ASTROEDU
Peer-reviewed Astronomy Education Activities

Navigation in the Ancient Mediterranean and Beyond

Learn the Ancient Skill of Celestial Navigation

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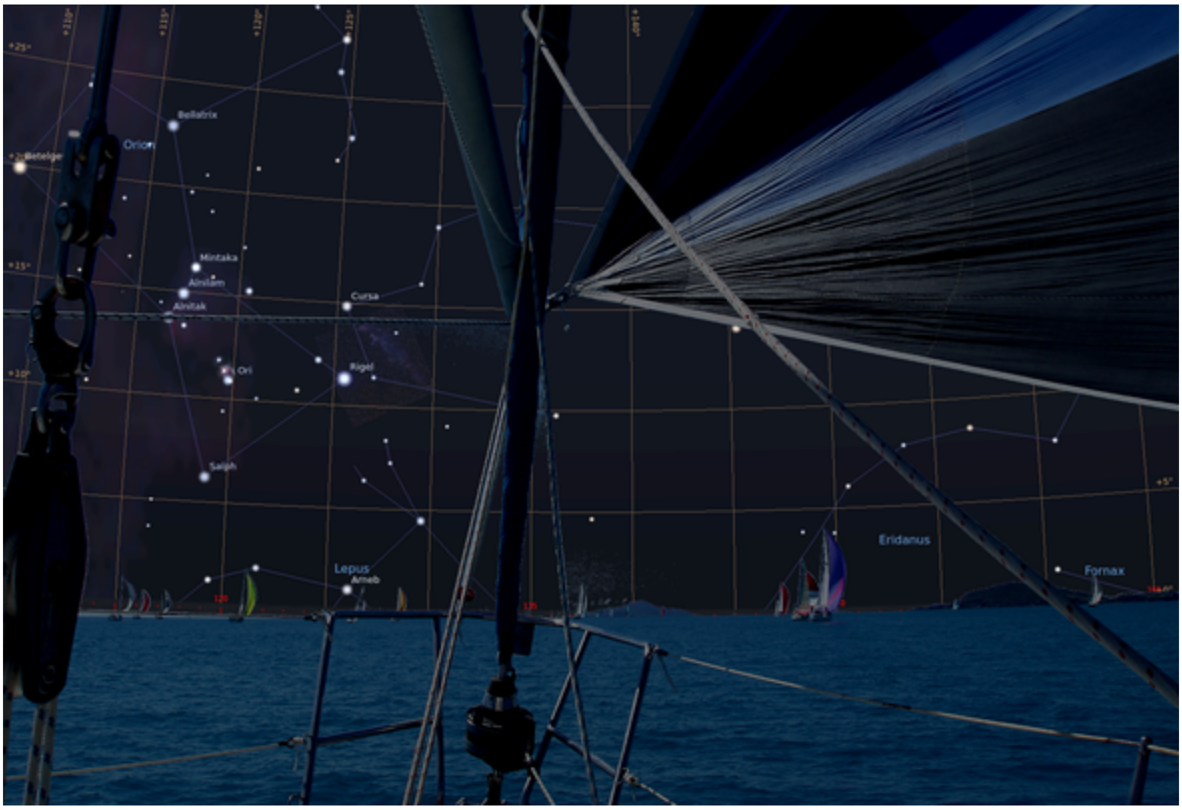


KEYWORDS

astronomy, Polaris, meridian, celestial navigation, Bronze Age, geography, stars, pole height, Mediterranean, navigation, ancient history, latitude, North Star, circumpolar

CATEGORY

Astrometry and celestial mechanics, Stars

LOCATION

Small Indoor Setting (e.g. classroom)

AGE

16 - 19 14 - 16

LEVEL

Middle School

TIME

1h30

GROUP

Group

SUPERVISED

No

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 - celestial navigation was developed many centuries ago. - apart from using Polaris, there are other methods to determine cardinal directions from the positions of stars. - ancient navigators successfully navigated on open waters by following stars and con-stellations.

LEARNING OBJECTIVES

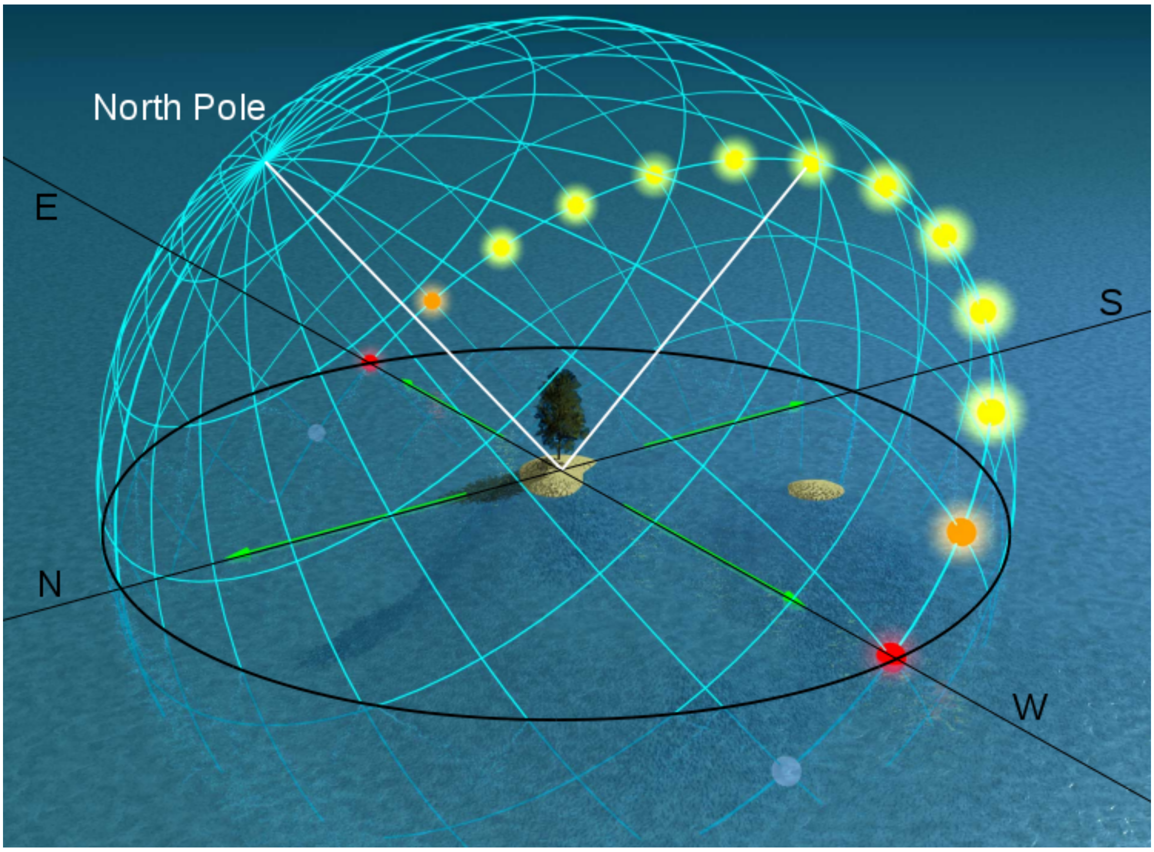
The students will be able to: - describe methods to determine the cardinal directions from observing the sky. - name prominent stellar constellations. - explain the nature of circumpolar stars and constellations. - use an Excel spreadsheet for calculations. - describe the importance of improved navigational skills for early civilisations.

BACKGROUND

Cardinal directions

The cardinal directions are defined by astronomical processes like diurnal and annual apparent movements of the Sun and the apparent movements of the stars. In ancient and prehistoric times, the sky certainly had a different significance than it does today. This is reflected in the many myths about the sky all around the world. As a result, we can assume that the processes in the sky have been watched and monitored closely. In doing this, the underlying cycles and visible phenomena were easy to observe.

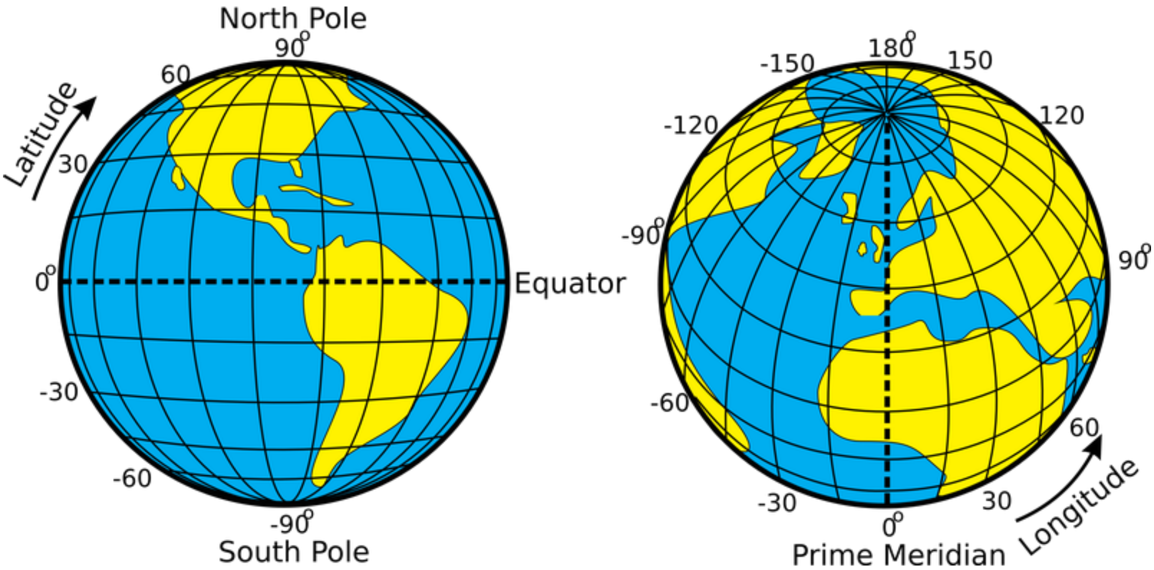
Figure 1 : Apparent diurnal movement of the Sun in the Northern Hemisphere at equinox. The Sun reaches its highest elevation above the horizon to the south. In the Southern Hemisphere, the Sun culminates to the north (Credit: Tau'olunga, https://commons.wikimedia.org/wiki/File:Equinox-50.jpg, 'Equinox-50', horizontal coordinate system and annotations added by Markus Nielbock, https://creativecommons.org/licenses/by-sa/3.0/legalcode).



For any given position on Earth except the equatorial region, the Sun always culminates towards the same direction (Figure 1). The region between the two tropics 23.5° north and south of the equator is special, because the Sun can attain zenith positions at local noon throughout the year. During night, the stars rotate around the celestial poles. Archaeological evidence from prehistoric eras like burial sites and the orientation of buildings suggest that the cardinal directions were common knowledge to a multitude of cultures many millennia ago (e.g. McKim Malville & Putnam, 1993; Rudgeley, 2000; Schmidt-Kaler & Schlosser, 1984). Therefore, it is obvious that they were applied to early navigation. The magnetic compass was unknown in Europe until the 13th century CE (Lane, 1963).

Latitude and longitude

Figure 2: Illustration of how the latitudes and longitudes of the Earth are defined (Credits: Peter Mercator, djexplo, CC0). Any location on an area is defined by two coordinates. The surface of a sphere is a curved area, so using coordinates like up and down does not make much sense, because the surface of a sphere has neither a beginning nor an end. Instead, we can use spherical polar coordinates originating from the centre of the sphere with the radius being fixed (Figure 2). Two angular coordinates remain. When applied to the Earth, they are called the latitude and the longitude. Its rotation provides the sym¬metry 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 North Pole from above. The opposite point is the South Pole. The equator is defined as the great circle half way between the two 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 this coordinate is the Prime Meridian, and passes Greenwich, where the Royal Observatory of England is located. From there, longi¬tudes are counted from 0° to 3180°.

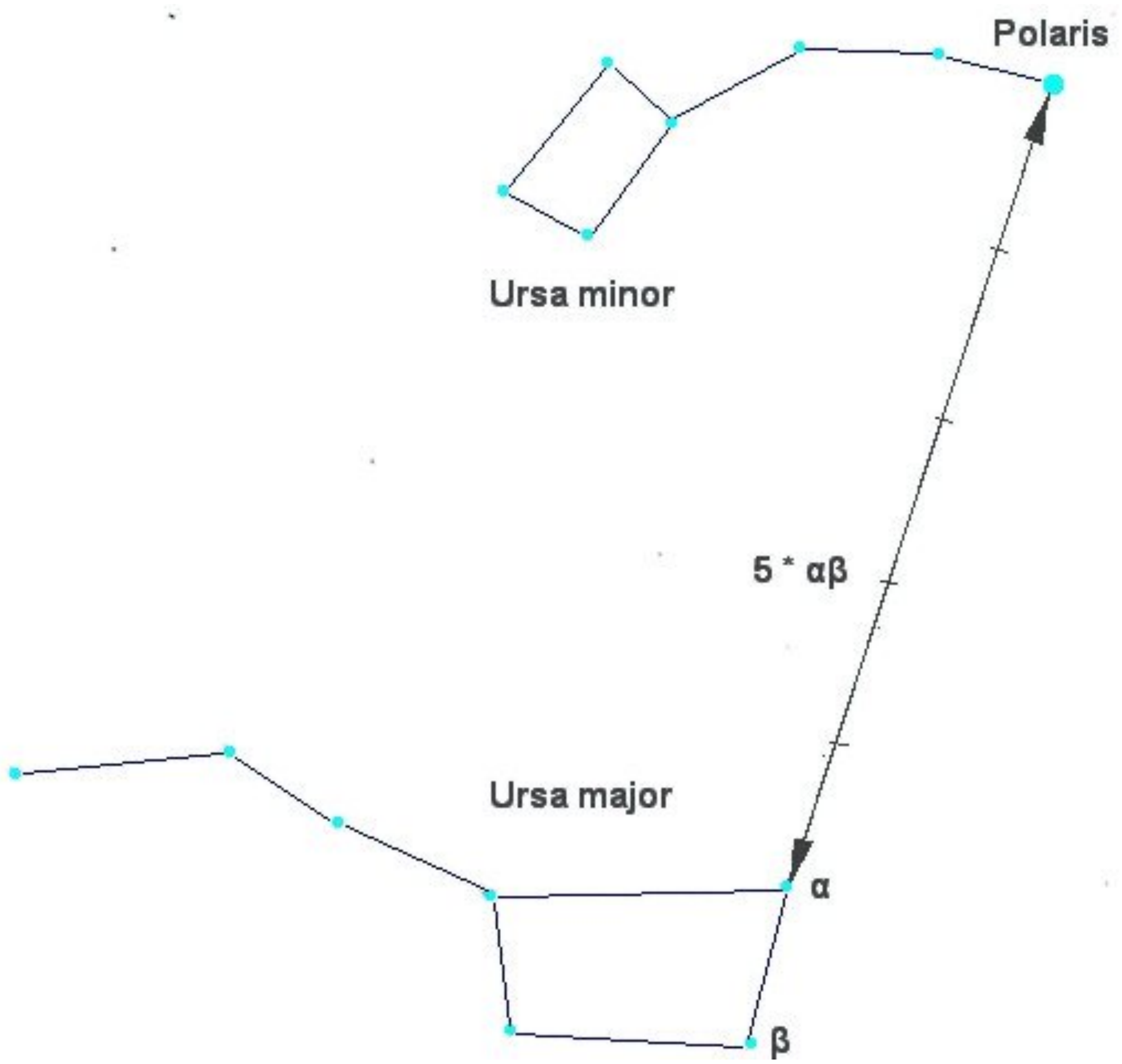
Example: Heidelberg in Germany is located at 49.4° North and 8.7° East.

Elevation of the pole (pole height)

Figure 3: Trails of stars in 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 the latitudes and longitudes on the sky, we get the celestial equatorial coordinate system. The Earth's equator becomes the celestial equator and the geographic 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, the northern celestial pole (Figure 3).

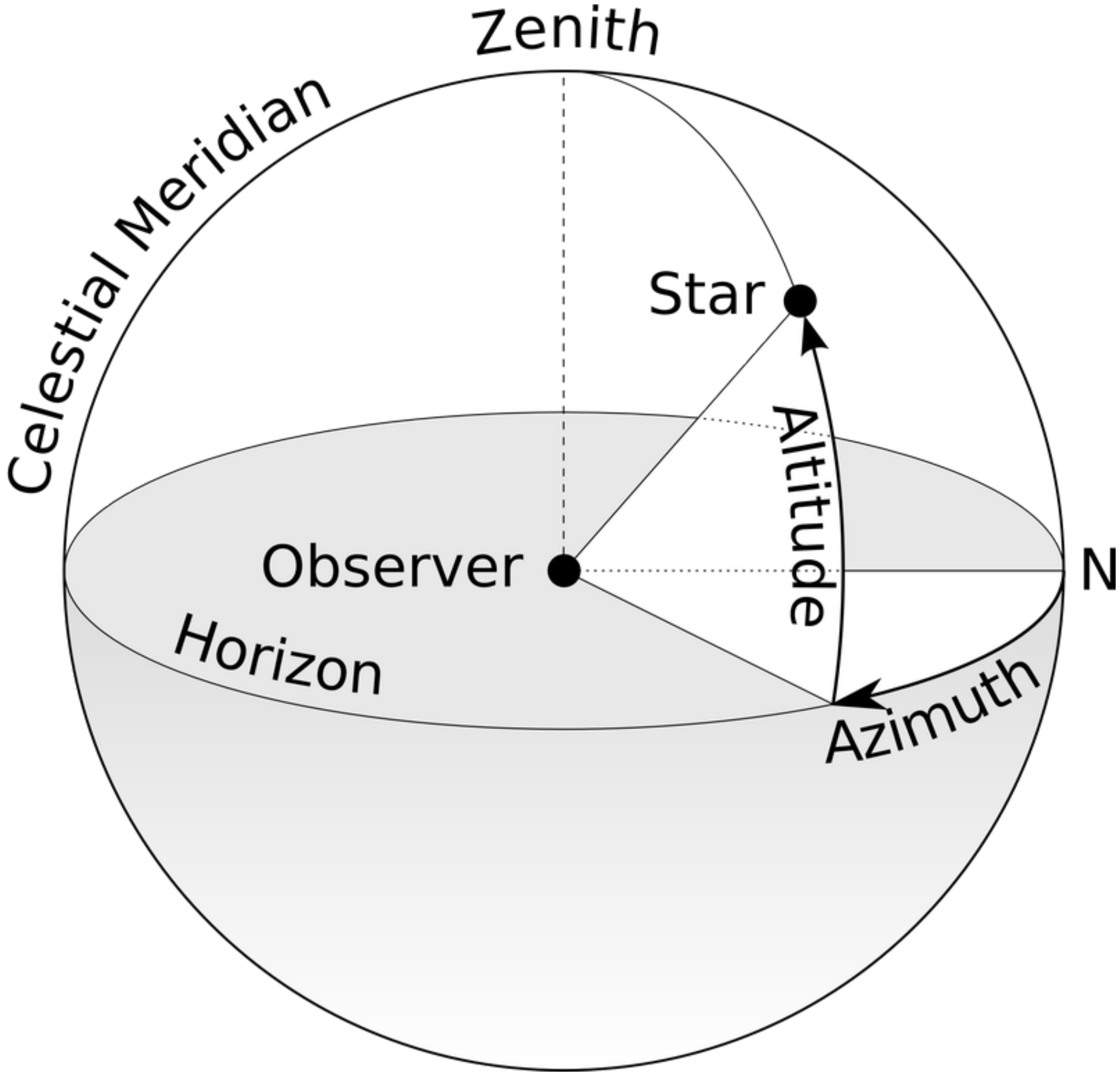
Figure 4: Configuration of the two constellations Ursa Major (Great Bear) and Ursa Minor (Little Bear) in the northern sky. Polaris, the North Star, which is close to the true celestial north pole, is the brightest star in Ursa Minor (Credit: Bonč, https://commons.wikimedia.org/wiki/File:Ursa_Major_- *Ursa_Minor* -_Polaris.jpg, 'Ursa Major – Ursa Minor – Polaris', based on https://commons.wikimedia.org/wiki/File:Ursa_Major_and_Ursa_Minor_Constellations.jpg, colours inverted by Markus Nielbock, https://creativecommons.org/licenses/by-sa/3.0/legalcode).



In the Northern Hemisphere, there is a moderately bright star near the celestial pole, the North Star or Polaris. It is the brightest star in the constellation the Little Bear, Ursa Minor (Figure 4). In our era, Polaris is less than a degree off. However, 1000 years ago, it was 8° away from the pole. Therefore, today we can use it as a proxy for the position of the celestial north pole. At the southern celestial pole, there is no such star that can be observed with the naked eye. Other methods have to be used to find it.

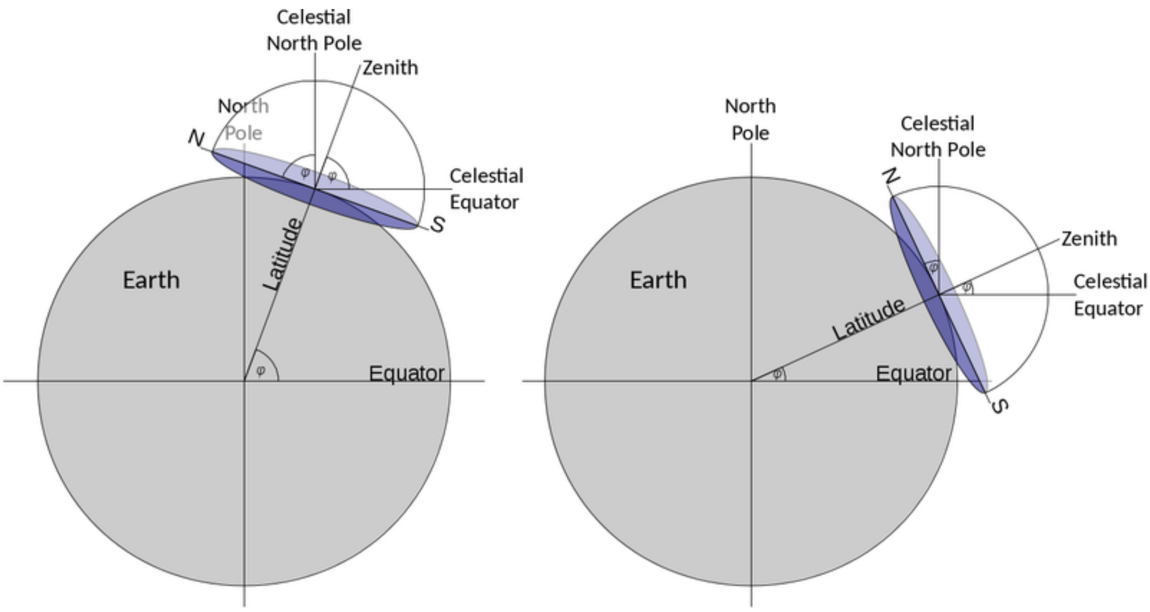
If we stood exactly at the geographic North Pole, Polaris would always be directly overhead. We can say that its elevation would be (almost) 90°. This information introduces the horizontal coordinate system (Figure 5). It is the natural reference we use every day. We, the observers, are the origin of that coordinate system located on a flat plane, whose edge is the horizon. The sky is imagined as a hemisphere above. The angle between an object in the sky and the horizon is the alti¬tude or elevation. The direction within the plane is given as an angle between 0° and 360°, the azi¬muth, which is usually counted clockwise from north. In navigation, this is also called the bearing. The meridian is the line that connects North and South poles at the horizon and passes the zenith.

Figure 5: Illustration of the horizontal coordinate system. The observer is the origin of the coordinates assigned as azi-muth 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).



For any other position on Earth, the celestial pole or Polaris would appear at an elevation smaller than 90°. At the equator, it would just graze the horizon, i.e. be at an elevation of 0°. The correla-tion between the latitude (North Pole = 90°, Equator = 0°) and the elevation of Polaris is no coinci-dence. Figure 6 combines all the three mentioned coordinate systems. For a given observer, at any lati¬tude on Earth, the local horizontal coordinate system touches the terrestrial spherical polar coordi¬nate system at a single tangent point. The sketch demonstrates that the elevation of the celestial north pole, also called the pole height, is exactly equal to the northern latitude of the observer on Earth.

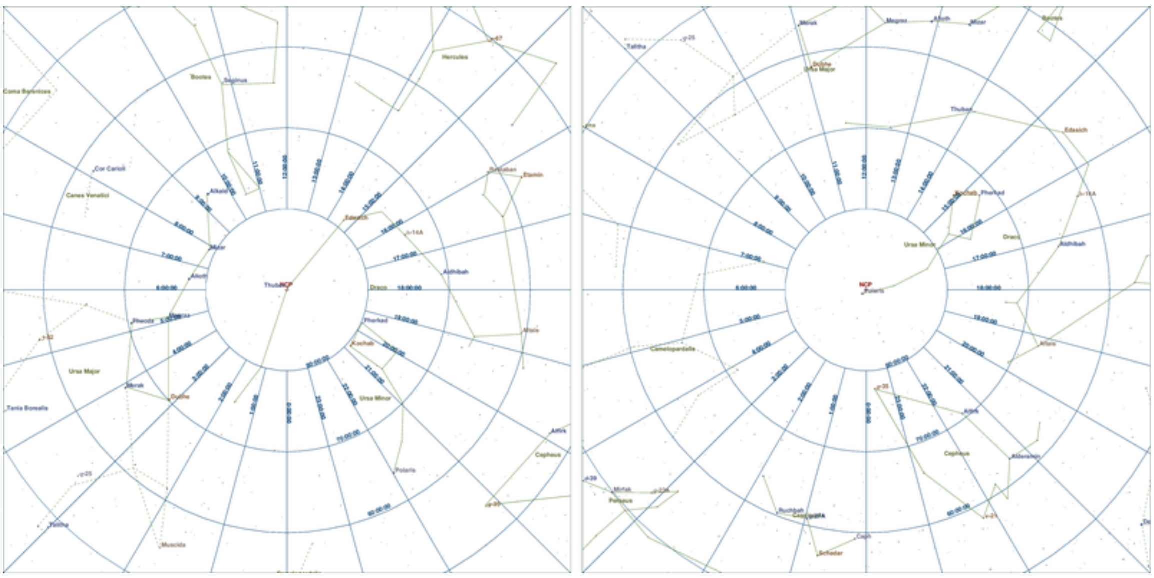
Figure 6: When combining the three coordinate systems (terrestrial spherical, celestial equatorial, local horizontal), it becomes clear that the latitude of the observer is exactly the elevation of the celestial pole, also known as the pole height (Credit: own work). From this, we can conclude that if we measure the elevation of Polaris, we can determine our lati-tude on Earth with reasonable precision.



Circumpolar stars and constellations

In ancient history, e.g. in the Bronze Age, Polaris could not be used to determine north. Because of the precession of the axis of the Earth, it was about 30° away from the celestial north pole in 3,500 BCE. Instead, the star Thuban (α Draconis) was more appropriate, as it was less than 4° off. However, it was consid¬erably fainter than Polaris and perhaps not always visible to the naked eye.

Figure 7: Star charts of the northern celestial pole region for the years 2750 BCE and 2016 CE (Credits: own work, created with XEphem Version 3.7.6, produced by Elwood C. Downey and distributed by the Clear Sky Institute Inc., Solon, Iowa, USA, http://www.xephem.com).



When looking at the night sky, some stars within a certain radius around the celestial poles never set; they are circumpolar (see Figure 3). Navigators were skilled enough to determine the true posi¬tion of the celestial pole by observing a few stars close to it. This method also works for the southern celestial pole. There are two videos that demonstrate the phenomenon.

CircumpolarStars Heidelberg 49degN (Duration: 0:57) https://youtu.be/uzeey9VPA48

CircumpolarStars Habana 23degN (Duration: 0:49) https://youtu.be/zggfQC_d7UQ

They show the movement of the night sky when looking north for two different latitudes, coinciding with the cities of Heidelberg, Germany (49° North) and Lisbon, Portugal (23° North). The videos illustrate the following: 1. There are always stars and constellations that never set. Those are the circumpolar stars and constellations. 2. The angle between the celestial pole (Polaris) and the horizon depends on the latitude of the observer. In fact, these angles are identical. 3. The circumpolar region depends on the latitude of the observer. It is bigger for locations closer to the pole. If the students are familiar with the use of a planisphere, they can study the same phenomenon by watching the following two videos. They show the rotation of the sky for the latitudes 20° and 45°. The transparent area reveals the visible sky for a given point in time. The dashed circle indicates the region of circumpolar stars and constellations.

CircumPolarStars phi N20 (Duration: 0:37) https://youtu.be/Uv-xcdqhV00

CircumPolarStars phi N45 (Duration: 0:37) https://youtu.be/VZ6RmdzbpPw

When sailing north or south, sailors observe that with changing elevation of the celestial pole, the circumpolar range is altered, too. Therefore, whenever navigators see the same star or constellation culminating – i.e. passing the meridian – at the same elevation, they stay on the 'latitude'. Although the educated ancient Greeks were familiar with the concept of latitude of a spherical Earth, common sailors were probably not. For them, it was sufficient to realise the connection between the elevation of stars and their course. Ancient navigators knew the night sky very well. They utilised the relative positions of constellation to determine their position in terms of latitude.

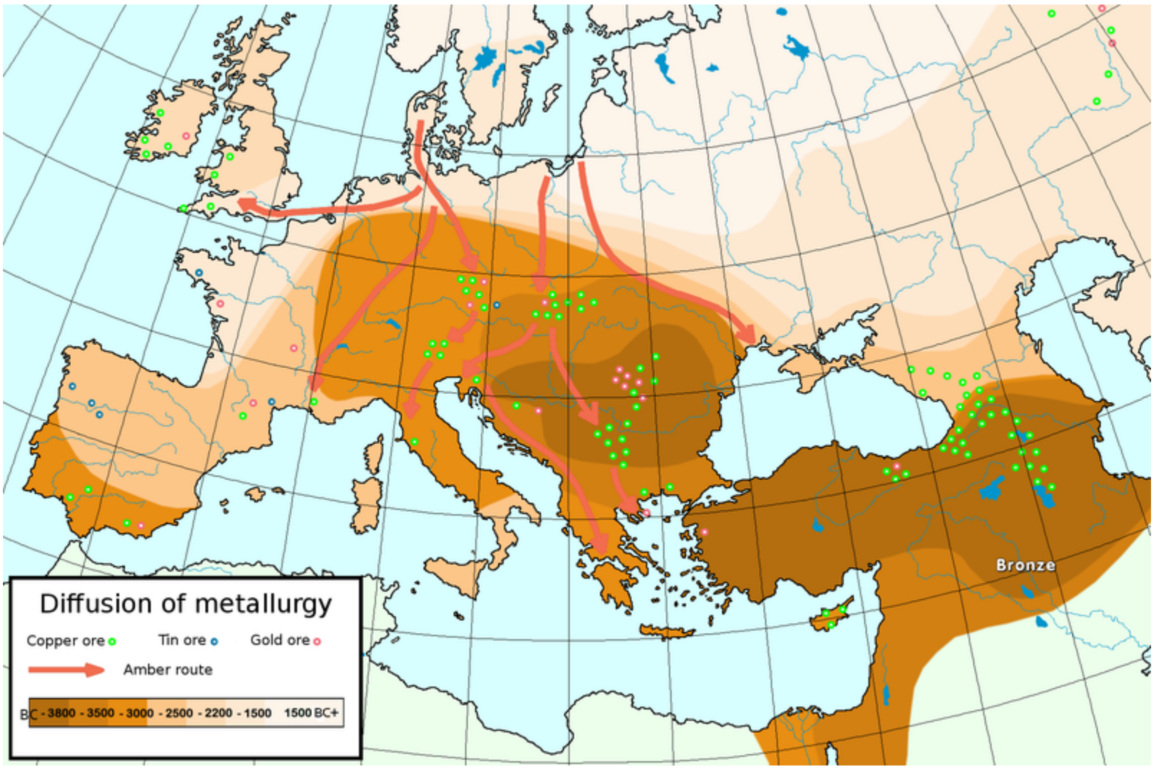
Early seafaring and navigation in the Mediterranean

Navigation using celestial objects is a skill that was practised long before humans roamed the Earth. Today, we know numerous examples of animals who find their course using the day or night sky. Bees and monarch butterflies navigate by the Sun (Sauman et al., 2005), just like starlings (Kramer, 1952). Even more impressive is the ability of birds (Emlen, 1970; Lockley, 1967; Sauer, 1958) and seals (Mauck, Gläser, Schlosser, & Dehnhardt, 2008) that identify the position of stars during night-time for steering a course. However, in our modern civilisation with intense illumination of cities, strong lights can be mistaken for celestial objects. For instance, moths use the moon to maintain a constant course, but if confused by a street lamp, they keep circling around it until exhaustion (Stevenson, 2008). Hence, light pollution is a serious threat to many animals. The magni¬tude of the problem is shown in Figure 8.

Figure 8: The Iberian Peninsula at night seen from the International Space Station (Credit: Image courtesy of the Earth Science and Remote Sensing Unit, NASA Johnson Space Center, mission-roll-frame no. ISS040-E-081320 (26 July 2014), http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=ISS040&roll=E&frame=081320).

Among the first humans to have navigated the open sea were the aboriginal settlers of Australia some 50,000 years ago (Hiscock, 2013). The oldest records of seafaring in the Mediterranean date back to 7,000 BCE (Hertel, 1990), done on boats or small ships that were propelled by paddles only. The routes were restricted close to the coast, where landmarks helped navigate to the desired destinations. To cross larger distances, a propulsion mechanism independent of muscle force was needed. Therefore, the sail was one of the most important inventions in human history, similar in its significance to the wheel. Around the middle of the 4th millennium BCE, Egyptian ships sailed the eastern Mediterranean (Bohn, 2011) and established trade routes with Byblos in Phoenicia, the biblical Canaan, now Lebanon. This is about the time when the Bronze Age began. Tin was an important item in the Bronze Age, and tin sources in central and western Europe triggered large scale trade (Penhallurick, 1986). Transportation over large distances inside and outside the Mediterranean was accomplished by ships.

Figure 9: Map of the diffusion of metallurgy. Bronze Age tin deposits were mostly found at the European Atlantic coast (Credit: User: Hamelin de Guettelet, https://commons.wikimedia.org/wiki/File:Metallurgical_diffusion.png, public domain).

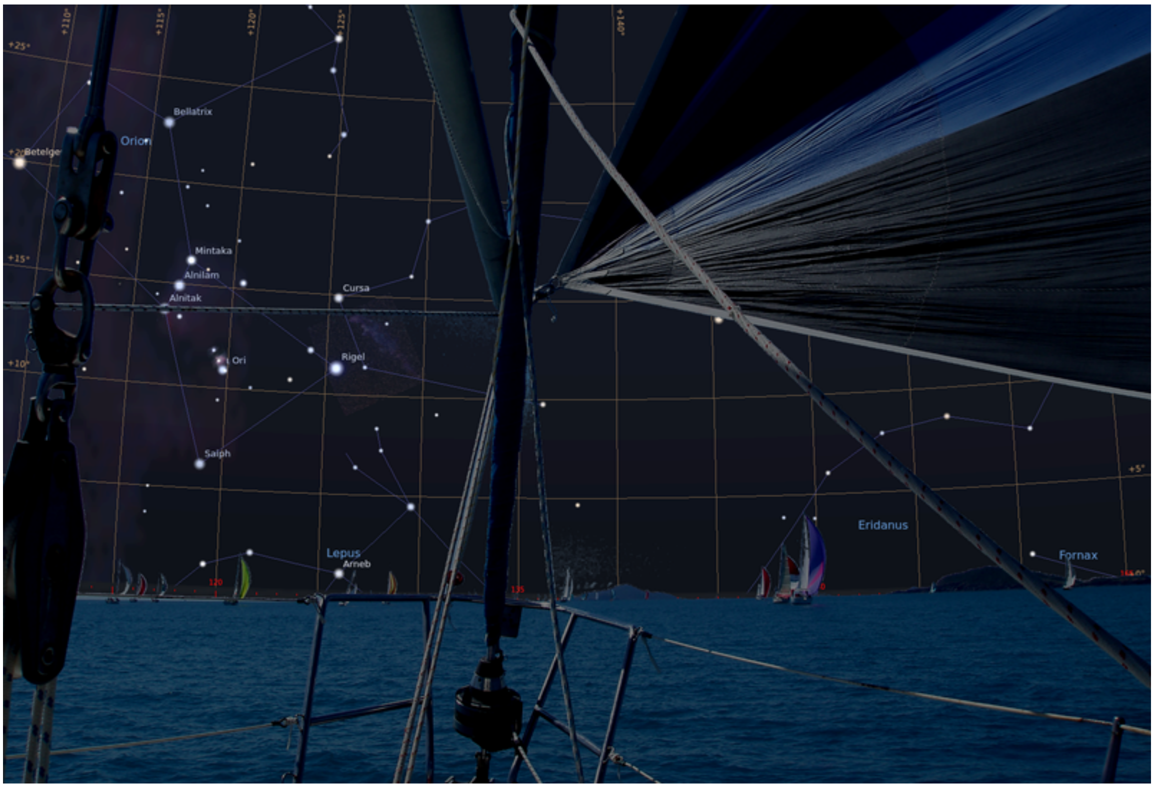


Soon, the navigators realised that celestial objects, especially stars, can be used to keep the course of a ship. Such skills have been mentioned in early literature like Homer's Odyssey which is believed to date back to 8th century BCE. The original sources are thought to originate from the Bronze Age, in which the Minoans of Crete were a particularly influential people. They lived between 3,650 and 1,450 BCE in the northern Mediterranean region and sailed the Aegean Sea. Since many of their sacral buildings were aligned with the cardinal directions and astronomical phenomena like the rising Sun and the equinoxes (Henriksson & Blomberg, 2008, 2009), it is reasonable to believe that they used this knowledge for navigation, too (Blomberg & Henriksson, 1999). The Minoans sailed to the island of Thera and Egypt, which would have taken them several days on open water.

Figure 10: Map of Crete with ancient Minoan sites in the early 2nd millennium BCE (Credit: Eric Gaba (Sting), https://commons.wikimedia.org/wiki/File:Crete_integrated_map-en.svg, annotations in red by Markus Nielbock, https://creativecommons.org/licenses/by-sa/4.0/legalcode).

The Greek poet Aratos of Soli published his Phainomena around 275 BCE (Aratus, Callimachus, & Lycophron, 1921), describing in detail the positions of constellations and their order of rising and setting. This was vital information for any navigator to maintain a given course. He would simply have pointed his ship at a bearing and be able to keep it, with the help of stellar constellations that appeared towards that heading. The azimuth of a given star when rising or setting remains con-stant throughout the year, except for a slow variation over 26,000 years caused by the pre¬cession of the Earth axis. Interestingly, Aratos' positions did not fit the Late Bronze and Early Iron Age but suited the era of the Minoan reign (Blomberg & Henriksson, 1999) some 2,000 years earlier. Around 1,200 BCE, the Phoenicians became the dominating civilisation in the Mediterranean. They built colonies along the southern and western coasts of the Mediterranean and beyond. Among them was the colony of Gades (now Cadíz), just outside the Strait of Gibraltar, which served as a trading point for goods and resources from northern Europe (Cunliffe, 2003; Hertel, 1990). Several documented voyages through the Atlantic Ocean took them to Britain and even several hundred miles south along the African coast (Johnson & Nurminen, 2009).

Figure 11: The night sky with bearing from Crete to Alexandria for 22 September 2000 BCE, 21:30 UT (Credit: own work, created with Stellarium, free GNU GPL software, after Blomberg & Henriksson (1999), Fig. 9).



The Greek historian Herodotus (ca. 484 – 420 BCE) reports of a Phoenician expedition funded by the Egyptian Pharaoh Necho II (610 – 595 BCE) that set out from the Red Sea to circumnavigate Africa and returned to Egypt via the Mediterranean (Bohn, 2011; Hertel, 1990; Johnson & Nurminen, 2009). The sailors apparently reported that at times the Sun was located north (Cunliffe, 2003), which is expected after crossing the equator to the south. All this speaks in favour of extraordinary navigational skills. After the Persians conquered the Phoenician homeland in 539 BCE, their influence declined, but was re-established by descendants of their colonies, the Carthaginians.

Figure 12: Trade routes of the Phoenicians during the European Bronze Age (Credit: DooFi, https://commons.wikimedia.org/wiki/File:PhoenicianTrade_EN.svg, https://creativecommons.org/licenses/by-sa/3.0/ legalcode).

Pytheas

A very notable and well documented long distance voyage has been described by ancient authors and scholars like Strabo, Pliny and Diodorus of Sicily. It is the voyage of Pytheas (ca. 380 – 310 BCE), a Greek astronomer, geographer and explorer from Marseille who at around 320 BCE apparently left the Mediterranean, travelled along the European west coast and made it up north until the British Isles and beyond the Arctic Circle, during which he possibly reached Iceland or the Faroe Islands that he called Thule (Baker & Baker, 1997; Cunliffe, 2003; Hergt, 1893). Massalia (or Massilia), as Thule was called then, was founded by Phocean Greeks around 600 BCE and quickly evolved into one of the biggest and wealthiest Greek outposts in the western Mediterranean with strong trade relations to Celtic tribes who occupied most of Europe (Cunliffe, 2003). Pytheas was born in the Late Bronze Age, when the trade with regions in northern Europe was flourishing. Not much was known in Greek geography about this part of the world, except that the barbarians living there mined tin ore and delivered the precious amber that the whole Mediterranean so desperately sought. Perhaps, it was out of pure curiosity that Pytheas set out to explore these shores.

Figure 13: Statue of Pytheas, erected at the Palais de la Bourse in Marseille in honour of his achievements (Credit: Rvalette, https://commons.wikimedia.org/wiki/File:Pythéas.jpg, ‘Pythéas’, https://creativecommons.org/licenses/by-sa/3.0/legalcode).

His voyage was a milestone, because Pytheas was a scientist and a great observer. He used a gnomon or a sundial, which allowed him to determine his latitude and measure the time during his voyage (Nansen, 1911). He also noticed that in summer the Sun shone longer at higher latitudes. In addition, he was the first to notice a relation between the tides, which are practically absent in the Mediterranean, and the lunar phases (Roller, 2006).

Figure 14: The journey of Pytheas of Massalia according to Cunliffe (2003) (Credit: ESA/Cunliffe, http://www.esa.int/spaceinimages/Images/2005/09/The_journey_of_Pytheas, http://www.esa.int/spaceinimages/ESA_Multimedia/Copyright_Notice_Images).

Glossary

Apparent movement Movement of celestial objects which is in fact caused by the rotation of the earth.

Cardinal directions Main directions, i.e. North, South, West, East

Circumpolar Property of celestial objects that never set below the horizon.

Culmination Passing the meridian of 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.

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

Meridian A line that connects North and South at the horizon via the Zenith.

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

Precession Besides the rotation of a gyroscope or any spinning body, 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 precession of the Earth axis takes roughly 26,000 years.

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 a beginning nor an end. 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 with one of them being related to the symmetry axis. Such axis defines two poles. In addition, there is the radius that represents the third dimension of space, which permits determining each point within a sphere. This defines the spherical polar coordinates. When defining points on the surface of a sphere, the radius stays constant.

Sundial A stick that projects a shadow cast by the Sun. The orientation and length of the shadow heps determine time and latitude.

Zenith Point in the sky directly above.

FULL DESCRIPTION

Introduction

It would be beneficial if the activity were integrated into a larger context of seafaring, e.g. in geography, history, literature, etc.

Tip: This activity could be combined with other forms of acquiring knowledge like an oral presentation in history, literature or geography focusing on navigation. This would prepare the field in a much more interactive way than what a teacher can achieve by summarising the facts.

Students could be shown some good documentaries available on sea exploration. As an introduction to celestial navigation in general and the early navigators, let the students watch the following videos. The last one is in French. This could be done in conjunction with French lessons in school. If not, narrate the story of Pytheas as outlined in the background information. A link to literature or history classes may be established by reading 'The Extraordinary Voyage of Pytheas' by B. Cunliffe.

Episode 2: Celestial Navigation (Duration: 4:39) https://www.youtube.com/watch?v=DoOuSo9qEll

How Did Early Sailors Navigate the Oceans? | The Curious Engineer (Duration: 6:20) https://www.youtube.com/watch?v=4DINhbkPiYY

World Explorers in 10 Minutes (Duration: 9:59) https://www.youtube.com/watch?v=iUkOfzhvMMs

Once Upon a Time ... Man: The Explorers - The First Navigators (Duration: 23:13) https://www.youtube.com/watch?v=KuryXLnHsEY

Pythéas, un Massaliote méconnu (French, duration: 9:57) https://www.youtube.com/watch?v=knBNHbbu-ao

Ask the students if they know for how long human beings have used ships to cross oceans. One may point out the migration of the 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 them, what could have been the benefit of exploring the seas. Perhaps, someone knows historic cultures or people who were famous sailors. The teacher can support this with a few examples of ancient seafaring peoples, e.g. from the Mediterranean.

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

Ask the students, how they find their way to school every day. What supports their orientation so that they do not get lost? When reference points (buildings, traffic lights, bus stops, etc.) have been mentioned, ask the students 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. Magnetic compasses were invented rather late around the 11th century CE, and they were not used in Europe before the 13th century. But what could be used as reference points at open sea? The students may mention celestial objects like the Sun, the Moon and stars.

Suggested additional questions, especially after showing the introductory videos
Q: Who was Pytheas? A: He was an ancient Greek scientist and explorer.

Q: Where and when did he live? A: He lived in 4th century BCE during the Late Bronze Age in Massalia, now Marseille.

Q: Where did he travel? A: Pytheas travelled north along the Atlantic coast of Europe to Britain and probably to the Arctic Circle and Iceland.

Q: What did he observe and discover during his voyage? A: He was the first Greek to travel far into the north. He noticed that the length of daylight depends on latitude. He was also the first to relate the tides to the phases of the moon.

Activity 1: Circumpolar constellations and stars

Materials needed: Worksheets Compasses Pencil Ruler Calculator

In the absence of a bright star at the celestial poles, ancient navigators were able to find the celestial poles by observing a few circumpolar stars. These navigators were experienced enough to determine the true north by recognising the relative position of such stars and by their paths around it.

In addition, they used circumpolar constellations and stars to infer their latitude. They never rise or set – they are always above the horizon. While today we can simply measure the elevation of Polaris above the horizon, ancient navigators saw Polaris many degrees away from the celestial north pole. In the Southern Hemisphere, there is no such stellar indicator anyway. So, instead of measuring the elevation of Polaris, they observed the stars and constellations that were still visible above the horizon when they attained their lowest elevation above the horizon (lower culmination) during their apparent orbit around the celestial pole.

Let the students watch the following two videos that demonstrate the phenomenon of circumpolar stars and constellations for two locations on earth. They show the simulated daily apparent rotation of the sky around the northern celestial pole.

CircumpolarStars Heidelberg 49degN (Duration: 0:57) https://youtu.be/uzeey9VPA48

CircumpolarStars Habana 23degN (Duration: 0:49) https://youtu.be/zggfQC_d7UQ

The students will notice that There are always stars and constellations that never set. Those are the circumpolar stars and constellations. The angle between the celestial pole (Polaris) and the horizon depends on the latitude of the observer. In fact, these angles are identical. The circumpolar region depends on the latitude of the observer. It is bigger for locations closer to the pole. If the students are familiar with the use of a planisphere, they can study the same phenomenon by watching the following two videos. CircumPolarStars phi N20 (Duration: 0:37) https://youtu.be/Uv-xcdqhV00 CircumPolarStars phi N45 (Duration: 0:37) https://youtu.be/VZ6RmdzbpPw They show the rotation of the sky for the latitudes 20° and 45°. The transparent area reveals the visible sky for a given point in time. The dashed circle indicates the region of circumpolar stars and constellations.

Questions Q: What is special about the geographic North and South Poles of the Earth compared to other locations? A: They define the rotation axis of the earth.

Q: How do you find north and the other cardinal directions without a compass? A: Celestial bodies, e.g. stars like Polaris, indicate the celestial north pole.

Q: Why does the North Star (Polaris) indicate North? A: In our lifetime, Polaris is close to the celestial north pole.

Q: Where in the sky would you find the celestial north/south pole if you stood exactly at the terrestrial North/South Pole? A: At the zenith, i.e. directly overhead.

Q: How would this position change, if you travelled towards the equator? A: Its elevation would decline from zenith to the horizon.

Q: What are circumpolar constellations? A: These are constellations that revolve around one of the celestial poles and never rise or set. They are always above the horizon.

Q: Which of the visible constellations would be circumpolar, if you stood on the terrestrial North/South Pole or the equator? A: The entire Northern/Southern Hemisphere (poles). None at the equator.

Q: If the North Star was not visible, how would you be able to determine your latitude? A: Since the circumpolar stars and constellations depend on the latitude, just like the elevation of Polaris, the ones that always stay above the horizon will indicate where I am.

Exercise

The task is now to walk in the footsteps of a navigator that lived around 5,000 years ago. Using those skills, the students will determine the constellations that are circumpolar when observed from given positions on Earth.

The table below contains the names of six cities along with their latitudes φ. Negative values indicate southern latitudes. The seventh row is empty, where the students can add the details of their home town. From this, they will have to calculate the angular radii ϱ from the celestial pole. The calculation is simple, because it is the same as the pole height and the latitude:

$$\varphi=\varrho$$

Then they can select the map that matches the hemisphere. The students use the compasses to draw circles of those radii around the corresponding pole. The constellations inside that circle are circumpolar. The constellations that are fully or partially visible for a given city are added to the table.

Possible solutions are added in italics. The table prepared for the exercise is contained in the worksheet.

City	Latitude (°)	Radius in map (cm)	Constellations
Tunis (ancient Carthage, Tunisia)	36.8	3.7	*Ursa Minor, Ursa Major (Big Dipper), Draco, Cepheus, Cassiopeia*
Cape Town (South Africa)	-33.9	3.4	*Crux, Pavo (Peacock), Achernar, most of Carina, Toliman of Centaurus*
Plymouth (UK)	50.4	5.0	*Ursa Minor, Ursa Major, Draco, Cepheus, Cassiopeia, Perseus (mostly), part of Cygnus with Deneb*
Wellington (New Zealand)	-41.3	4.1	*Carina (incl. Canopus), Ara, Pictor, Dorado*
Mumbai (India)	19.0	1.9	*Ursa Minor*
Grytviken (South Georgia)	-54.3	5.4	*Centaurus (complete), Lupus, Main part of Puppis, Phoenix, Grus*
			-

Table 1: List of cities along with their latitudes. The solutions from activity 1 are added in italic writing.

Detailed instructions Determine the map scale. The angular scale is 90° from the poles to the outer circle, i.e. the celestial equator. Convert the latitudes in the table into radii in the scale of the maps and add them to the table. For each of the cities: Select the suitable map. Use the compass to draw a circle with a radius that was determined for that city. Find and note the visible circumpolar constellations. If they are too many, just select the most prominent ones.

Discussion In ancient times, Polaris did not coincide with the celestial north pole. Explain the importance of circumpolar stars and constellations for ancient navigators.

Possible result: They provided an excellent tool to maintain latitude and prevented navigators from getting lost at open sea.

Figure 15a: Star chart of the Northern Hemisphere

Figure 15b: Star chart of the Southern Hemisphere (Credit: Markus Nielbock, https://commons.wikimedia.org/wiki/File:NorthernCelestialHemisphere.png, https://commons.wikimedia.org/wiki/File:SouthernCelestialHemisphere.png, https://creativecommons.org/licenses/by/4.0/legalcode, created with PP3, http://pp3.sourceforge.net)

Solutions The map scale is: 1cm $\propto$ 10°

Northern sky

Southern Sky

Activity 2: Stars guide the way

Materials needed: Worksheet Pencil Protractor Computer with MS Excel installed Excel spreadsheet ‘AncientMediterranean_BrightStars_EUSPACE-AWE_Navigation.xlsx’

In the absence of a star like Polaris that indicates a celestial pole, ancient navigators used other stars and constellations to determine cardinal directions and their ship’s course. They realised that the positions where they appear and disappear at the horizon (the bearings) do not change during a lifetime. Experienced navigators knew the brightest stars and constellations by heart.

Figure 16: Bearings of selected rising bright stars for latitude 45° at an elevation of 10° above the horizon (own work).

Questions

Q: Can you determine the cardinal directions from other stars than Polaris? Note that there is no star at the South Pole. A: Yes. If you know the stars and constellations, they can guide the way, as they return to the same positions each day.

Q: How can you use rising and setting stars and constellations to steer a course on sea? A: The position at the horizon when rising and setting does not change (except for a very slow long term variation).

Q: Would you be able to see the same stars every night during the year? A: No, the time of rising and setting changes. Stars visible during winter nights are up during summer daytimes.

Exercise The students will produce a stellar compass similar to Figure 16. The calculations that are needed to convert the sky coordinates of the stars into horizontal coordinates, i.e. azimuth and elevation, are quite complex. Therefore, this activity comes with an Excel file that does it for them. It consists of 57 bright stars plus the Pleiades, which is a very prominent group of stars.

All they have to do is enter the latitude of their location and the elevation of the stars in the corresponding line at the bottom of the spreadsheet. For the elevation, 10° is a good value. This means that they will get the azimuths of the stars when observed at an elevation of 10°. One can also use different values, but this exercise is meant for finding stars that just rise or set. The azimuth is an angle along the horizon, counting clockwise from the north.

The last two columns (AZ1, AZ2) then display two azimuths, one when the star is rising and one when the star is setting. Note that the distribution of azimuths for rising and setting stars is symmetric relative to the meridian, i.e. the line that connects North and South. The cells that show #NA do not contain valid numbers. These stars never rise or set. They are either circumpolar or below the horizon.

The students translate the values into the stellar compass below. They use a protractor and indicate the position of each star on the circle. Then they write its name next to it.

Discussion One of the methods to navigate through the ancient Mediterranean was to stay close to the shores. Besides the danger of shallow waters, explain why Bronze Age mariners must have developed methods that would allow them to safely navigate on open waters. You may want to look at a map of the Mediterranean.

Possible answers: The ancient people visited islands for trade or other reasons. Many of them are not visible from the Mediterranean coastlines. The voyages would often last longer than a few hours. Vessels of that age were able to cover five nautical miles per hour on average. There are also reports that were passed on through the ages which tell us about celestial navigation.

Activity 3: Do it yourself! (Supplemental)

Materials needed: Results of the previous activities Portable red lamp e.g. a dimmed torch or a torch covered with a red filter A magnetic compass if available

Nothing is more instructive than applying what has been learned and exercised in theory to real conditions. Therefore, the results from the previous two activities can be tested in the field by observing the night sky.

This activity can be done by the students themselves at home or as a group event with the class.

Select a clear evening and a site with a good view of the horizon. Once it is dark enough to see the stars, let the students use their dimmed torches to inspect their maps with the circumpolar ranges from activity 1. A dimmed torch – better still, a red one – helps to keep the eyes adapted to the dark.

After identifying the brightest stars, let them use their stellar compasses from activity 2. The students should point the markers of one or some of the stars to the stars at the sky. Let them identify north (or south, depending on which celestial pole is visible from your location). If in the Northern Hemisphere, does this match the direction to the North Star, Polaris? In the Southern Hemisphere, a magnetic compass might be needed.

Let the students identify the constellations they see in the sky on their maps. Ask them to look north (south in the Southern Hemisphere) and name the stars and constellations that are just above the horizon. Does this coincide with the maps? Note that there should be a circle that indicates the circumpolar range for the local latitude.

Try to highlight that by doing this activity, they are working like the navigators from 4,000 years ago.

EVALUATION

According to the questions listed in the description of the activity, the teacher should guide the students to recognise the positions and the apparent movement of the celestial objects as indicators for cardinal directions.

Before working on activity 1, the students should look closely at the map provided. A visit to a planetarium may help remember the constellations. Let the students name constellations they already know.

Ask the students (see Q&A in the activity description) where the North Star will be seen when observed from the terres¬trial North Pole and the Equator. Then ask them, how this position changes when travelling between these locations. Once that concept is understood, introduce the rotation and the apparent motion of the stars. Show them the picture of the star trails and ask them where they come from. Ask them, which of the stars or constellations remain above the horizon for the different locations on Earth mentioned above. Those are circumpolar stars and constellations.

Explain the usage of the Excel spreadsheet needed for activity 2. Let the students compare their results for different latitudes.

Discuss with the students the possible reasons for seafaring in the ancient epochs.

The third optional activity acts as a wrap-up and can be used to evaluate what the students have understood.

CURRICULUM

ADDITIONAL INFORMATION

CONCLUSION

This lesson unit provides an insight into the navigational methods of the Bronze Age Mediterranean peoples. The students explore the link between history and astronomical knowledge. Besides an overview of ancient seafaring in the Mediterranean, the students use activities to explore early navigational skills using the stars and constellations and their apparent nightly movement across the sky. In the course of the activities, they become familiar with the stellar constellations and how they are distributed across the northern and southern sky.

CITATION

Nielbock, M., , *Navigation in the Ancient Mediterranean and Beyond*, astroEDU, 1645 doi:10.14586/astroedu/1645