Maritime Science

This activity is adapted from Teach Engineering lessons and activities "How to be a great navigator," "The North (Wall) Star," and "Vector Voyage!"
http://www.teachengineering.org/index.php
Integrated Teaching and Learning Program, College of Engineering, University of Colorado at Boulder

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Introduction:

In this lesson students will learn how great navigators of the past stayed on course — that is, the historical methods of navigation. The concepts of dead reckoning and celestial navigation are discussed. Students will perform basic celestial navigation by reading angles from stars to the horizon to determine their classroom latitude. Finally, students will pretend to sail from Europe to North America (on paper, using vectors) and determine the location of their landfall.

Materials:
(Materials in bold are provided by SMILE)

North Star Activity:
For each team of 5:
1 straw or 12-inch ruler (straws if students will keep the quadrants)
1 piece of string (about 6 inches each)
1 sheet of poster-board or stiff paper (i.e., two pieces of construction paper glued together)
1 small weight (washer, metal nut or any small, heavy object)
1 protractor (from summer activities)
Tape
Pencil

Handouts:
- Make a Paper Quadrant-Instructions Sheet
- Star Trails Sheet
- Polaris Latitude Worksheet
- Latitude Diagonal Worksheet

Vector Voyage:
Each student should have:
Vector Voyage Worksheets 1 and 2
3 different colored pencils (blue, green and red match Worksheet instructions)

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Handouts:

- Vector Voyage Worksheet 1
- Vector Voyage Worksheet 2
- Blank Vector Voyage Worksheet
- Vector Voyage Solution Worksheet 1
- Vector Voyage Solution Worksheet 2
- Vector Voyage Solution Worksheet 3

Background:

The world today is highly organized and in our day-to-day lives we rarely think of ourselves as navigators. Either taking a hike or simply going to a large park, the thrill of wondering what's around the next corner exists, but we generally know where we are. Today people rely on technological devices and precise maps to stay on track. But, what if the batteries in a high-tech device fail? What if the map falls out of your pocket? What do you do if you do become lost in the wilderness? (Possible answers: Use a compass, look at your map, look for known landmarks, call for help.) Even visiting a city, entering a new building, traveling via subway, or getting separated from someone in a department store, we can become lost. This is when it is beneficial to know some basics of navigation.

The following topics will be discussed: dead reckoning; how early navigators knew their speed, time and direction; and celestial navigation in determining your latitude
Dead reckoning is the process of navigation by advancing a known position using course, speed, time and distance to be traveled. In other words, figuring out where you will be at a certain time if you hold the speed, time and course you plan to travel. Although dead reckoning normally has a 10% error associated with it, sailors relied on this form of navigation — also, called deduced reckoning — to travel the seas until celestial navigation was developed. Columbus — and most other sailors of his era — used this method. With dead reckoning, the navigator finds their position by estimating the course and distance they have sailed from some known point. Starting from a known point, such as a port, the navigator measures out their course and distance from that point on a chart, pricking the chart with a pin to mark the new position.

Today, navigators record their speed using a "Ship's Log," but how did early navigators know their speed to even be able to keep track of it? In Columbus' day, the ship's speed was measured by throwing a log over the front side of the ship, or "Heaving the Log." There were two marks on the ship's rail that were a measured distance apart. When the log passed the forward mark, the pilot would start a quick chant; when the log passed the aft mark, the pilot would stop chanting. (The exact words to such a chant are part of a lost history of navigation.) The pilot would then note how much of the chant he recited, which would then enable him to determine the speed of the boat based on the distance traveled. This method would not work when the ship was moving very slowly, since the chant would be over before the log actually reached the aft (last) mark.
Speed x Time = Distance

This makes sense when you look at the units:

$$\frac{miles}{hour} * hour = miles$$

The hours cancel to give your distance in miles.

Many years after the development of the Heaving the Log method, another technique came along, called the Chip Log, to measure a ship's speed. The Chip Log apparatus consisted of a small weighted wood panel that was attached to a reel of rope, which had knots tied at equal distances. Sailors would throw the wood panel into the sea, behind the ship, and the rope would start unwinding from the reel. The faster the ship was moving forward the faster the rope would unwind. Using a 30-second sand glass to time the number of knots that went overboard in a given time interval, the ship's speed could be determined. The Chip Log method is in fact the origin of the nautical speed unit, the knot, and of the Ship's Log, which is currently used by Sailors record their ship's speed.

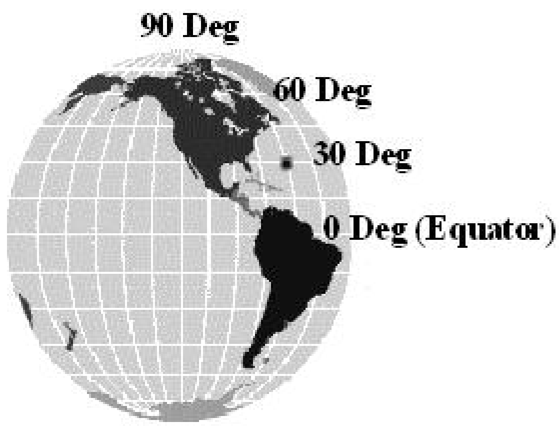

Figure 1. The Earth, measured in degrees. Copyright © J. White, University of Colorado at Boulder, 2003.

Along with their speed and distance, they needed to know the direction of travel. This was done, logically, using a compass. Since they knew their distance and direction, they could determine their current location based on their previous location.

Celestial navigation is the art and science of finding one's geographic position by means of astronomical observations, particularly by measuring altitudes of celestial objects: sun, moon, planets, or stars. This lesson looks at the basic, but very important and useful, celestial measurement of the elevation of the North Star, also called Polaris.

In ancient times, navigators planning to sail out of sight of land would simply measure the altitude of Polaris — using a cross staff, or sextant — as they left homeport. They were essentially measuring the latitude of their homeport. To return after a long voyage, they needed only to sail north or south, as appropriate, to bring Polaris to the altitude of homeport, then turn west or east as appropriate and "sail down the latitude," keeping Polaris at a constant angle.

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Vocabulary/Definitions:

Altitude:	The height of a celestial object above the horizon, measured in degrees.
Course:	The direction you intend to steer a vessel. A vessel's course does not take into account current and drift.
Course made good:	The course that you actually travel, taking into account the wind and ocean currents.
Estimated Position (EP):	A position determined through dead reckoning and may include effects of current and wind.
Landfall:	The land sighted or reached after a voyage.
Polaris:	Another name for the North Star.
Position:	The actual geographic location of a vessel identified by coordinates of latitude and longitude (for example, 040 degrees E and 45 degrees N).
Sextant:	Another name for a cross staff, which is a device used to measure altitude.
Zenith:	A point in the sky directly above a person or location (zenith elevation = 90 degrees).

If we are ever lost, or even just feel that we are lost, we often say that we need to "get our bearings," a common expression which means to figure out where you are. Before navigation by dead reckoning is possible, you need at least four pieces of information. Does anyone know what they are?

Starting Point - where you began.
Course - what direction you are traveling.
Speed - how fast you are traveling.
Time - how long you have been traveling.

Using this information and the principle of dead reckoning, you can figure out where you are. If any of these pieces of information is missing, you will not be able to determine where you will end up.

Celestial navigation requires multiple observations over time to pinpoint a location. By locating the North Star, only two pieces of information are known: the direction North, and that you are somewhere on a latitude circle of the Earth. However, this is better than nothing, for if you know the latitude of your target, you may not know how far away it is, but you know you will reach it if you stay on that latitude and keep going. Use a globe to discuss these concepts with students.

Lesson Discussion Questions:

How did people navigate before navigation instruments were designed? (Answer: natural landmarks, sun, moon, stars, dead reckoning, following animals, etc.)

True or False: If you use dead reckoning, you will never become lost. (Answer: False. Many factors — such as the chant used by sailors — that are involved in dead reckoning are not always precise, throwing off your estimate.)

True or False: If you find the North Star, you can estimate exactly where you are. (Answer: True if you are in the Northern Hemisphere, but false if you are in the Southern Hemisphere since the North Star cannot be seen from there. In ancient times, the navigators planning to sail out of sight of land would simply measure the altitude of Polaris as they left homeport, essentially measuring the latitude of their homeport. To return after a long voyage, they needed only to sail north or south, as appropriate, to bring Polaris to the altitude of home port, then turn left or right as appropriate and sail down the latitude, keeping Polaris at a constant angle.)

If you left your port and sailed southeast for two days but did not record your speed, would you know where you are? (Answer: No. You only know that you are on a line somewhere SE of your port.)

If you left your port and sailed southeast at 5 miles/hour but did record the time when you left, would you know where you are? (Answer: No. Again, you only know that you are on a line somewhere SE of your port.)

If you left your port and sailed at 5 miles/hour for two days but did not record the direction, would you know where you are? (Answer: No. You only know that you are somewhere on a circle 240 miles (48 hours x 5 mph = 240) from your port.)

Which of the above situations is the worst? Why? (Answer: the latter. In the first two scenarios, you do not know how far away you are, but you know the direction. In the last scenario, you know how far you are, but have no idea which way will take you back to homeport.)

Activity: The North (Wall) Star

Learning Objectives

After this activity, students should be able to:

- Understand the relationship between the altitude of the North Star in the sky and the latitude of the observer.
- Invent a simple device to read latitude.
- Understand the advancement of navigational techniques based on historical contributions.
- Measure angles.
- Calculate averages.
- Create a bar graph and calculate circumference (with 7th and 8th grade math extension).
- Understand the interactions of objects in the universe.

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Introduction/Motivation
How did ancient navigators planning to sail out of sight of land stay on course and return home? (Answer: They would simply measure the altitude of Polaris (the North Star) when they left homeport.) In today's terms, this would be called to measure the latitude of homeport. How did knowing the latitude of Polaris allow them to find their way home? (Answer: To return after a long voyage, early navigators needed only to sail north or south, as appropriate, to bring Polaris to the altitude of homeport. Then he would turn left or right, as appropriate, and "sail down the latitude," keeping Polaris at a constant angle.) In this activity, you will learn the basics of celestial navigation.

Background
Because the Earth rotates 360 degrees in one day, the stars appear to move across the sky just like the sun. Actually, the stars are stationary (relative to us), and we rotate around them — just like we rotate around the sun. Polaris is the only bright star in the Northern hemisphere that does not move (not much, anyway), while all other stars do move, as seen in the "Star Trails" Worksheet. This lack of movement by Polaris is because it is almost directly above the spin axis of the Earth.

Figure 1. A circular path, called star trails, is formed by many photographs — taken at consecutive intervals — of stars moving through the night sky. Copyright © http://antwrp.gsfc.nasa.gov/apod/image/0009/dometrails_cfht_big.jpg

Challenge the students to figure out from this simple observation where Polaris would appear in the sky if you were standing on the North Pole. (Answer: straight up.) Where would it appear to someone standing on the equator? (Answer: on the horizon.) The first part of this activity shows students how Polaris lies in line with the Earth's axis, but many Earth diameters (distance) away. Students will use this concept to relate the angle of elevation of the North Star (Polaris) above the horizon to latitude on Earth.

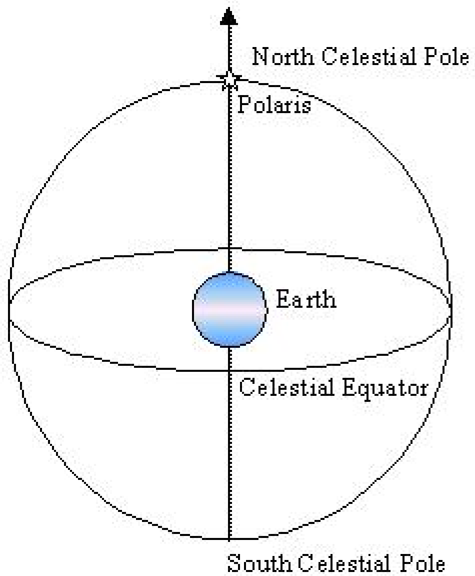

Figure 2. Because it lies on the Earth's axis of rotation, Polaris sits directly above the North Pole. Copyright © M. Lippis, University of Colorado at Boulder, 2003.

Before the Activity
Determine whether students will make paper or protractor quadrants (see below).
Cut out a paper star or picture of a star and place it high in the center of a classroom wall (the higher the better!) to act as your classroom's North Star.

With the Students
Show the students the Star Trails Sheet, either as an overhead or hold it up. Ask what the picture is of, and have the students brainstorm ideas of why it looks the way it does. Try to elicit more in-depth explanations of the pattern and the star in the middle, explaining that the picture is of star trails due to the earth's rotation. Guide the students to the idea that Polaris — the North Star — does not move because it is directly above the Earth's axis of rotation. Why is Polaris not directly overhead when we look at the night sky? (Answer: Because we are not at the North Pole.) How high is Polaris in the sky? (Answer: It depends on where you are.) The North Star can help you find out where you are on Earth.

Give students a Polaris Latitude Worksheet, and ask them to follow the instructions. Now the students will use the principles described in the Polaris Latitude Worksheet to determine the latitude of their desks in the classroom. Point out the classroom's "North Star."
Give each student a "Make a Paper Quadrant-Instructions" Sheet, and follow the directions. Or, if enough protractors are available, make Protractor Quadrants (see instructions below). (Note: Paper is obviously the best choice for students who want to keep their quadrant.)

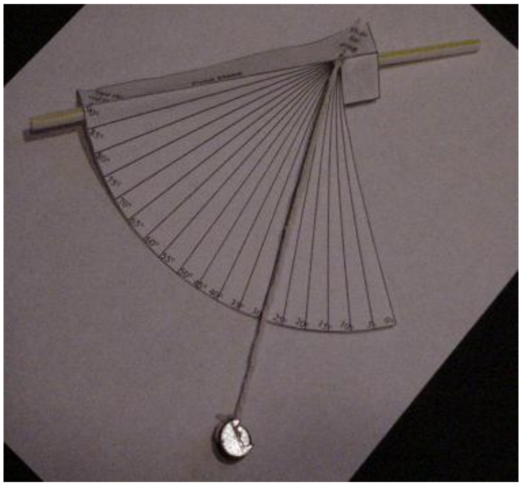

Figure 3. A student-made paper quadrant.

To Make a Protractor Quadrant: If working with a small group or if many protractors are available, use the following steps to make a Quadrant:

a) Tape a straw or ruler to the protractor so that it lies along both the 90-degree and center mark of the protractor (i.e., bisects the half-circle protractor).
b) Tie or tape a 6-inch piece of string to the center hole of the protractor, making sure the string hangs freely.
c) Tie a weight to the other end of the string. The string should lie along the 0-degree mark of the protractor if the straw or ruler is held parallel to the ground.
d) Each student should determine the relative latitude of their desk by positioning their eye, along with their quadrant, level with the edge of their desk.

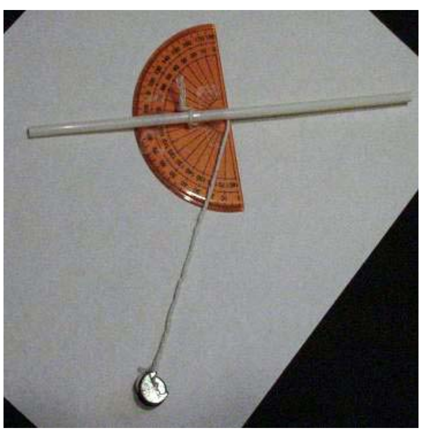

Figure 4. A student-made protractor quadrant.

Find the classroom's North Star elevation by sighting through the straw, or by touching a ruler to the cheekbone (under your eye) and then pointing the other end directly at the star.
Let the weight swing freely until it stops so that the string is pointing straight down. Have your partner read the scale. If working alone, slightly tilt the stick so that the string touches the quadrant scale. Then with your finger and thumb, hold the string against the scale, and bring the scale end around where you can read it. Record this measurement on the back of your worksheet.
Trade positions with your partner and have them take a second measurement. Record this measurement on the back of your worksheet.

Troubleshooting Tips
Although it may be tricky to get the paper and/or protractor quadrant reading precise the first time, encourage students to keep trying. Make sure the students allow the weighted string to come to a complete rest before taking their quadrant measurement.

Activity Extension
Have the students use the quadrants that they made in this activity to measure the elevation of the real North Star. Then, compare the answers to your city's actual latitude. This could be done as homework or in class if extra time is available.

Choose a city along a line of latitude about 140 miles directly south of the city you are in. Tell the students that the height of Polaris when viewed from that city is about 2 degrees LOWER than the height you see in your city. From this information, challenge them to come up with an estimate of the Earth's circumference. (Answer: Divide 140 miles by 2 degrees, and you find that 1 degree of latitude is equal to 70 miles. The Earth, a circle, has 360 degrees. Multiply that by 70, and you come up with 25,200 miles — very close to the circumference of the Earth at the equator, which is about 24,900 miles or 40,070 km.)

Activity: Vector Voyage!
Learning Objectives
After this activity, students should be able to:
- Understand the importance of speed and direction in determining one's location when traveling.
- Understand that vectors can represent distances and directions and are a good way to keep track of movement on maps.
- Use vectors to understand directions, distances, and times associated with movement and speed.
- Predict (hypothesize).
- Use velocity and time to determine location.
- Discover how wind and current affect your velocity and location.
- Use the Pythagorean Theorem for speed conversions (with 8th grade extension activity).

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Introduction/Motivation
How did ancient sea captains keep their ship on course throughout their voyage? (Answer: They used dead reckoning to figure out where they were going.) Did they follow the sun, the shoreline or even the stars? (Answer: Yes. However, by knowing the speed, time and course of their travel, they could determine where and approximately when they would arrive.) Columbus — and most other sailors of his era — used dead reckoning to navigate. With dead reckoning, the navigator finds their position by estimating the course and distance they have sailed from some known point. Starting from a known point, such as a port, the navigator measures out their course and distance from that point on a chart, pricking the chart with a pin to mark the new position. These early navigators used math to help them find their way and stay on course when wind, current and other factors might affect their journey. Unfortunately, Columbus never actually reached the destination where he thought he would end up. Why do you think that happened? How accurate is dead reckoning?

Procedure
Dead reckoning is the process of navigation by advancing a known position using course, speed, time and distance to be traveled. In other words, figuring out where you will be at a certain time if you hold the speed, time and course you plan to travel.

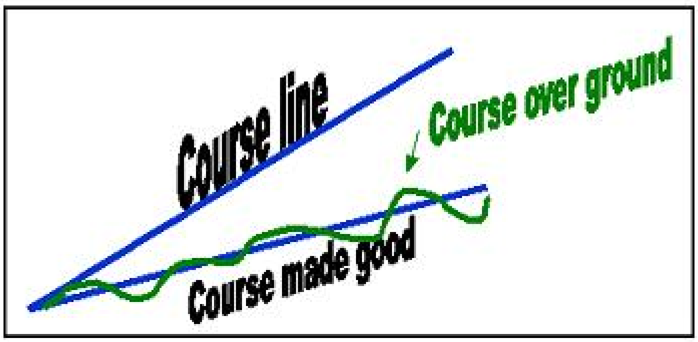

Figure 1. Graphical illustration of a vessel's voyage using vectors.

The course is the direction you intend to steer the vessel. For this exercise, the "course," or heading, is always due west (270 degrees measured clockwise from 0 degrees north). A heading is which way the vessel is going at a given point. The track actually followed can be very crooked due to wave action, current, wind and the helmsman (the person responsible for steering the vessel). Course made good is the course actually traveled.

Vectors are arrows that represent two pieces of information: a magnitude value (the length of the arrow) and a directional value (the way the arrow is pointed). In terms of movement, the information contained in the vector is the distance traveled and the direction traveled. Vectors give us a graphical method to calculate the sum of several simultaneous movements. If movement is affected by only one variable (represented by vector A or B), then a vessel would arrive at the end of that vector. If movement is affected by two variables (represented by the sum of A and B), then a vessel's final position can be found by linking the two vectors together.

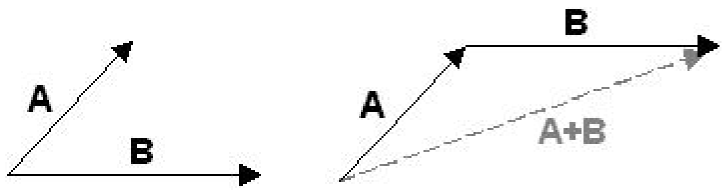

Figure 2. Vectors illustrate the final position of vessel's voyage.

Should sailors worry about wind and current when traveling long distances? (Answer: Yes. Wind and currents can take a ship far from the course it would follow otherwise. If the navigator is not keeping track of the effects of the wind and current, the ship could become hopelessly lost.)

How are vectors related to speed? (Answer: A (velocity) vector will tell both speed and direction (N, S, E, W), while speed alone does not tell you direction.)

Give each student a Vector Voyage Worksheet 1.
Using the specified color of pencil, have them draw the 10 square movement vectors straight across the map and answer the questions on the worksheet.

Have the students redraw the 10 square movement vectors on the map while adding the wind vector corrections for each month. Each month's movement vector must start from the end of the previous month's wind vector (refer to Vector Voyage Solution Worksheet 1). Have the students answer the questions on the worksheet.

Have the students redraw the 10 square movement vectors and wind correction vectors on the map while adding the current vector corrections for each month. Each month's current vector now starts from the end of the previous month's wind vector. Each month's movement vector must now start from the end of the previous month's current vector (refer to Vector Voyage Solution Worksheet 2). Have the students answer the questions on Vector Voyage Worksheet 2.

Once they are done, point out how they would have landed on the U.S. without the effects of wind or ocean currents. However, because of wind and ocean currents, they ended up in Cuba.
Tell the students that each square is 100 miles in length. Have them calculate the distance for Part 1. (Answer: 3,500 miles.)

Troubleshooting Tips
Getting started drawing the vectors may be confusing for students. If necessary, help the students by drawing the first two vectors with them on the chalkboard or in groups.

The wind correction vector is added to the end of the first vector arrow for month 1. The vectors for Part 3 of the worksheets must build off of the added vectors in Part 2. Both the wind and the ocean affect the landfall; this is represented accurately only by building off the wind correction vectors.

Vector Voyage Solution Worksheet 3 offers a summary of this activity and clearly illustrates the vector movement directly. This solution worksheet is an excellent teacher reference for students who are having difficulty with this exercise.

Activity Extensions

Using blank Vector Voyage Worksheets, have students plot their own courses — recording movements, directions and corrections along the way. They should give the new course instructions to a partner to determine if s/he can sail to the new spot.

Have the students calculate the actual total distance traveled by the ship on the way to Cuba. The actual distance traveled by the ship is the resulting vector from the sum of the three movement vectors each month. Students can draw these vectors on their maps by starting at the beginning of the solid 10 square vector for each month and drawing an arrow straight to the final position of the ship for that month. Use the Pythagorean Theorem ($a^2+b^2=c^2$) to find the lengths of these vectors. (Answer: The distance from Spain to Cuba is 3,683 miles.) The students should also be able to calculate the distance from Spain to Florida in the same manner. (Answer: 3,940 miles)

Have the students calculate the speed of the ship in miles per month and miles per hour. (Rate=distance/time) (Answer: Florida is 1.37 mph or 985 miles/month, Cuba is 1.7 mph or 1,228 miles/month, and New York is 1.39 mph or 1,000 miles/month.) Are these speeds fast or slow? How about for a time with no engines? What would happen to the food supply if there were always a breeze of 6 squares east?