive steps while they follow the steps of James Cook's second voyage around the world. Besides practising basic math and understanding the underlying fundamental concept, they build their own longitude clock that visualises in a simple way how determining longitude via time measurement works.

## CITATION

Nielbock, M., , *The Quest for Longitude*, astroEDU, 1646 doi:10.14586/astroedu/1646

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