How to be a Great Navigator!

Unit Topic: Navigation
Grade Level: 7th grade (with suggestions to scale for grades 6 to 8)
Lesson No. 2 of 10
Lesson Subject(s): Dead Reckoning, North Star – Latitude, Vectors
Key Words: Dead Reckoning, Celestial Navigation, North Star, Vectors, Speed, Distance, Time.

Lesson Abstract —

In this lesson, students are shown 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. The activities include:

- Vector Voyage – students will use vector analysis to understand the concepts of Dead Reckoning.
- The North Wall Star - students will perform basic celestial navigation by reading angles from stars to the horizon to determine their latitude. This activity will discuss the North Star and show how it can be used for navigation.

Lesson Opening Topics / Motivation —

The world today is highly organized and in our day-to-day lives, we rarely think of ourselves as navigators. Going on hikes, or to a large park, the thrill of *what's around the next corner* exists, but we usually know where we are. Today people rely on technological devices and precise maps to stay on track. But what if the batteries in such a device dies? 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 in the city, when going to a new store, traveling via subway, or getting separated from someone in a department store, we can be lost. This is when it pays off to know some basics of navigation.

Lesson Desired Student Outcomes —

Students will understand the concept of distance equal to speed multiplied by time. They will know that the elevation or height in degrees of the North Star is equal to the latitude of the observer.

Science: Students should be able to:

- Predict (hypothesize). (1)

- Use a protractor to measure altitude. (1)
- Interpret altitude data to form conclusions about latitude. (1)
- Share maps to show the benefits of collaboration. (1)
- Use velocity and time to determine location. (2)
- Discover how wind and current affect your velocity and location. (2,3)
- Understand how a cross staff, sextant, and clock help determine your location. (5).

Math: Students should be able to:

- Use numbers to count. (1)
- Measure angles. (5)
- Calculate averages. (3)
- Make a bar graph. (3)
- Calculate the circumference of a circle. (5)
- Use and understand vectors as they relate to slope. (2)
- Use the Pythagorean Theorem. (2)
- Convert from one unit of speed to another. (6)

Colorado State Standards Met

http://www.mcrel.org/compendium/search.asp

- Science Standard 1, 2, 3, 5
- Math Standard 1, 2, 3, 5, 6

Lesson Background & Concepts for Teachers —

Overview

The following topics will be discussed:

- Dead Reckoning
- How Navigators knew their Speed, Time and Direction
- Celestial Navigation – Determining your Latitude

Dead Reckoning

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. Prior to the development of celestial navigation, sailors navigated by *deduced* (or *dead*) *reckoning.* Columbus and most other sailors of his era used this method. In 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.

Speed, Time, and Direction

How did they know their speed? In Columbus' day, the ship's speed was measured by throwing a log over the side of the ship. There were two marks on the ship's rail a measured distance apart. When the log passed the forward mark, the pilot would start a quick chant, and when it passed the aft mark, the pilot would stop chanting. (The exact words to such a chant are part of a lost oral tradition of navigation.) The pilot would note the last syllable reached in the chant, and he had a mnemonic that would convert that syllable into a speed in miles per hour. This method would not work when the ship was moving very slowly, since the chant would run to the end before the log had reached the aft mark.

$$\text{Speed} \times \text{Time} = \text{Distance}$$

This makes sense when you look at the units:

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

The hours cancel to give your distance in miles.

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

Celestial Navigation

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, Polaris.

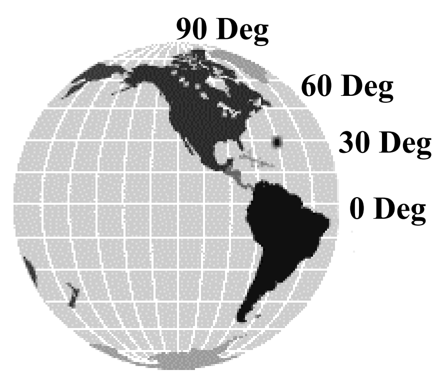


Image created by: J. White, CU-Boulder

In ancient times, the navigators planning to sail out of sight of land would simply measure the altitude, using a cross staff or sextant, of Polaris as they left homeport. They were essentially measuring the latitude of the 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.

Lesson Vocabulary List —

- **Altitude –** Height of a celestial object above the horizon measured in degrees.
- **Zenith** – Point in the sky directly above a person or location (zenith elevation = 90 degrees).

- **Course –** The course is the direction you intend to steer a vessel and 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.
- **Position** – The actual geographic location of a vessel identified by coordinates of latitude and longitude. (for example, 040 degrees E and 45 degrees N).
- **Estimated Position (EP)** – Determined through dead reckoning and may include effects of current and wind.

Activity Attachments —

Activity 1: Vector Voyage! – Students will pretend to sail from Europe to North America (on paper, using vectors) and determine the location of their landfall.

Activity 2: The North "Wall" Star – Students find their relative Classroom Latitude (and actual latitude as homework or if an evening session is possible).

Lesson Closure and Follow-up —

If we ever feel lost, we often say we need to "get our bearings." Before navigation by dead reckoning is possible, you need at least fours pieces of information. Does anyone know what they are?

- Starting Point – where you were.
- 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 know where you end up.

Celestial Navigation requires multiple observations over time to pinpoint a location. Finding the North Star alone only give you two pieces of information: the direction North and that you are somewhere on a latitude circle of the Earth. This is better than nothing; 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 the latitude and keep going. Use a globe to discuss these concepts with students.

Lesson Extension Activities —

- Print out some Blank Vector Voyage Worksheets and have students plot their own courses — recording movements, directions, and corrections along the way. They can give the new course instructions to a partner and determine if the partner can sail and "find" their spot.
- Have the students use the quadrants from Activity 2 to measure the elevation of the real North Star and compare the answers to your city's actual Latitude. This could be done as homework or as a group if an evening meeting is possible.

- On the Polaris Latitude Sheet, have students pick another latitude line on the Earth picture and draw their own tangent line to that point. They can then measure the new angle between the new tangent line and the line to Polaris to see if it matches their latitude. Are there any places on Earth that this technique would not work? (Answer: yes, it will not work anywhere in the Southern Hemisphere because the North Star is not visible there. However, other celestial measurements can be made anywhere to measure latitude.)

Lesson Assessment and Evaluation —

Pre-Lesson Assessment

- Discussion Question: Solicit, integrate, and summarize student responses.
  - Let's think of some ways people navigated before navigation instruments were designed? (Answer: natural landmarks, sun, moon, stars, dead reckoning, following animals, etc.)

Post-Introduction Assessment

- Voting: Ask a true/false question and have students vote by holding thumbs up for true and thumbs down for false. Count the number of true and false, and write the number on the board. Give the right answer.
  - True or False: If you use dead reckoning, you will never become lost? (Answer: False. The factors — such as the chant used by sailors — that play into the original dead reckoning were 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. 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 the 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.)

Post-Lesson Assessment

- Question/Answer:
  - If you left your port and sailed southeast for two days but did not record your speed, do you know where you are? (Answer: No. You only know 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, do you know where you are? (Answer: No. Again, you only know 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, do you know where you are? (Answer: No. You only know you are somewhere on a circle 240 miles from your port.)
  - Which of these 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.)

Homework

- Internet search: assign students to research on the Internet some of the concepts explored in this lesson. Lead a brief discussion of student findings during the next class period.

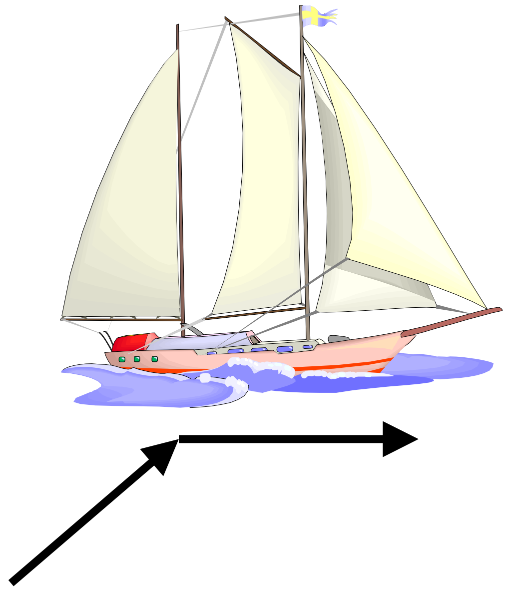
Lesson References —

http://nmp.nasa.gov/st6/TECHNOLOGY/star_trkr.html

http://vesuvius.jsc.nasa.gov/er/seh/navigate.htm

http://antwrp.gsfc.nasa.gov/apod/image/0009/dometrails_cfht_big.jpg

Activity: Vector Voyage!



This activity is planned for 28 students working individually.

Activity Materials List —

- Voyage Worksheets 1 and 2

Activity Equipment and Tools List —

- 3 different colored pencils

Activity Cost Estimate —

< $5 (assuming cost for printed copies)

Activity Attachments —

- Voyage Worksheets 1 and 2
- Blank Vector Voyage Worksheets
- Vector Voyage Solution Sheets 1 and 2

Activity Time Estimate —

30 – 40 min.

Activity Procedure —

A. Background

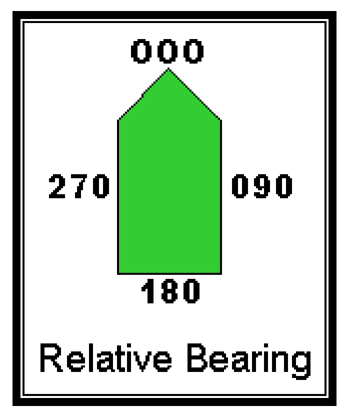


Image created by: Matt Lippis, University of Colorado, Boulder

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. In this exercise, students will use vectors to plot their course based on a time and speed. They will then correct the positions with vectors representing winds and currents. Ancient captains did this throughout their voyage to keep their ship on course!

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.

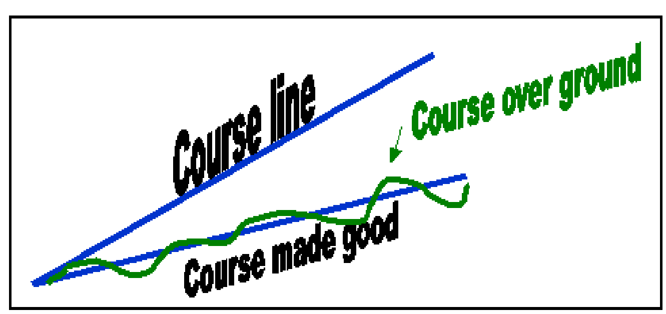
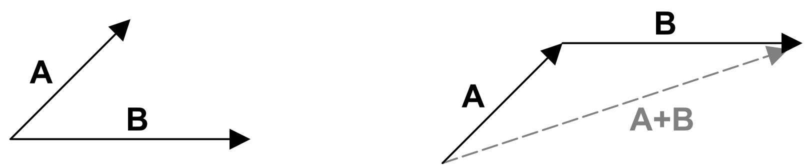


Image created by: Matt Lippis, University of Colorado, Boulder

Course Made Good is the course you actually traveled. These definitions may be oversimplified but give you the idea for this activity.

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.

Given two vectors of movement (A and B) that affect a vessel at the same time, the final position of the vessel can be found by linking the vectors together (A + B, see below).



B. Before the Activity

1. Print 28 Vector Voyage Worksheets 1 and 2 for the students, and solution sheet #1, and solution sheet #2 for yourself as an answer key.
2. Provide a brief introduction to vectors.

C. With the Students

Ask: 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 affects of the wind and current, the ship could become hopelessly lost.)

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

1. Give each student a Vector Voyage Worksheet.
2. Have them draw the 10 square movement vectors straight across the map and answer the questions on the worksheet.
3. 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 Solution Sheet). Have the students answer the questions on the worksheet.
4. 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 Solution Sheet). Have the students answer the questions on the worksheet.
5. 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.)

Math Skills Reinforced —

6th, 7th and 8th: Using vectors to understand directions, distances, and times associated with movement and speed.

8th: The Pythagorean Theorem and speed conversions (see extension activities).

Activity Troubleshooting Tips —

Getting started drawing the vectors make be confusing. If necessary, help the students out by drawing the first two vectors with them on an overhead or as a group.

Activity Desired Student Outcomes —

After this activity, students should realize that your original speed and direction are not always the only factors that determine your final location when traveling. Students should understand that vectors can represent distances and directions and are a good way to keep track of movement on maps.

Activity Assessment & Evaluation —

Pre-Activity Assessment

- Discussion Question:
  - 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 otherwise follow. If the navigator is not keeping track of the affects of the wind and current, the ship could become hopelessly lost.)

Activity Embedded Assessment

- Vector Voyage Worksheets: Have students fill out questions on attached worksheet as directed in Section C4 above.

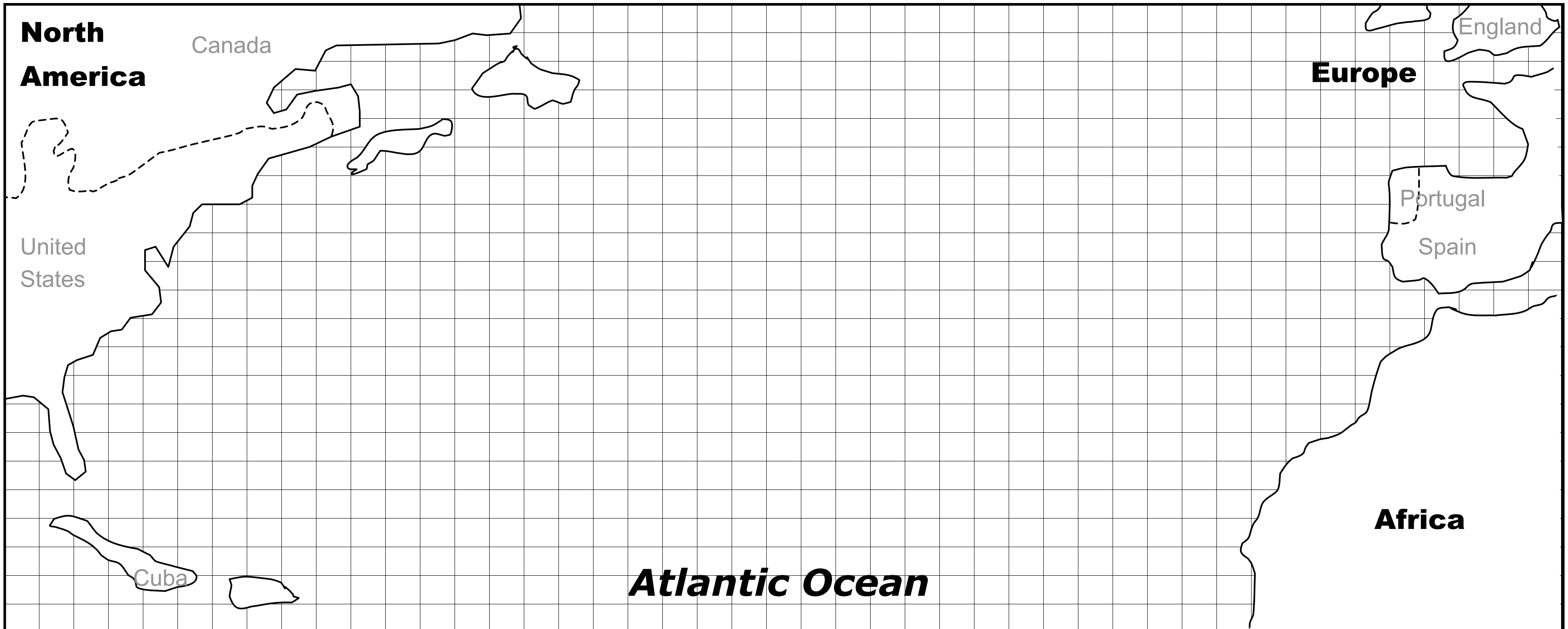
Post-Activity Assessment

- Student Generated Question:
  - Have each student pick a spot on the African coast and then determine the wind and current correction vectors that would take their ship there after 1 month of sailing east 10 squares. They should exchange these corrections with a partner (without letting the partner see their sheet), and calculate where they would arrive in Africa using their partner's corrections on their own sheet.

Suggestions to Scale Activity for Grades 6 to 8 —

- 6th Grade: Do the wind correction part of the activity together as a class. Have the students try the current correction on their own.
- 7th Grade: Do as is.

- 8th Grade: 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 3683 miles.) The students should also be able to calculate the distance from Spain to Florida in the same manner. (Answer: 3940 miles.)
- 8th Grade (if more needed): Have the students calculate the speed of the ships 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 1228 miles/month, and New York is 1.39 mph or 1000 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?


North
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Portugal
Spain
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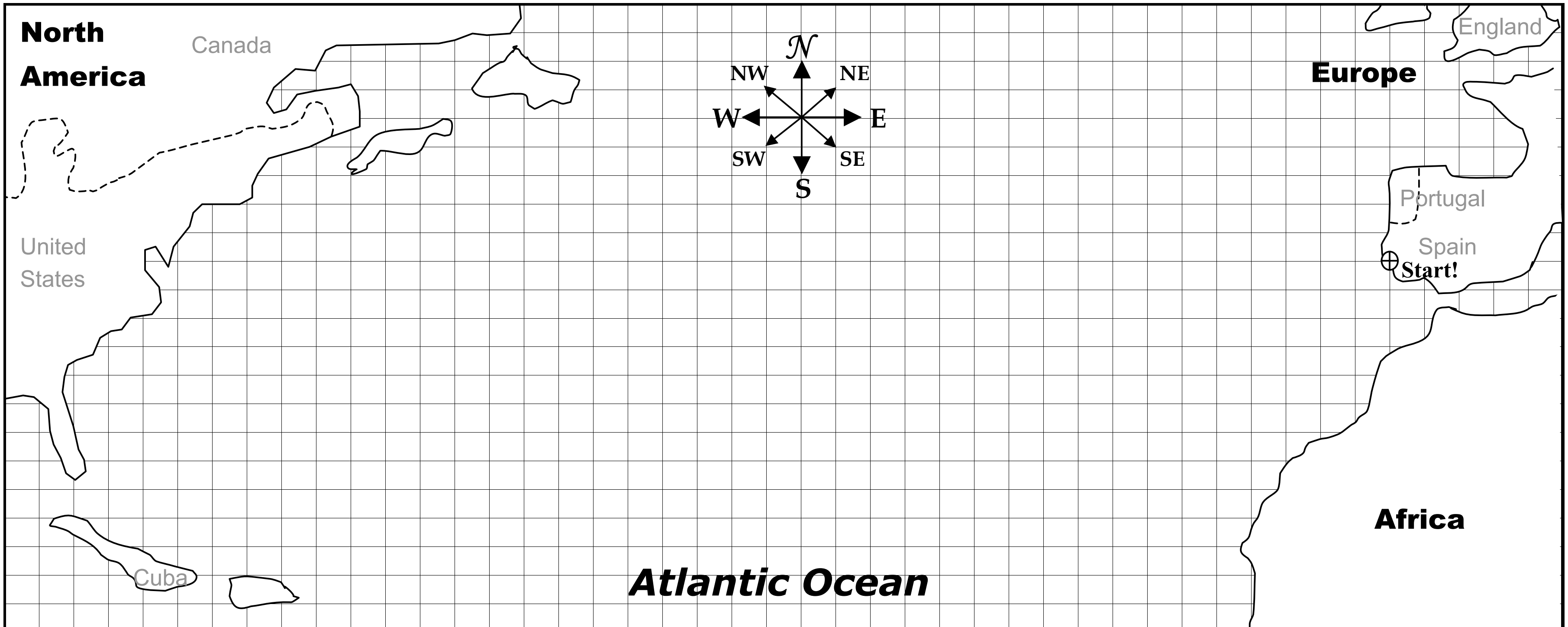


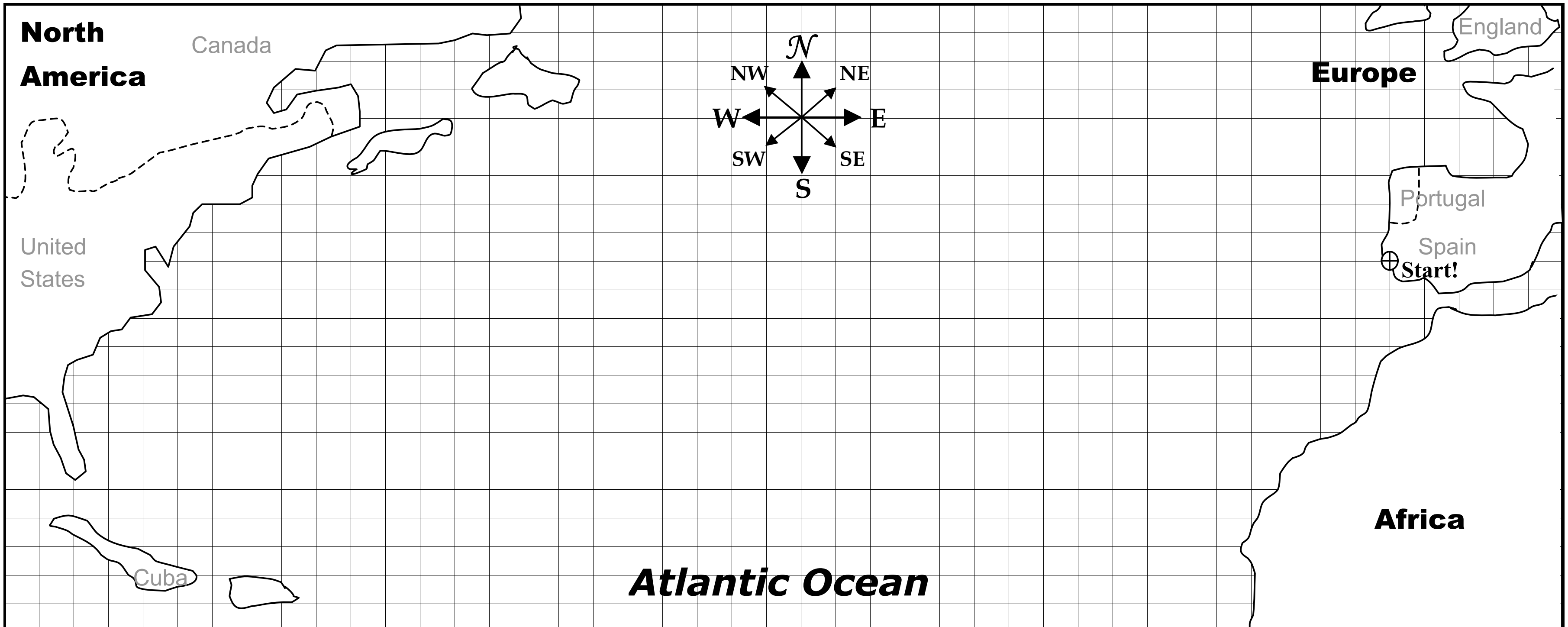
Vector Voyage Instructions

Part 1: Your ship can sail 10 squares/month. Starting from Spain and travelling west (or bearing 270), draw one vector for each month of travel using your red pencil. In what country will you make landfall? ___________ How many months will it take to reach land (how many 10-square vectors is it)?___________

Part 2: Unfortunately, the wind does not always blow the way you want! To see how the wind effects our travel, let includes the wind vector. First, draw your ship vector, just like in part 1, using your red pencil. Now at the end of that vector, add the wind vector using your blue pencil. Now draw the resulting vector (just adding the two vectors) with your blue pencil. That's where you're at at then end of the first month. Now do the same for the next month and the month after that until you reach land. Remember that the wind changes, so each month you'll have to add a different wind vector. The list of different wind's for each month is on the following line.

Month 1: 2 squares South   Month 2: 4 diag squares South-East   Month 3: 2 squares West   Month 4: No wind

Where will you make landfall now? ___________ How many months to reach land (only count the solid 10-square vectors!)?___________



Vector Voyage #2 Instructions

Part 3: Unfortunately, ocean currents affect boats too! Each month, you must also add a current correction vector to find your actual final position. So just like in Part 2, for each month draw you ship vector (in red), and your wind vector (in blue) and now add on your ocean vector (in green). Now using your green pencil, draw the resulting vector from all of these (add the red and the blue and green vectors). Do this for each month until you hit land. Remember the wind and the ocean vector's will be different for each month. They are listed below.

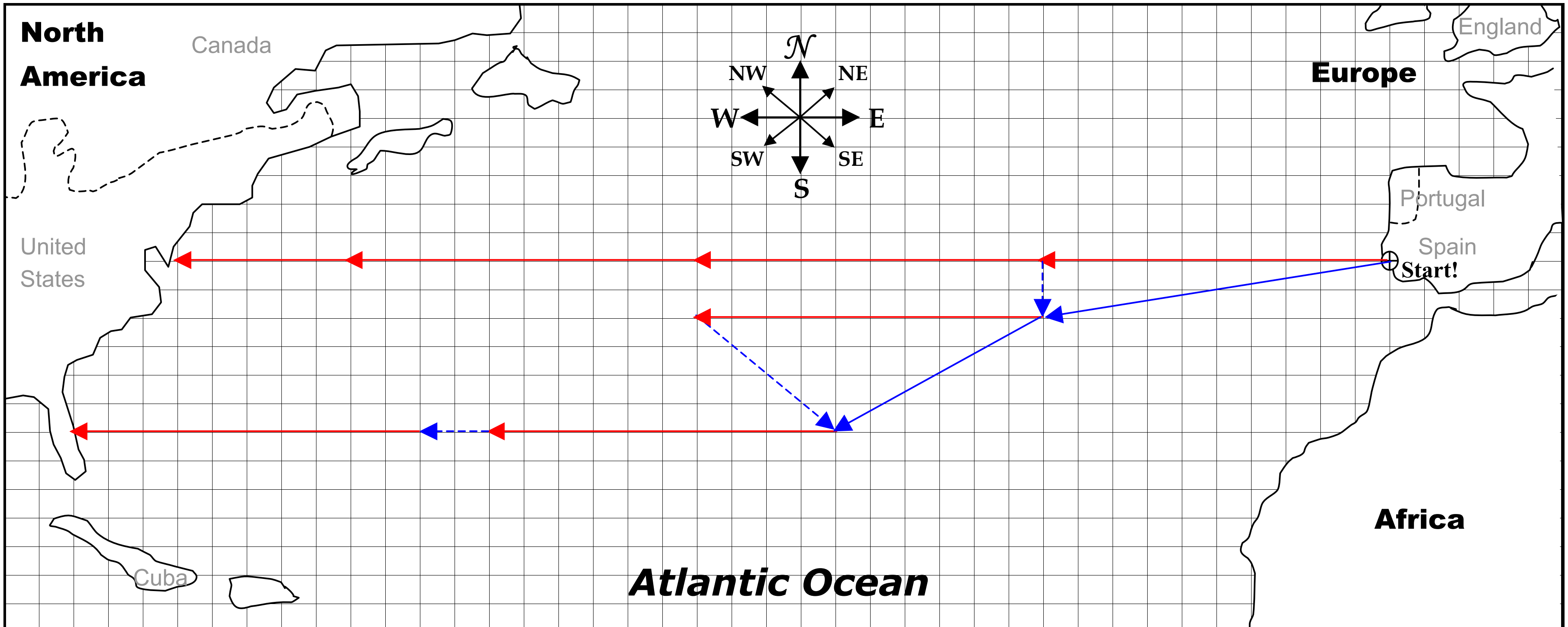
Wind Vectors:

Month 1: 2 squares South   Month 2: 4 diag squares South-East   Month 3: 2 squares West   Month 4: No wind

Ocean Vectors:

Month 1: 2 squares South   Month 2: 4 squares West   Month 3: 3 diag squares South-West

Where will you make landfall now? ___________ How many months to reach land (only count the solid 10-square vectors!)?___________



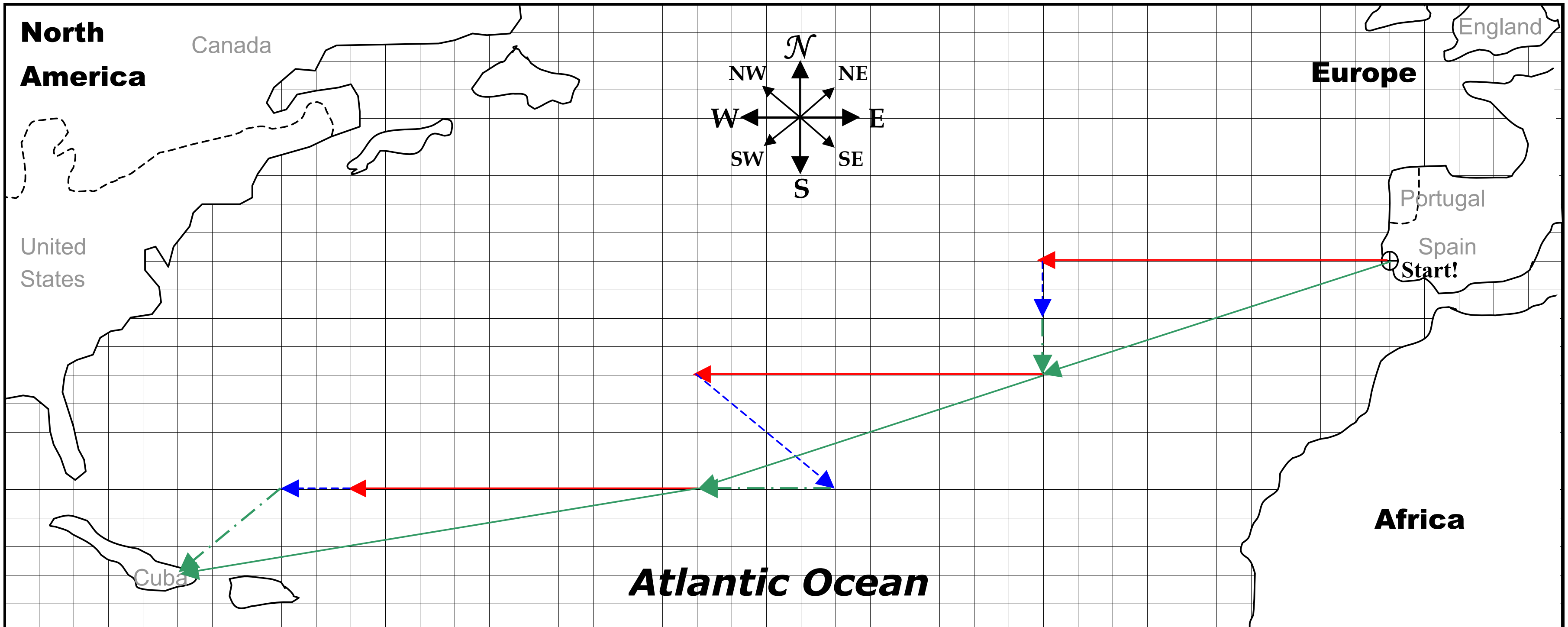
Vector Voyage Instructions

Part 1: Your ship can sail 10 squares/month. Sailing directly West from the Start position (Spain), draw one vector for each month of travel. In what country will you make landfall? _**USA (NY)**__ How many months will it take to reach land (how many 10 square vectors is it)?__**3.5**____

Part 2: Unfortunately, the wind does not always blow the way you want! Each month, you must add a wind correction vector to find your position:

Month 1: 2 squares South Month 2: 4 diag squares South-East Month 3: 2 squares West Month 4: No wind

Where will you make landfall now? _**USA (FL)**_ How many months to reach land (how many 10 square vectors is it)?_____**4**______



Vector Voyage #2 Instructions

Part 3: Unfortunately, ocean currents affect boats too! Each month, you must also add a current correction vector to find your actual final position. So just like in Part 2, for each month draw you ship vector (in red), and your wind vector (in blue) and now add on your ocean vector (in green). Now using your green pencil, draw the resulting vector from all of these (add the red and the blue and green vectors). Do this for each month until you hit land. Remember the wind and the ocean vector's will be different for each month. They are listed below.

Wind Vectors:

Month 1: 2 squares South   Month 2: 4 diag squares South-East   Month 3: 2 squares West   Month 4: No wind

Ocean Vectors:

Month 1: 2 squares South   Month 2: 4 squares West   Month 3: 3 diag squares South-West

Where is your actual landfall? ____**Cuba**___ How many months to actually reach land (how many 10 square vectors is it)?_____**3**____

Activity: The North (Wall) Star

This activity is planned for 28 students working in groups of two. (Also can be done individually so students can keep their quadrants.)

Activity Materials List —

- 14 straws or 12-inch rulers (straws if students will keep the quadrants)
- 14 pieces of string (about 6 inches each)
- 14 sheets of particle-board or stiff paper (i.e., two pieces of construction paper glued together)
- 14 small weights (washers or metal nuts)

Activity Equipment and Tools List —

- 14 protractors (if available; share if necessary)
- Tape
- Pencils

Activity Cost Estimate —

$5

Activity Attachments —

- Make a Quadrant Sheet
- Star Trails Sheet
- Polaris Latitude Sheet

Activity Time Estimate —

40-50 min.

Activity Procedure —

A. Background

Celestial Navigation

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 activity starts with a basic but very important and useful celestial measurement. In ancient times, the navigator who was planning to sail out of sight of land would simply measure the altitude of Polaris (the North Star) as he left homeport. (In today's terms, this is measuring the latitude of homeport.) To return after a long voyage, he 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.

Earth and the North Star

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 Northern hemisphere that does not move (not much, anyway), while all other stars do move, as seen in the Star Trails Sheet. This lack of movement is because Polaris is almost directly above the spin axis of the Earth. 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.

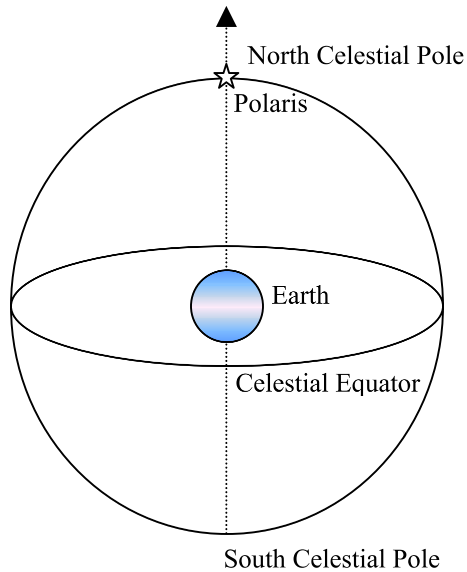


Image created by: Matt Lippis, University of Colorado, Boulder

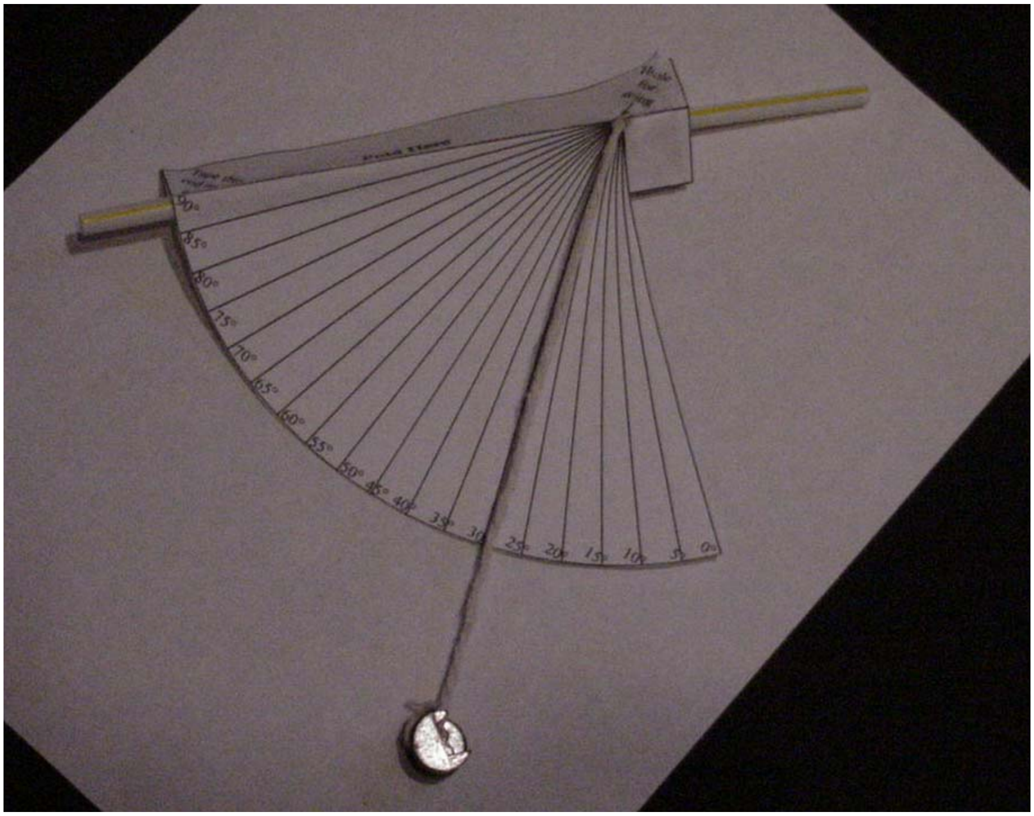
B. Before the Activity

1. Decide whether to make paper or protractor quadrants (see below).
2. Print out all activity sheets needed.
3. 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!

C. With the Students

1. Show the students the Star Trails Sheet 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 not directly overhead when we look at the sky at night? (Answer: We are not at the North Pole.) How high is it in the sky? (Answer: It depends on where you are.) The North Star can help you find out where you are on Earth.
2. Give students a Polaris Latitude Sheet, and ask them to follow the instructions. (Students can share rulers and protractors, if necessary.)

Now the students will use this principle to determine the latitude of their desks in the classroom. Point out the classroom "North Star" and ask students, "Does anyone have a protractor big enough to measure the angle to the star? No? Well, time to do some engineering!"

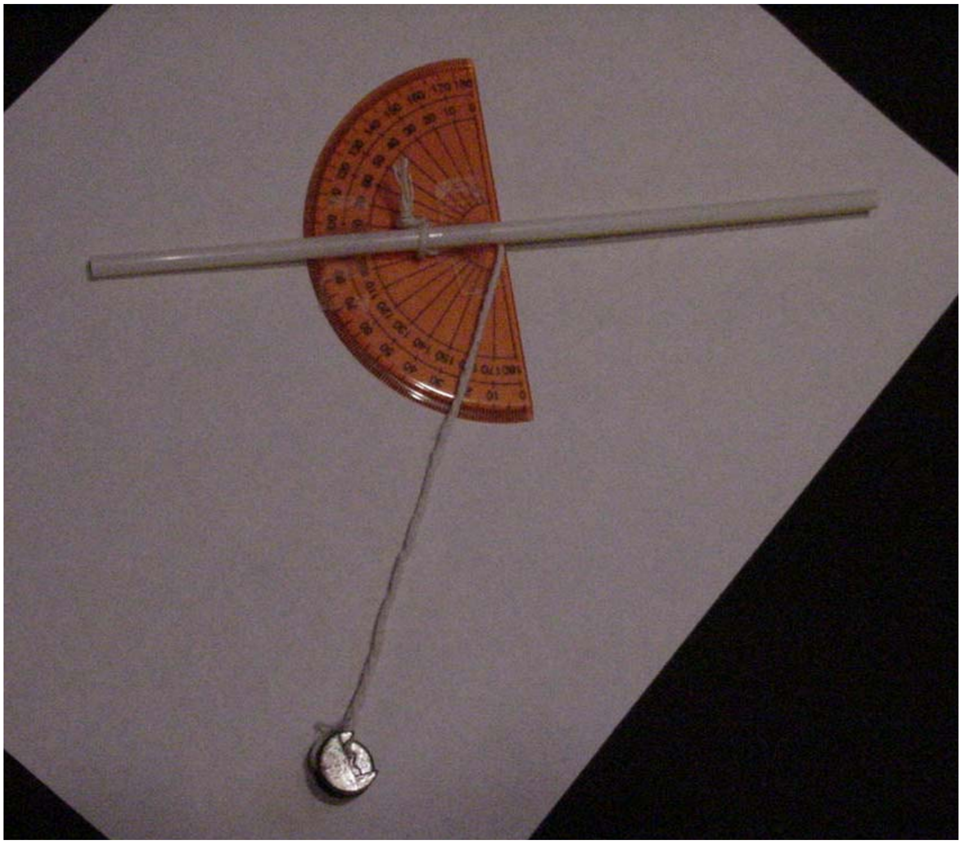


3. Give each student a Make a Paper Quadrant Sheet, and follow the directions. (Paper is obviously best for students who keep their quadrant.) Or, if enough protractors are available, make Protractor Quadrants (see below).

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 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.



4. 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.
5. Find the North Star elevation by sighting through the straw, or by touching the ruler to the cheekbone (under your eye) and then pointing the other end directly at the star.
6. Let the weight swing freely until it stops so that the string is pointing straight down.
7. Have your partner read the scale. If working alone, 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.

Math Skills Reinforced —

6^{th}, 7^{th} and 8^{th}: Measuring angles and calculating averages.

7^{th} and 8^{th}: Bar graphs and calculating circumference (math extensions).

Activity Troubleshooting Tips —

It is tricky to get the reading precise the first time. Make sure the students allow the string with the weight to come completely to rest before taking their quadrant measurement.

Activity Desired Student Outcomes —

After this activity, students should understand the relationship between the altitude of the North Star in the sky and the latitude of the observer.

Activity Assessment & Evaluation —

Pre-Activity Assessment

- Brainstorming: Have the students brainstorm ideas of why the Star Trails Sheet looks the way it does: (Answer: It is a picture of star trails due to the earth's rotation.)

Activity Embedded Assessment

- Worksheets: Students measure angles on paper and then calculate the latitude of their desks relative to a star in the classroom.

Post-Activity Assessment

- Problem Solving: Now that they have become celestial navigators, ask the students to guess the latitude of the photo location of the Star Trails Sheet. (Answer: about 5-10 degrees North of the Equator.)

Suggestions to Scale Activity for Grades 6 to 8 —

- 6^{th} Grade: Do activity as is.
- 7^{th} Grade: Plot and discuss differences in results of the desk latitudes found. If a row of desks is facing the wall with the star, do students at the ends of the row have different latitude values than those in the middle? (Answer: They could because the ends of the row are farther from the star and will therefore see a slightly smaller angle.) Is the difference in latitude of the nearest two rows to the star the same as the difference between the farthest two rows? (Answer: The first two rows should have a larger difference because the room is flat. The further you are from the star, the less effect moving back one row will have on the angle of the star.)
- 8^{th} Grade: 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: 1 degree of latitude is equal to 70 miles. 360 degrees multiplied by 70 is 25,200 miles — very close to the circumference of the Earth at the equator, which is about 24,900 miles or 40,070 km.)

References —

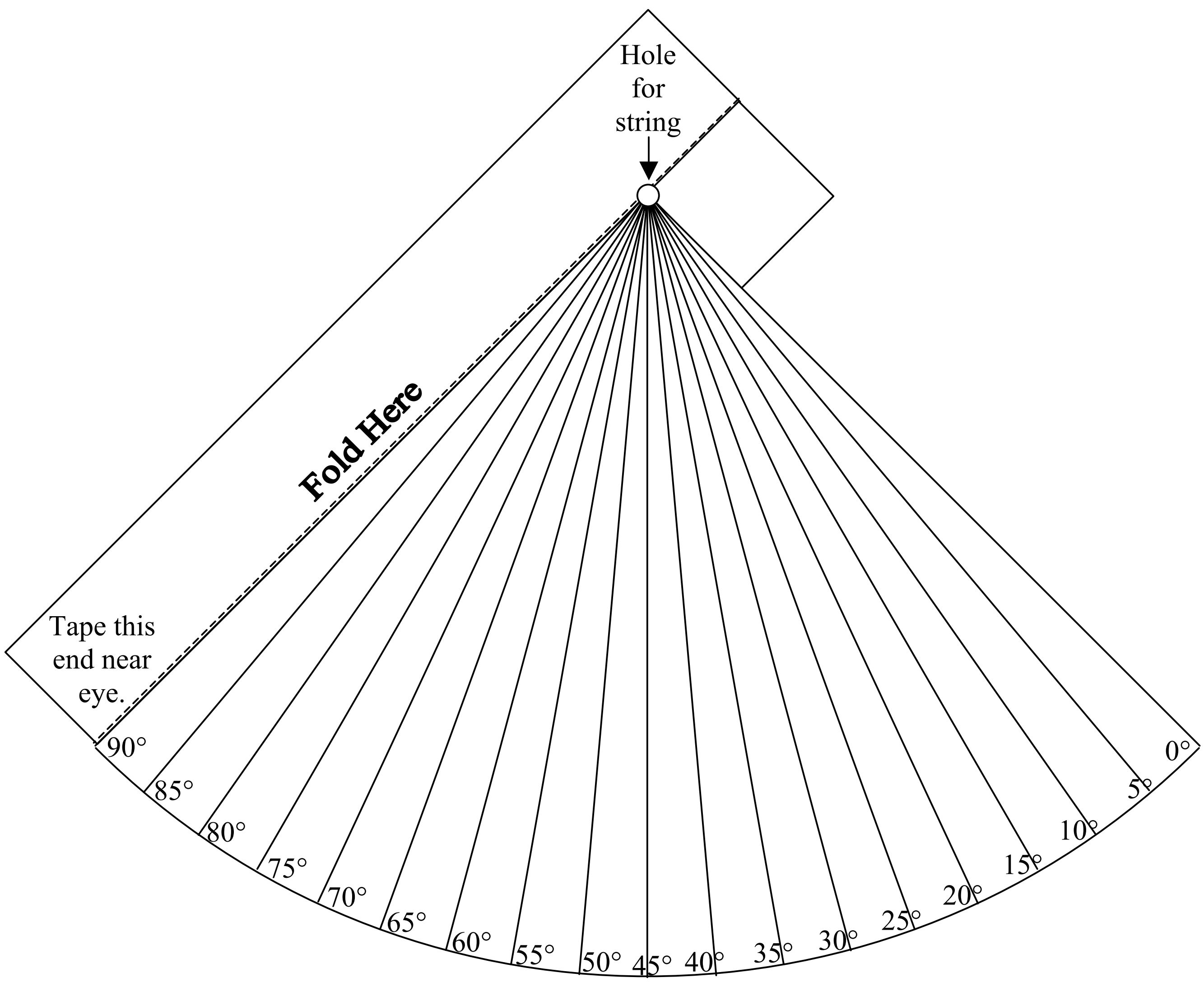
http://antwrp.gsfc.nasa.gov/apod/image/0009/dometrails_cfht_big.jpg
http://vesuvius.jsc.nasa.gov/er/seh/navigate.htm

http://antwrp.gsfc.nasa.gov/apod/image/0009/dometrails_cfht_big.jpg

Make a Paper Quadrant

1. **Cut out the quadrant below.**
2. **Glue the quadrant onto something stiff (like a folder or piece of heavy construction paper), and cut the board to the shape of the quadrant (outer perimeter only).**
3. **Tape the folded edge (labeled "Fold Here" with the dashed line) onto your straw or ruler, several centimeters back from the end.**

4. **Punch a hole using a hole punch or a pencil and put a 15 cm. (6 inch) long string through the hole.**
5. **Tie a knot at the end of the string on the blank side of the quadrant. Tie a weight to the other end of the string so it hangs in front along the lines and numbers.**



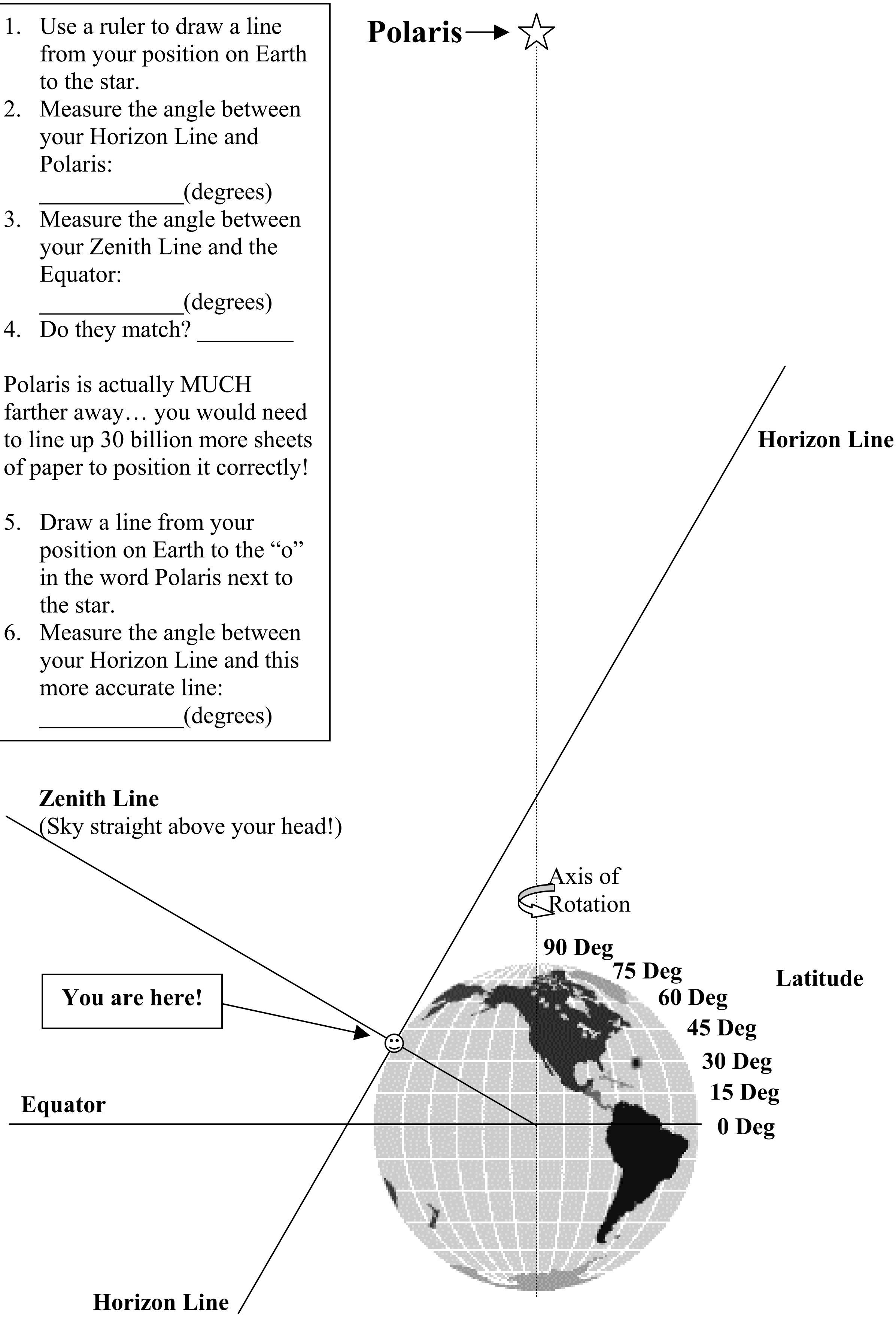
Star Latitude Worksheet!

Name: _______________ Date: ________________

1. Use a ruler to draw a line from your position on Earth to the star.
2. Measure the angle between your Horizon Line and Polaris: ____________(degrees)
3. Measure the angle between your Zenith Line and the Equator: ____________(degrees)
4. Do they match? ________

Polaris is actually MUCH farther away… you would need to line up 30 billion more sheets of paper to position it correctly!

5. Draw a line from your position on Earth to the "o" in the word Polaris next to the star.
6. Measure the angle between your Horizon Line and this more accurate line: ____________(degrees)



vesuvius.jsc.nasa.gov/er/seh/navigate.htm