# MODULE 3: NAVIGATION AND THE AGE OF EXPLORATION

## OVERVIEW

Since ancient times, humans have looked up at the stars. The patterns they saw appeared unchanging; Greek and Roman observers grouped the stars in constellations that looked exactly the same from year to year. They saw their gods, heroes, and animals in the heavens: Orion the Hunter, Cassiopeia the Queen, the Great and Small Bears, Leo the Lion, Cygnus the Swan; and so forth. The stars' constancy supported Aristotle's theory of the earth-centered universe; more practically, the stars' positions enabled early travelers to navigate at night.

The Romans used the stars chiefly to determine direction (rather than position). The most important of the stars was the North Star, or Polaris. In the northern hemisphere, it never changed its position; it seemed to be a fixed point in the heavens. The North Star is not the brightest star in the northern sky, but it is still easy to locate: it is the last star in the tail of the constellation known as Ursa Minor, the Small Bear (or Little Dipper). Nearby is the Great Bear, Ursa Major (or Big Dipper). The two stars farthest from the tail of the Big Dipper are the pointer stars: they always point to the North Star. The Big Dipper appears to wheel around the North Star as the seasons change, high above it in the summer and below it in the winter; but the pointer stars always direct the eye to the one star whose position in the night sky never changes.

For a picture showing the relative position of both the Big and Little Dippers, go to the Mystic Seaport website:

www.mysticseaport.org/public/education/planetarium.

The position of the sun could also determine direction. In the northern hemisphere, it is due south when it reaches its highest point in the sky. The limitations of using the sun and stars as aids to navigation are fairly obvious (the sky must be clear). Around the year A.D. 1000, Chinese explorers first discovered the magnetic compass. It found its way to Europe about 200 years later, and by the time Columbus and Magellan embarked on their voyages, every seafaring ship had a compass and extra needles.

By the 16th Century, it was fairly easy to determine direction (north, east, south, west). It was also possible to determine how far north or south a ship was. Position north of the equator is *latitude*, and latitude could be found by using simple devices like the backstaff and the astrolabe, which measured the angle of elevation of celestial objects above the horizon. (The ancient Greeks had astrolabes and knew the mathematics behind them. One of the most famous designers of astrolabes was Hypatia of Alexandria.) The angles

changed as travelers went north or south, and their positions could be determined by reference to charts; no actual mathematical calculations were necessary.

The disc was held, using the ring on top, so that the horizontal axis lined up with the horizon. The sun was sighted along the movable bar attached (like the hand of a clock) to the center, and the angle of elevation could be determined. An improvement on the astrolabe was the sextant, which could measure angles more accurately:

More difficult to solve was the *longitude* problem: determining how far east or west from a fixed position a ship was. . In the early days of exploration, ships that crossed the Atlantic tended to stay at the same latitude all the way so they would not risk getting lost, but storms could blow them off track, and the fixed routes made them easy prey for pirates. Scientists knew that measuring longitude depended on accurately measuring time at sea. A navigator would need two precise timepieces, one set to a standard reference time (the time at the Prime Meridian) and another set to the time of the place where the sailor was. The time of day could be determined at sea by noting when the sun was at its highest point in the sky, i.e., noon. To keep track of the time, a clock was needed; but not even the best pendulum clocks worked at sea. The problem was not solved until the 19th Century, when the English clockmaker John Harrison perfected his chronometer. Harrison's chronometer was not affected by motion, temperature, or humidity, and it kept time as accurately on sea as it did on land. Today, navigation satellites enable a ship at sea to find its exact position at any moment. Such so-called global positioning depends on radio signals and works day or night, regardless of weather conditions.

The early explorers had no such technology, but their voyages would not have been possible without the technology of their own day. The compasses that pointed north and the instruments that measured latitude were essential, but so were innovations in ship design. The galleys of the Romans, the triremes of the Phoenicians, and the dhows of the Arabs could not have crossed the Atlantic Ocean. Technology was important to the mariners who sailed the waters of the Mediterranean because their ships had to weather storms and hold cargo. The distances they traveled were short, and they were seldom far from land. The Age of Exploration began after the Middle Ages, and one of its chief instigators was Prince Henry the Navigator of Portugal (1394-1460). It was the development of the *caravel*, produced by the shipbuilders of Prince Henry, that enabled Columbus to make his discoveries. The caravel had a shallow draft that enabled it to come close to shore and sails that could be adjusted so the ship could sail into the wind— essential if sailors wanted to return home against prevailing winds. The caravel was a ship designed to bring explorers back.

The following activities will help students appreciate some of the technological innovations that brought about the Age of Exploration.

## ACTIVITIES

## 1. Making a Simple Astrolabe.

To make a simple astrolabe that can be used to approximate angles of elevation, go to the website www.sci-ctr.edu.sg/ssc/publication/cv/astrolabe.html and follow the directions for construction. Cut out the pattern shown and mount it on sturdy cardboard:
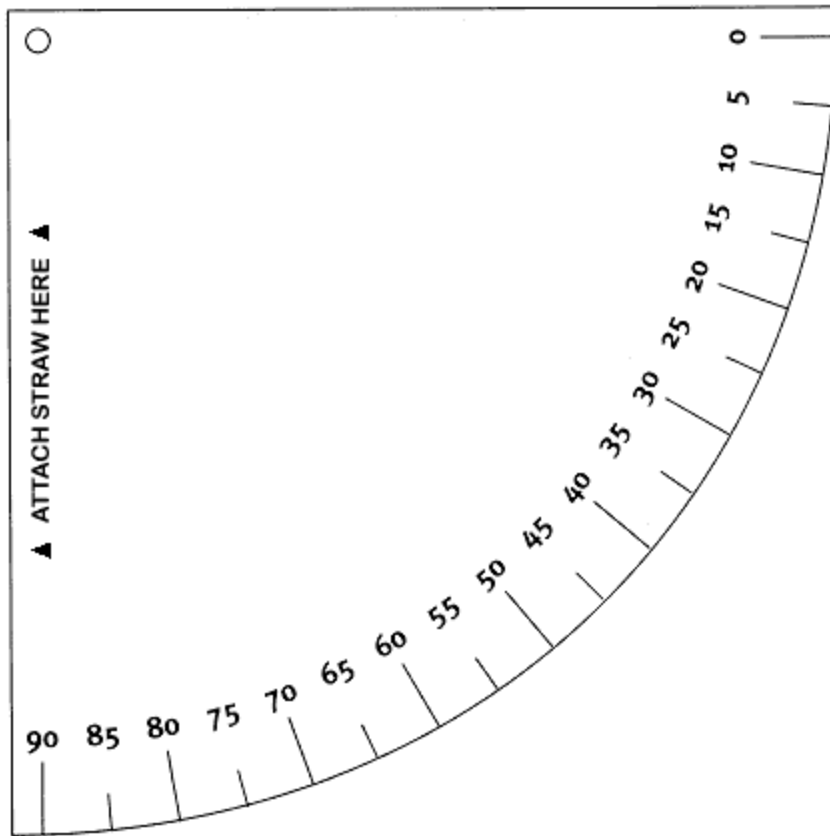


A straw is glued to one side, and a weight on a string is attached to the hole at the top so that when the weight keeps the string vertical, the angle of elevation is 0°. Other angles of elevation can be determined by sighting an object through the straw. It would be dangerous to look at the sun, but the students should get the idea of how an astrolabe was used to find angles. If a sailor measured the angle of elevation of the sun at noon, he could consult a prepared chart and determine his latitude. The sailors did not have to be mathematicians—astronomers had already done the work for them. An astrolabe could help sailors determine their latitude, or their distance north of the equator. In modern units of measurement, each degree of latitude corresponds to approximately 69 miles. A ship at a latitude of 40° north is 2760 miles north of the equator. A second ship at a latitude of 45° north is 345 miles north of the first ship

## 2. Making a Magnetic Compass

A **lodestone**, or "the stone that leads," is a natural magnet. It is believed that they were first discovered in the region of ancient Turkey known as Magnesia. A lodestone will attract pieces of iron. It can also be used to magnetize compass needles for short periods of time. (Lodestones are available at any scientific supply house.) The great explorer

Magellan took 35 needles with him on his flagship, and he himself guarded the lodestone that could be used to magnetize them.

To explain why a compass works, introduce the concept of the magnetic field. Place a bar magnet on an overhead projector and cover it with a sheet of clear plastic (perhaps an overhead transparency). Sprinkle iron filings lightly onto the sheet. They will arrange themselves in natural curves around the magnet. The curves will seem to go from pole to pole, or at the very least will radiate outward from each pole. The iron filings are aligning themselves with imaginary lines of magnetic force called lines of "flux." A magnetic field will exert a force on certain materials, notably iron and other magnets. The earth itself has a magnetic field surrounding it. The lines of flux go north to south. When a compass is placed in the earth's magnetic field, the needle will align itself with one of the lines of flux; one end will point north, the other south. Usually the colored half of the compass needle points north.

To make a simple compass, you need water, a cork, an ordinary sewing needle, and a lodestone. Cut a thin slice of the cork and float it in a bowl of water. Rub the needle across the lodestone several times and place it gently on the cork. One end of the needle should point north.

Enrichment: Orienteering. Arrange a kind of treasure hunt in the school courtyard or a similar area. Supply the students with manufactured compasses and a set of directions to follow: 10 meters due north, then turn 270° and measure 5 meters, and so forth. At the end of each segment, there will be something to find: perhaps a word, a letter, etc.

**3. Primitive Navigation Using Landmarks**.

Polynesian cultures used landmarks to find their way over great distances. They traveled from Tahiti to Hawaii by careful visual observation. Even though they were on the Pacific Ocean, they took note of various shoals, atolls, depth of the ocean in certain spots, reefs, and so forth. It is believed that birds also rely on visual landmarks to find their way south and north.

Ask the students to make maps of their route to school using *only* visual landmarks, not street names or numbers. For example: turn left at the McDonald's, then continue past the nursing home to the fork in the road, etc. The directions must be given both ways: how do they get to school, and how do they get home again. If time allows, have students pair off and follow other students' routes for a short distance.

**3. The Pendulum**

It is generally believed that Galileo was the first scientist to discover the principle of the pendulum. A pendulum of a given length will take the same amount of time (the "period" of the pendulum) to complete each back-and-forth swing, so long as the angle of the swing is not too great. This is easy to verify experimentally.

Materials Required: string; stopwatch or other timing device; ringstand or any support for the pendulum; various masses (called "bobs") to hang at the end of the string. A simple pendulum might look like the following:



Procedure: Tie a bob to the end of a piece of string, attach the other end to a support on a ringstand so that the pendulum swings back and forth freely. Let the distance from the center of the bob to the upper point of attachment be as close to one meter as possible. Move the bob very slightly to one side and release it. Using a stopwatch, measure how many seconds it takes for the bob to complete 10 back-and-forth trips (called "cycles" or "vibrations"). The total time should be close to 20 seconds. Now start again, but move the bob farther to one side so it swings through a larger arc. It will appear to be moving faster. Measure the time for 10 cycles; once again, it should be close to 20 seconds. Now replace the first bob with either a heavier or a lighter one and repeat the experiment; once again, the time for 10 cycles should approximate 20 seconds. Because it takes 20 seconds to complete 10 cycles, the period of the pendulum, or the time for one cycle, is 20 ÷ 10, or 2 seconds.

Try to determine the period of a shorter pendulum. Reduce the length of the string to, say, 70 or 80 centimeters. To find the period, start the pendulum swinging, then carefully time how long it takes to complete ten cycles. The period is the time divided by 10, and because the pendulum is shorter than the first one, its period should be smaller. The actual formula for the period of a pendulum is:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

In the formula, T = the time for one cycle; $l$ = the length of the pendulum; $g$ = the acceleration due to gravity. If $l$ is measured in centimeters, then $g = 980$ cm/sec$^2$. The calculations can be done easily on a calculator. Have the students make a pendulum of length 50 cm. Using a calculator, do the following: divide 50 by 980, take the square root of the answer, multiply it by 2B (or 6.28). The result is the period of the pendulum in

seconds: in this case, about 1.4 seconds. Start the pendulum and a stopwatch at the same time; let the pendulum complete ten cycles; then look at the elapsed time on the stopwatch. It should be 14 seconds.

## 4. Keeping Time

The measurement of time was revolutionized by Galileo's experiments with pendulum motion. A pendulum of a given length will have an unvarying period, regardless of how fast it is moving back and forth. A pendulum of length one meter, swinging freely, will take almost exactly two seconds for each back and forth trip, regardless of the mass of the pendulum bob or the arc of the swing. We have seen that it is easy to duplicate Galileo's pendulum experiments.

Once Galileo discovered that pendulums could be used to keep time, he lost interest in them. The first accurate pendulum clock was made by the Dutch physicist Huygens, who solved the problem of keeping the pendulum moving against frictional forces. The mechanism of the clock was designed to provide a force on the pendulum that exactly balanced the frictional force tending to slow it down.

Pendulum clocks had problems. The period of a pendulum depends on its length, but changes in temperature cause changes in length. The earth's gravity also varies slightly from place to place, and that would affect the rate at which the pendulum swung. Pendulum clocks required stability: they would not work at sea, on a rocking, pitching ship. A new type of timekeeper had to be devised, and its inventor was an English carpenter and clockmaker named John Harrison. His "chronometer" was given its first transatlantic test in 1764 when his son took it to Barbados. The chronometer was set to the time in Plymouth, England. Harrison's son found that when it was exactly noon in Barbados, it was 3:55 p.m. in Plymouth. Each hour translates to 15° of longitude, so Barbados was about 60° west of Plymouth. Within a few decades, all ships carried chronometers, and they could determine both their latitude and longitude at any point on the ocean.

To simulate how clocks are used to measure longitude, go to the Nova website for a simple interactive activity: www.pbs.org/wgbh/nova/longitude. (The Nova episode "Lost in Time" is available on video and also offers much information on the search for longitude.)

## 5. Latitude and Longitude Activities

Actual longitude and latitude calculations may be too difficult for middle school children, but it is easy enough for them to understand how coordinates can be used to pinpoint locations on the surface of the earth. Imagine the earth covered by grid lines. The lines of latitude (horizontal) are the always the same distance apart, but the lines of longitude move closer together as they approach the poles.

For the following activities, provide the students with a map of the west coast of the United States and the nearby Pacific Ocean; they should also have access to a globe.

Whale Migrations: The gray whales of the Pacific migrate south in the winter to the warm waters off the coast of Mexico to give birth. In the spring, the whales (and the newborn calves) move north again to Alaskan waters to return to their food supply. Supply the students with a world map that has a longitude/latitude grid. Have them mark the following points according to the coordinates given:

| DATE | LATITUDE | LONGITUDE |
|------|----------|-----------|
| Feb. 1 | 22° N | 112° W |
| Mar. 1 | 34° N | 120° W |
| Apr. 1 | 50° N | 130° W |
| May 1 | 55° N | 150° W |
| June 1 | 60° N | 170° W |
| Aug. 1 | 67° N | 170° W |
| Sept. 1 | 57° N | 160° W |
| Oct. 1 | 50° N | 140° W |
| Nov. 1 | 30° N | 118° W |
| Dec. 1 | 25° N | 110° W |

Several variations of this activity are possible: tracking a hurricane; bird migrations; etc.

Using Longitude to Approximate Distance

On a globe or a map of the world, have students find two cities on or near the equator. Determine the longitude of each one, to the nearest degree. Find the difference between the two longitudes. Each degree of difference corresponds to a distance of approximately 67 miles at the equator. (The calculations are more difficult further north and south of the equator.) For example, Quito, the capital of Ecuador, is at longitude 77° W. Nairobi, the capital of Kenya, is at approximately 36° E. The difference between the two is 109°. (Because Quito is east of the prime meridian and Nairobi west, the two longitudes must be added to find the difference. For two cities on the same "side" of the prime meridian, say Quito and Belem, Brazil, the difference is found by subtracting.) 109 times 67 miles is about 7300 miles, the distance from Quito to Nairobi.

The reasoning is fairly simple. The circumference of the earth at the equator is approximately 24,000 miles. The number of degrees in a circle is 360. 24,000 ÷ 360 = 66.67, so each degree of longitude corresponds to about 67 miles.

**Recommended Reading on Technology in the Age of Exploration:**

Boorstin, Daniel: *The Discoverers* (Vintage)

Burke, James: *Connections* (Little, Brown)

Sobel, Dava: *Longitude* (Penguin)