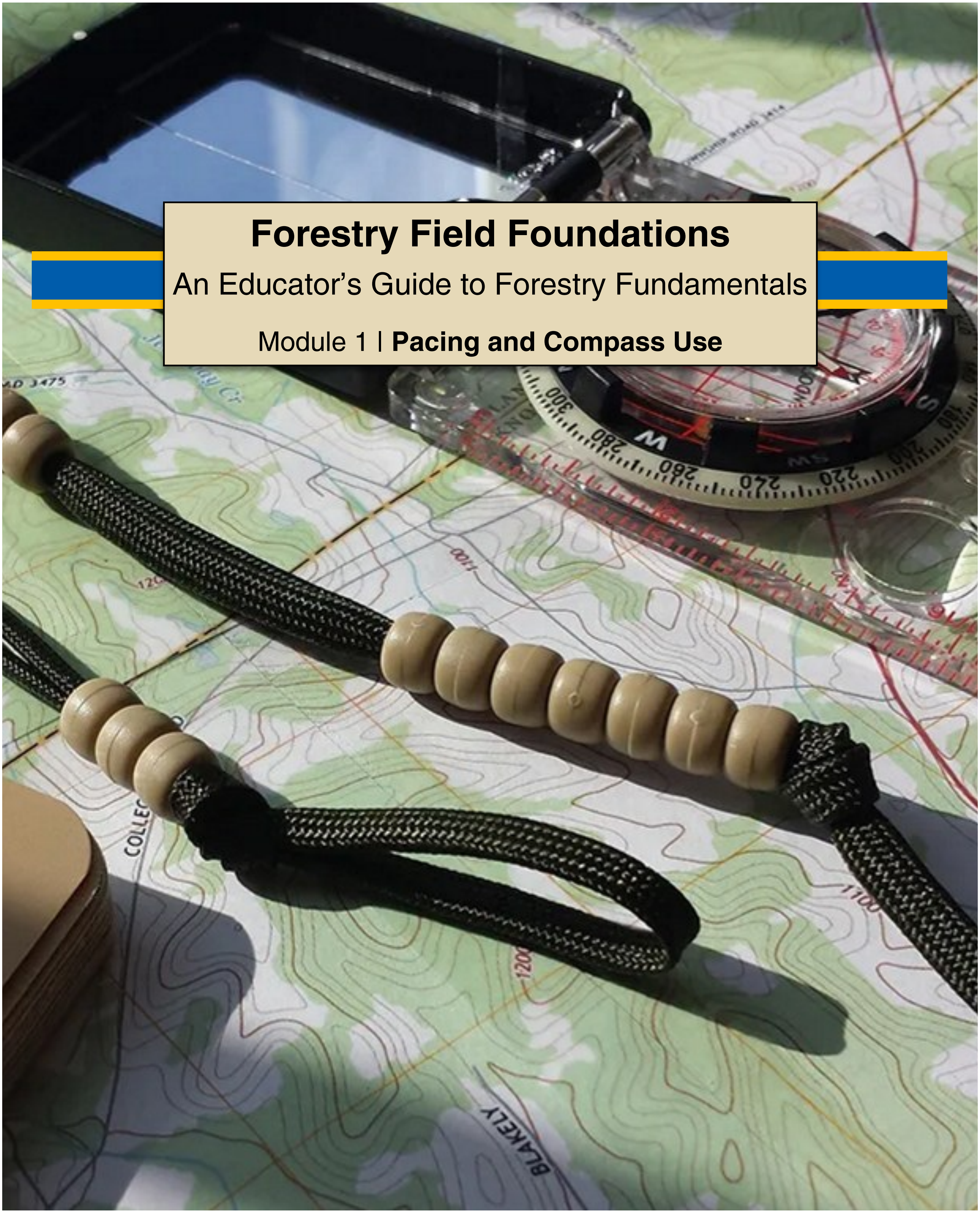

Forestry Field Foundations

An Educator's Guide to Forestry Fundamentals

Module 1 | **Pacing and Compass Use**

UCCE

FOREST EDUCATION AND OUTREACH

UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

Curriculum Overview

The Forestry Field Foundations curriculum is designed for use by high school and post-secondary educators in the instruction of forestry and natural resource management skills. Lesson topics and field activities have been collaboratively designed by natural resource professionals and credentialed educators to include concepts and skills essential for early career forestry jobs. Each lesson is organized around core competencies aligned with California Career and Technical Education Model Standards and Natural Resource Systems Career Pathways Content Standards (National Council for Agriculture Education).

Modules and their component lessons are designed to be taught in sequence, or for individual units of study.

Curriculum Resources
The following organizations also provide forestry education resources that can supplement this curriculum

- Oregon Forest Resources Institute — Inside Oregon Forests
- Oregon State University Extension Service — Fire Bright: Learn Work Lead
- National 4-H — Forestry Invitational
- National Future Farmers of America — Forestry Careers Development Event
- Washington State University Extension — Virtual Cruisers Vest

The UC Cooperative Extension (UCCE) Forestry Research and Extension Program provides professional learning, outreach, and education to the public regarding forestry and natural resource management. UCCE is the collaboration between the University of California, County Board of Supervisors, and the U.S. Department of Agriculture working together to bring practical, trusted, science-based solutions to our local communities.

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Module Overview

Evaluating distance and direction is a foundational skill in forestry field work. When preparing a management plan, foresters first perform field surveys to locate and assess important landscape features. While digital tools are common today, the ability to estimate distance and direction without tools allows professionals to perform tasks in a timely and cost-effective manner. This lesson will introduce students to basic concepts of pacing and compass use. When combined, they become a foundational and transferable skill employed by foresters and natural resource professionals.

Learning Goals

Students will be able to

- Pace distances across variable terrain
- Use a compass to determine directionality
- Combine pace and compass work to navigate across variable terrain

Module Duration

Total instruction Time	**90-120 minutes**
Lesson A: Pacing	25-35 minutes
Lesson B: Compass Orientation	25-35 minutes
Lesson C: Field Traverse	40-50 minutes

Audience: **Post-secondary Students** (*Community college, CCC, Environmental Stewards)*

Secondary Students (*Career Technical Education, FFA, 4H*)

Instructional Setting: **Open area** (*indoor or outdoor*), preferably with variable slope (*flat and steep*)

Standards Alignment:

California Career Technical Education Model Curriculum Standards
E11.0 - Understand the basic concepts of measurement, surveying and mapping

National Council for Agriculture Education – Natural Resource Systems Career Pathway Content Standards
NRS.03.02 - Demonstrate cartographic skills, tools and technologies to aid in developing, implementing and evaluating natural resource management plans.

Materials & Preparation

Lesson A: Pacing — Instructional Time 25-35 minutes

Students will learn how to pace and measure distances across variable terrain.

Materials

For each student

- ☐ Pacing Worksheet
- ☐ (*Recommended*) Calculator

For the class

- ☐ Reel tape or logger's tape
- ☐ Pin flags or cones
- ☐ (*Recommended*) Clipboards / writing surface
- ☐ (For Instructor) Slope Corrections Table

Preparation At-A-Glace

Print	Pacing Worksheet.
Set up	Pacing Calibration Course(s) in open area. Use multiple courses for larger class sizes.
Practice	Finding your pace to familiarize yourself with the steps and timing of this process.

Lesson B: Compass Orientation — Instructional Time 25-35 minutes

Students will learn how to use a compass to determine the azimuth of an object or point of interest

Materials

For each student

- ☐ Compass Worksheet
- ☐ Compass (0-360 degree azimuth bearing)

For the class

- ☐ (*Optional*) Reel tape or logger's tape
- ☐ (*For Instructor*) Flagging

Preparation At-A-Glace

Print	Compass Worksheet.
Identify	Open area for students to complete Compass Worksheet, and landscape features for Compass Assessment Course (Extension)
Set up	Compass Assessment Course
Calibrate	Declination on compass(es): ngdc.noaa.gov/geomag/calculators/magcalc.shtml

Lesson C: Field Traverse — Instructional Time 40-50 minutes

Students will learn how to sight predetermined azimuths and navigate across variable terrain.

Materials

For each student

- ☐ Closed Traverse Worksheet
- ☐ Open Traverse Course Assessment
- ☐ Compass
- ☐ (*Extension*) Pin flag

For the class

- ☐ *(Optional)* Reel tape or logger's tape

Preparation At-A-Glace

Print	Closed Traverse Worksheet and Open Traverse Course Assessment
Identify	Open area for students to complete Closed Traverse Worksheet and Open Traverse Course Assessment.
Set up	Open Traverse Course Assessment

Lesson A - Pacing

Instructional Time 🕒 25-35 minutes

Background and Context

Pacing is a foundational skill in forestry. Foresters frequently use their pace to measure distance when orienteering, laying out timber harvest plans, or collecting forest mensuration data. Pacing is also essential when ground-truthing information provided by GPS and digital rangefinders, particularly when such devices are not available or malfunction.

In forestry, a **pace** refers to the distance covered by two walking strides. The exact distance of a pace varies on the individual and circumstance — not only does one's pace become less accurate at long distances, but obstacles, variable slopes, weight carried, height, footwear, and even fatigue can affect the accuracy of one's pace. To conduct rapid measurements in the field, it is therefore important to familiarize with one's pace under various conditions.

Pacing allows one to build an understanding of distances and areas, while also introducing students to the concept of estimation. A forester is often required to balance limited time while meeting measurement goals. While certain tools such as reel tapes, or loggers tapes, can measure distances to the nearest inch, this level of precision is time consuming and not always required. By combining pace with field observations, a forester can quickly locate important landscape features, such as property boundaries or mapped landmarks.

Learning Objectives — Students will be able to:

- Determine individual pace and use it to measure distances across variable terrain
- Convert between key forestry measurement units (i.e. pace, chains, feet)

Preparation

1. Print **Pacing Worksheet** for each student
2. Set up **Pacing Calibration Course** (*Figure 1*)
    a. Locate a flat area that is at least 100 feet long.
    b. Mark a start line using pin flags or cones.
    c. From the start line, pull the reel tape or logger's tape in a perpendicular direction until you reach 100'.
    d. At distances of 66' and 100', mark the track using pin flags or cones.
    e. (*recommended*) If you have a larger class size, consider setting up multiple courses.

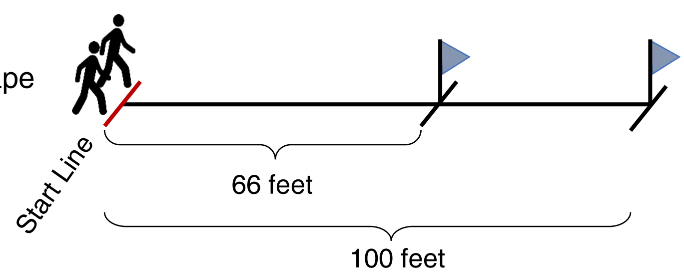


Figure 1 – Example Pacing Calibration Course

3. (*Activity Extension*) Set up **Pacing Calibration Courses on sloped ground**
    a. Time permitting, use the Slope Corrections Table to set up additional courses on moderate and steep slopes.
4. **Practice finding your pace** (*Figure 2*)
    a. Find your pace to familiarize yourself with the instructional flow and timing of this process.
    b. Rapidly calculating the number of pace per distance, and the length of your pace will help explain this concept to students

Procedure

Engage and Introduce

1. Select two points on the landscape and ask students to estimate the distance between them without using any tools.

   Examples: How far apart are those two trees?
   What distance are we from the road edge?

2. Have students (in pairs or whole group) compare answers and approaches to the task of estimating distance.

3. Guide discussion:
   - ? How consistent were students' measurements?
   - ? What methods did they employ to measure distance?

4. With a reel tape, measure the exact distance between the two points and share your results with the students.
   - ! If students estimated distance with their footsteps, prompt them to consider what they can do with knowledge of the exact distance —This allows them to calculate the actual length of their footstep!

5. Guide students to recognize their natural walking pace as a powerful unit of measurement.

Explore and Build Skills

6. In forestry, pace is a simple measure of linear distance defined as the distance covered by two steps of regular walking stride. Model how to determine one's pace with the Pacing Calibration Course(s) (*Figure 1*).
   - Stand with both your heels on the start line.
   - Determine which foot (left or right) you naturally start walking with — this will be your leading foot.
   - Beginning with your leading foot, walk to the 66 ft marker and count a pace each time your other foot lands. (*See Figure 2*)
   - Repeat this process at least two more times and calculate your *average pace count*.
   - Divide the distance traveled (66 ft) by your *average pace count* to calculate the length of your *pace.*

Activity — Pacing Worksheet

7. Assign students to complete the Pacing Worksheet Part 1 using the Pacing Calibration Course(s) (*See Figure 1*).
   - Review *Teaching Notes— Pacing Pointers*.

Teaching Notes

Key Terms

- Pace
- Chain
- Horizontal distance
- Slope distance

Pacing Pointers

- Paces are measured from the heel of one foot to the heel of the same foot in the next stretch.
- Paces must be <u>consistently reproducible</u> under varying field condition.
- Paces should not be labored or measured.
- Avoid focusing on your feet or the intended destination as this may subconsciously bias your walking stride.

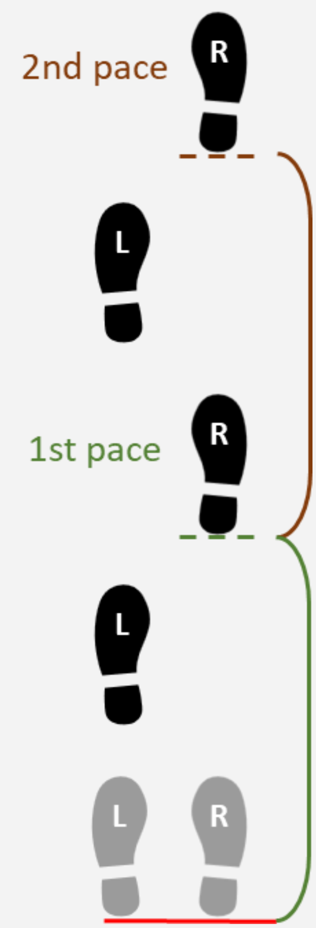


Figure 2 - Two paces (left foot leading)

Discussion and Reflection

8. Guide discussion on worksheet questions & answers:
   - ? Compare your pace with others— what accounts for observed differences between individual paces?

     Ask students to line up according to the number of their paces in a chain – do any patterns emerge in who takes more/less paces? Discuss the effect of height, terrain, and other factors on pace.
   - ? What might introduce error when pacing—are there ways to mitigate or reduce error?
   - ? Why are 66 and 100 feet useful reference distances to remember when performing distance calculations? (*Hint: 66 is approximately 2/3rds of 100*)

9. Guide students to understand:
   - Pace can be influenced by many factors: e.g. weather, footwear, pack weight, leg length, topography, distance, fatigue, etc.
   - Underscore the importance of developing a pace that is consistent and reproducible under field conditions and periodically recalibrating one's pace.
   - Slope will impact one's pace, either shortening or lengthening strides depending on the individual, the steepness of the terrain, and the direction of travel (*uphill vs downhill)*. To account for the influence of slope, one can add or subtract extra paces as needed.

Student Assessment

10. Basic—Choose a desired distance and assign students to practice their pace by pacing it, and checking their accuracy with each other, a reel tape, or logger's tape.

11. Intermediate—Assign students to pace distances which are fractions or multiples of 66 and 100 foot, or (e.g. 132 feet, 75 feet). Discuss how they can quickly determine the number of paces required for these distances.

12. Advanced—Assign students to measure a geometric area on the site. How might they verify the accuracy of their measurements – Consider how estimation may be used if the area is square or circular in shape. Consider the difference in accuracy between online tools such as Google Earth and field tools such as a logger's tape.

Teaching Notes

Forestry Connections

Foresters commonly measure distances in **chains** (1 chain = 66 feet), a foundational unit of measurement used to establish the Public Land Survey System in the 1800s.

The chain and 100 feet are common reference distances useful for quick calculations in the field. For example, when using the Topo Scale on a Clinometer, the user can use fractions to quickly measure tree height from different distances (e.g. 33ft, 99ft, 132ft).

Accuracy is important in forestry measurements, but so is efficiency. Measuring to the level of information required is an important skill. For example, when evaluating tree health in a forest, an paced estimate of height may be sufficient as opposed to a more accurate measurement if measuring carbon volume.

Assessment Pointers

Consider challenging students with a distance that incorporates principles of proportion and arithmetic.

66-(100/4) = 41
100+(100/2) + (66/2) = 216
(66/2) + 1 pace (assuming 5') = 38

Approximating the footprint of an area to a geometric shape can allow one to use simple geometry to calculate area.

Triangle = (base x height)/2
Circle = πr^2
Rectangle = width x length

Lesson Extension

Engage and Introduce

13. In forestry and natural resources, distance is typically referred to in terms of **horizontal distance,** or the distance between two points regardless of their relative elevation (*Figure 3*).
    - **Slope distance** refers to the distance between two points along a slope. When pacing a horizontal distance on a slope, the slope distance must first be calculated to determine the distance of travel.

Activity — Pacing on Sloped Ground

14. Set up additional Pacing Calibration Courses on moderate and steep slopes to explore the effect of slope on pace.
    - Identify the slope angle using a clinometer or alternative method (*Teaching Notes)*
    - Using the Slope Corrections Table below, locate the relevant slope distance for 66 feet and 100 feet based on the percent slope and intended horizontal distance. For example, on a 25% slope, a *horizontal distance* of 50 feet would measure out a *slope distance* of 51.54 feet.
    - Prompt students to consider how they would find the percent slope without a clinometer.

Teaching Notes

Measuring Slope

Reference the following resources to better understand methods of measuring slope distance:

- University of Minnesota Extension Forest Management Practices Factsheet: Managing Water Series #13
- https://www.nwcg.gov/course/ffm/vert-horiz-and-slope/45-slope

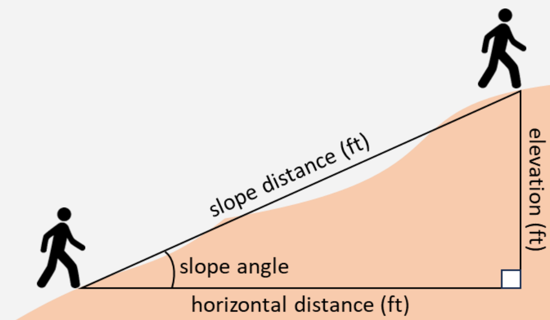


Figure 3 – Slope and horizontal distance relationship

% SLOPE **0** (*Horizontal Distance*)	**DEGREE SLOPE** **0** (*Horizontal Distance*)	**33 feet**	**50 feet**	**66 feet**	**100 feet**	**132 feet**
5	2.86	33.04	50.06	66.08	100.12	132.16
10	5.71	33.16	50.25	66.33	100.50	132.66
15	8.53	33.37	50.56	66.74	101.12	133.48
20	11.31	33.65	50.99	67.31	101.98	134.61
25	14.04	34.02	51.54	68.03	103.08	136.06
30	16.70	34.45	52.20	68.91	104.40	137.81
35	19.29	34.96	52.97	69.93	105.95	139.85
40	21.80	35.54	53.85	71.08	107.70	142.17
45	24.23	36.19	54.83	72.37	109.66	144.75
50	26.57	36.90	55.90	73.79	111.80	147.58
55	28.81	37.66	57.06	75.32	114.13	150.65
60	30.96	38.48	58.31	76.97	116.62	153.94
65	33.02	39.36	59.63	78.72	119.27	157.43
70	34.99	40.28	61.03	80.56	122.07	161.13
75	36.87	41.25	62.50	82.50	125.00	165.00
80	38.66	42.26	64.03	84.52	128.06	169.04
85	40.36	43.31	65.62	86.62	131.24	173.24
90	41.99	44.40	67.27	88.79	134.54	177.59
95	43.53	45.52	68.97	91.03	137.93	182.07
100	45.00	46.67	70.71	93.34	141.42	186.68

Pacing Worksheet — Part A: Determining Pace

Student Page

Instructions:
Complete the tables below to determine your pace*.

* **1 pace** = **two steps** of consistent & reproducible stride		**Slope Type**	**How many paces did I take?** Pace count 1	**Pace count 2**	**Pace count 3**	**Average Pace Count** *Count 1 + 2+ 3 / 3*	**Feet Per Pace** *Distance traveled (feet) / average paces count*
Known distance traveled	**1 Chain (66 feet)**	**flat slope**				*	*
Known distance traveled	**100 feet**	**flat slope**				*	*

Remember these metrics!	
	On average, it takes me _________ *paces to travel 1 chain (66 feet)*
	On average, it takes me _________ *paces to travel 100 feet*
	Each pace I take is approximately _________ *feet*

Discussion:

1. Compare your pace with others— what accounts for any observed differences between individuals' paces?

2. What might introduce error when pacing— are there ways to mitigate or reduce error?

3. Why are 66 feet and 100 feet useful distances to remember?

Pacing Worksheet — Part B: Pacing on Sloped Ground

Student Page

Instructions:
Complete the tables below to determine your pace on sloped ground.

			How many paces did I take?				
		Slope Type	**Pace count 1**	**Pace count 2**	**Pace count 3**	**Average Pace Count**	**Feet Per Pace** $\frac{\textit{Distance traveled (feet)}}{\textit{average paces count}}$
Known distance traveled	**1 Chain (66 feet)**	**moderate** (uphill) ↗					
		moderate (downhill) ↘					
		steep (uphill) ↗					
		steep (downhill) ↘					
	100 feet	**moderate** (uphill) ↗					
		moderate (downhill) ↘					
		steep (uphill) ↗					
		steep (downhill) ↘					

Extra Practice: Choose possible slope conditions and complete the table based on your pace and estimation methods.

Distance	Slope Type	How many paces must I take?	Workspace
99 ft			
150 ft			
33 ft			
50 ft			
132 ft			
200 ft			

Discussion:
1. Describe the effects of pacing uphill and downhill on your average pace counts. How can you compensate for these effects?

Lesson B - Compass Orientation

Instructional Time ⌚ 25-35 minutes

Background and Context

Compasses are a foundational tool in forestry field work. Foresters rely on compasses to determine aspect, read maps, triangulate positions, navigate in the field, and even record forest features. The magnetic needle of a compass allows the user to visualize the direction of the earth's magnetic field. When calibrated to account for angle of deflection from True North, a compass can be used to identify direction.

Compasses come with either azimuth bearings (0-360 degrees) or quadrant bearings (0-90 degrees). While either are acceptable for use in field navigation, azimuth compasses are more commonly used in forestry and natural resources work.

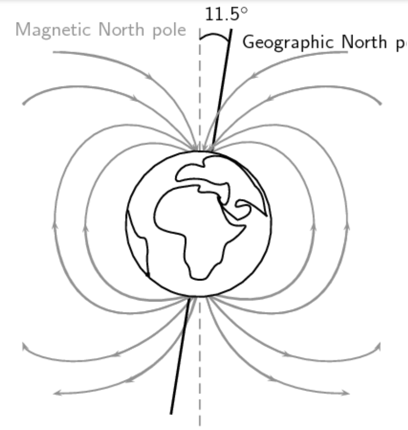


Figure 4 – Relative difference between the magnetic and geographic (True) North pole

Learning Objectives — Students will be able to:

- Determine an object's position on the landscape using a compass

Preparation

1. Print **Compass Worksheet** for each student

2. **Calibrate compass declination**
   a. Declination is the angle of deviation of the compass needle from true north (US Geological Society). Review the difference between magnetic and true north and adjust compass declinations to that of your location: ngdc.noaa.gov/geomag/calculators/magcalc.shtml
   b. *(Optional)* If time allows, walk students through the declination setting process and have them calibrate their own compass.

3. Identify open area for completion of the **Compass Worksheet**
   a. Student pairs must be able to spread apart ~20 feet to complete the worksheet exercise.

4. (*Lesson Extension*) Set up **Compass Assessment Course**
   a. Locate a space with 3-4 trees or landscape features. (*Figure 4*).
   b. Consider making one of the features an object with an obvious magnetic influence to prompt back-sighting.
   c. Flag, or mark, each feature on the landscape.
   d. (*recommended*) Consider setting up multiple courses if you have a larger class size.

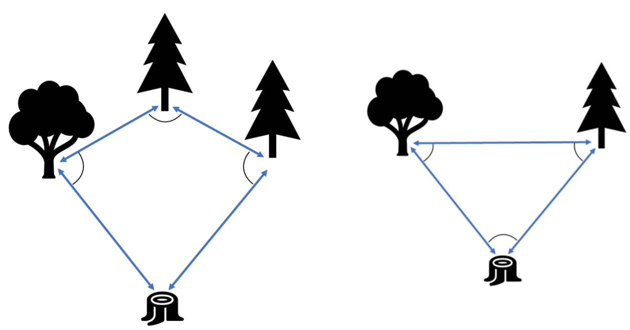


Figure 4 – Example Compass Assessment Course with (left) four points of interest with interior angles totaling 360 degrees and (right) three points of interest with interior angles totaling 180 degrees.

Procedure

Engage and Introduce

1. Distribute compasses to students and discuss what they collectively know about this instrument (structure, function, uses, etc.). Compasses with azimuth bearings (0-360 degrees) are recommended for this activity.

Figure 5 - Compass Anatomy

2. Review the anatomy of a compass (*Figure 5*).

3. Explain that compass orientation and pacing are skills that combine to allow foresters to conduct various field navigation tasks. **Sighting** describes the process of aligning a landscape feature with its azimuth relative to your position using a compass' guides. Sighting is both necessary for determining a landscape feature's azimuth, as well as navigating along a given azimuth's trajectory.

Teaching Notes

Key Terms

- Compass orientation
- Declination
- Magnetic needle
- Orienting arrow
- Rotating bezel or azimuth ring
- Index Line
- Azimuth
- Sight/sighting
- Back-azimuth

General Compass Use

The phrase "red in the shed" is a common pneumonic used when determining and sighting azimuths – it refers to the magnetic needle being in alignment with the orienting arrow (the "shed").

Even small ferromagnetic objects can interfere with the magnetic needle of a compass.

Be observant of common objects which can distort a compass reading:

- Magnets
- Metal pens/pencils
- Metal gates and fences
- Metal canteens
- Clipboards
- Ore-containing boulders
- Mobile devices
- Radio
- Measuring Tapes

Magnetic needle	Floating needle whose red portion always points towards magnetic North.
Orienting arrow	Static red outline of an arrow that aligns with magnetic needle when orienting compass.
Azimuth ring	Rotating outer ring of compass with markings indicating azimuth bearings (0-360º).
Index line	Tick mark indicating where azimuths readings are taken.
Sighting Notch/ Line	Guide to help align compass with landscape features to increase accuracy of readings.
Azimuth	Horizontal angle or bearing of a point measured clockwise from true (astronomic) north.
Declination scale	Inner scale markings on rotating bezel indicating the degree of declination offset on

Procedure

Explore and Build Skills

4. Model how to determine the azimuth with a compass.
    - Orient the compass so the **index line** (not the orienting arrow) faces a point of interest (*Figure 6*).
    - Keeping the compass level, bring it to eye-level and rotate the **azimuth ring** until the red **orienting arrow** aligns with the red portion of the **magnetic needle** — "red in the shed".
    - To improve accuracy, **adjust the mirror** until both the magnetic needle and point of interest are clearly visible when the compass is held at eye level.
    - Once aligned, read the value of the azimuth ring at the index line to determine the object's azimuth relative to the compass user's position.

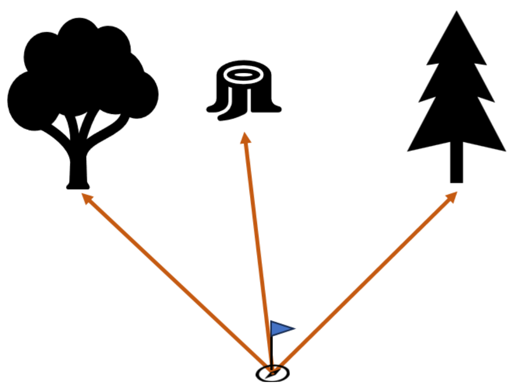


Figure 6 – Sighting the azimuth of a point of interest

5. Assign students into pairs or small groups to practice sighting the azimuth on 2-3 additional points of interest.
6. Guide discussion:
    ? When multiple people determine the azimuth of the same object, or point, why did results differ?
    ? How might a forester, or natural resource manager, apply the skill of determining an object's azimuth?

Teaching Notes

Compass Guides

Depending on make and model, a compass may have several sighting guides:

- Vertical line on the mirror.
- Notch on the mirror case.
- Small window along the hinge of the compass baseplate.

These guides help to maintain compass alignment with a landscape feature throughout the process of sighting an azimuth, which increases the accuracy of readings.

(*Hint*). Align the **index line** with the **sighting notch** when making fine adjustments to the azimuth ring.

Forestry Connections

Foresters frequently use a compass to record where objects or points of interest lie in relation to known points when conducting field tasks such as:

- Establishing permanent forest inventory plots
- Establishing witness trees to monument a location, such as a section corner, or plot center-point
- Stem-mapping precise location of trees in a plot
- Mapping features such as a road system or forest boundary

7. Guide students to understand:
    - The point of origin, or the location from which an azimuth is determined, matters greatly when communicating and recording azimuths for later reference or use.
    - Determining an azimuth accurately is essential to conducting various navigation, geolocation, and mensuration field tasks.

Activity — Compass Worksheet

8. Assign students into pairs to complete the Compass Worksheet. Ensure students have adequate space to complete the activity

Discussion and Reflection

9. Guide discussion and reflect on student results from the Compass Worksheet:
   - ? What relationship was there between each partner's compass readings?
   - ? Did distance (short vs. far) affect pacing?

10. Guide students to understand:
    - Reliably following an azimuth when pacing variable distances is an essential navigational skill, especially when terrain varies.
    - Sighting a back-azimuth (the bearing 180 degree opposite of the given azimuth) can be a useful tool.
    - A compass is only as accurate of a tool as the user. When pacing a long distance, sighting to distinct features or periodically sighting back to your starting point can help maintain accuracy.

Student Assessment

11. Assign students to compare differences in their surroundings between north and south facing slopes.

12. Guide students to understand:
    - Knowing the direction of landscape features can inform wind direction, growth potential, or even water availability during a rain.

Lesson Extension

Activity — Compass Assessment Course

14. Assign students to diagram the 3-4 features of interest you selected in the Compass Assessment Course (*Figure 4*)

15. Guide discussion:
    - ? What is the sum of the interior angles you just measured?
    - ? What may have caused issues in sighting between the assigned features?

Teaching Notes

Fire Connection

Triangulation is am important technique used to estimate the location of wildfires. During a fire, observers at lookout towers will take azimuth bearings to a visible smoke plume. Through coordination with other towers, two, or more, compass readings can identify the intersection point to locate the source of a fire. Ideally, more vantage points are better, but two may be enough. depending on the azimuth

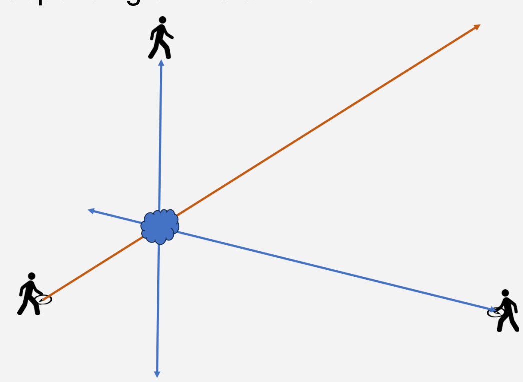


Figure 7 – Triangulating a fire

Forestry Connection

The direction of a slope (aspect) has a significant impact on the amount of light and heat exposure on that site. In Earth's norther hemisphere, south-facing slopes receive more direct sunlight than north-facing slopes, which can result in different plant communities. South facing slopes are generally harsher sites, and drier throughout the day.

The eastside of the Sierra Nevada mountains are generally drier than the westside.

Geometry Connection

The interior angle of any shape can be found using the formula (n-2) x 180 where n is equal to the number of sides.

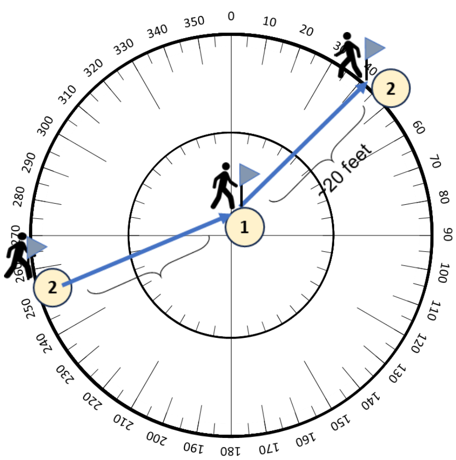
Compass Worksheet

Instructions:

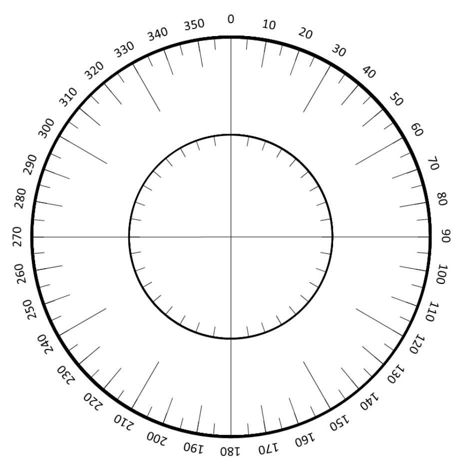
1) With a partner, stand approximately 20 feet apart. You can estimate or pace out this distance.
2) Use a compass to determine the azimuth between your positions and record your measurements in the table
3) Repeat the exercise at a longer distance.
4) On the blank compass face, record:
    - A line representing the sighted azimuth from you to your partner.
    - A line representing the sighted azimuth from your partner to yourself.

	Student #1	Student #2
Azimuth at ~20 feet		
Azimuth at >40 feet		

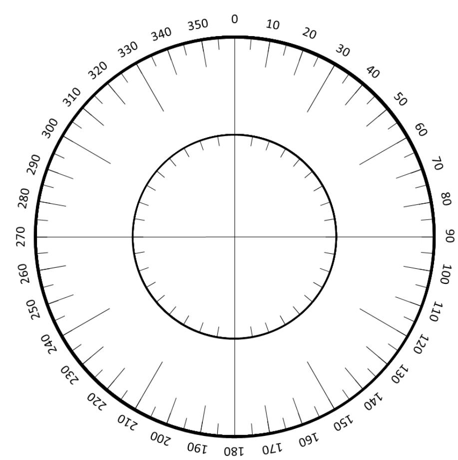
Example:



20 feet



40 feet



Discussion:

1. Compare your azimuth reading with your partner. Describe any relationships you notice between the different compass readings.

2. How similar were your measurements? Did distance affect your results?

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Lesson C - Field Traverse

Instructional Time 🕒 40-50 minutes

Background and Context

Sighting one or more predetermined azimuths and pacing along their trajectories allows a compass user to adeptly navigate in the field under a variety of circumstances, otherwise known as **traversing**. For example, if following instructions to locate an inventory plot's center-post, a forester might sight a given azimuth from a known location (e.g. road intersection), aligning this azimuth with a prominent landscape feature, then traversing terrain along this azimuth's trajectory to arrive at the target destination.

The act of sighting an azimuth for use in navigation sometimes requires the navigator to sight far-away landscape features for use as guides to stay true to an azimuth's line of travel. Veering off-azimuth, especially over long distances, can place a navigator far off-course, underscoring the importance of periodically determining a back-azimuth to verify accuracy of travel.

Distance, when performing field navigation, is almost always measured in terms of horizontal distance. When traversing variable terrain, developing methods to account for and mitigate the effects of obstacles and slope are paramount for accurate estimation. Thus, accurate and reliable field navigation relies on a practiced navigator's awareness for sources of error and ability to correct for error with consistent and reliable methods. It is not uncommon for a forester to initially chart a direct line of travel to a target location and adjust it several times due to unforeseen field conditions (downed trees, gullies and ravines, thick brush, etc.).

Learning Objectives — Students will be able to:

- Sight and pace along a given azimuth using a compass and pace
- Traverse variable terrain using compass and pace

Preparation

1. Print **Closed Traverse Worksheet** for each student

2. Identify open space for completion of **Closed Traverse Worksheet** and **Open Traverse Course Assessment**
    a. (*Recommended*) locations with variable terrain and obstacles for students to navigate around/over.

Procedure

Engage and Introduce

1. Pose the following scenario to students:

   You have been tasked with reflagging the boundary of a cultural site. The only reference to the site available is a journal from the previous forester containing a set of azimuths and distances from a US Geological Survey marker.

   Prompt students to outline their strategy to finding the site, detailing important steps and potential challenges they may encounter.

2. Guide discussion:
   - How would you apply your ability to determine the azimuth of a landscape feature in this scenario?
   - How would you ensure you stay on-azimuth while pacing long distances?
   - What aspects of terrain and topography might impact your ability to stay on-azimuth?

3. Guide students to understand:
   - Determining the azimuth of a landscape feature is similar to the process of sighting a given azimuth
   - **Traversing** describes the act of following one or more sets of azimuths and distances to arrive at a destination or define a boundary.
   - Foresters often employ a suite of skills and approaches to accurately traverse variable terrain, topography and distances; for example: sighting back-azimuths, sighting waypoints and circumnavigating obstacles.

Explore and Build Skills

4. Model how to sight a predetermined azimuth.
   - First, select an azimuth X° for students to sight.
   - Rotate the azimuth ring to align azimuth X° with the index line.
   - Keeping the compass level, rotate the compass housing until the red orienting arrow aligns with the red portion of the magnetic needle ("red in the shed").
   - Use the compass sighting guides (vertical mirror line, notch, or window) to identify a landscape feature in the distance in-line with azimuth X° .
   - The identified landscape feature now becomes a static waypoint along the azimuth's trajectory that can be navigated toward.

Teaching Notes

Key Terms

- Traverse

Open & Closed Traverse

An open traverse describes one or more interconnected line segments and azimuths measured from a start point, leading to a final location.

A closed traverse is similar, with the exception that the start point also serves as the end point. Thus, the traverse forms the boundaries of an enclosed area.

Open traverses are more common when navigating to a specific location in the forest while a closed traverse may be used to map or estimate the size of an area.

Tackling Tricky Terrain

It is sometimes necessary to offset one's pacing if your line of travel runs through an obstacle (large tree, downed log, gully, etc.)

If an offset is used, reset your position back to the original line of travel after circumventing the obstacle.

Figure 8 – Offsetting 90° around an obstacle

Forestry Connections

Foresters often sight predetermined azimuths when locating a previously established georeferenced location.

Example:

- Navigating from plot to plot during forest inventory sampling.
- Locating a USGS survey corner marker.

Procedure

5. Have students practice sighting azimuths in pairs or small groups to get comfortable and confident with the process.
    - In each pair, have one student direct the other to pace a randomly selected distance and azimuth.
    - Have them switch roles and repeat to ensure each student gains experience giving instructions.
6. Guide discussion:
    - ? When navigating a long distance along a given azimuth, why is it advantageous to sight a waypoint that is farther away compared to several waypoints at closer intervals along the azimuth's trajectory?
7. Guide students to understand:
    - A strategically chosen waypoint should limit the number of times a navigator stops to resight an azimuth. Every stop in a traverse allows for the introduction of human error into the process, especially when following an azimuth over a long distance. (*Teaching Notes—Waypoint Selection*).

Activity — Triangle Traverse

8. Assign students to complete the Triangle Traverse Worksheet in an identified open area.
9. Explain that they will be traversing terrain in the shape of an equilateral triangle with side-lengths of their choosing. (*Teaching Notes—Equilateral Triangles*)
10. Give each student a pin flag and model key points of the worksheet instructions:
    - Mark a start location with a pin flag
    - Select and record a desired azimuth Aº and distance X to travel from the starting location.
    - Sight and pace along azimuth Aº distance X.
    - At this point, add 120º to Aº to get azimuth Bº.
    - Sight and pace along azimuth Bº distance X.
    - At this point, add 120º to Bº to get Cº
    - Note this end location and its proximity to the start location
11. Draw students' attention to the fact start and end points should have been the same due to the geometry of equilateral triangles.

Teaching Notes

Waypoint Selection

When sighting an azimuth for traversing, it is important to select a prominent or distinguishable landscape feature to serve as a waypoint to navigate towards.

Depending on distance to be traveled, it is best to select a waypoint that limits the need to stop and resight the azimuth you are traversing along. Fewer stops results in less error being introduced into compass use and pacing, producing a more accurate traverse.

Equilateral Triangles

- Side lengths are equidistant
- Each interior angles = 60º
- Sum of all Interior angles = 60º + 60º + 60º = 180º
- Each exterior angle = (180º - 60º) = 120º

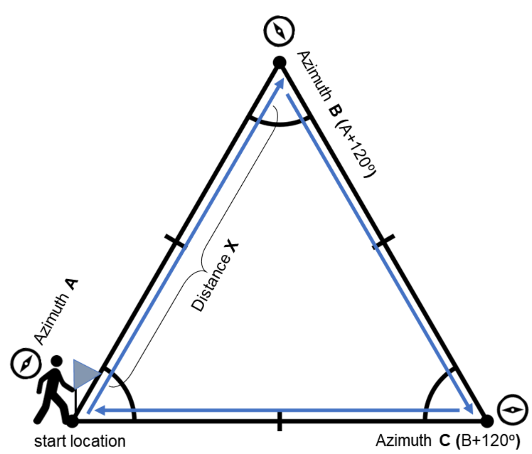


Figure 7 - Triangle Traverse Diagram

Discussion and Reflection

12. Guide discussion and reflect on results of the Traverse Worksheet:
    - How close were the start and end points?
    - What contributed to this accuracy and precision?
    - How did slope steepness, and walking uphill/ downhill affect pace?
    - Did distance (X) affect accuracy and/or precision?
    - Was it necessary to navigate around obstacles? If so, what methods were employed?
    - What was the size of the area measured?
13. Guide students to understand:
    - Accurate and efficient field navigation is often a multi-stepped process.
    - Accurate and efficient field navigation requires multiple methods to reduce error.

Student Assessment

14. Assign students to complete the Open Traverse Course Assessment to practice their navigation skills (Figure 9).
    - Choose a start point in an open space.
    - Randomly select 4-5 azimuths and 4-5 distances.
    - Pace your azimuths and distances, charting it on the graph below as you go.
    - Consider determining the start and end point ahead of time to compare student accuracy.
    - At your discretion, include visual and physical obstacles to simulate field conditions (e.g. going over logs, around trees, etc.).

Lesson Extension

Activity — Paper Traverse Course

15. Have students chart the steps of the Open Traverse Course Assessment on graph paper.
    - Students can use a compass or protractor to measure azimuth angles and distances (on a smaller scale).
    - The Paper Traverse Course can be used prior to the Open Traverse Course to conceptualize the task, or afterwards to check the accuracy of results.

Teaching Notes

Forestry Connections

Determining and sighting azimuths accurately becomes paramount when traversing long or complex distances, as a slight error will impact all subsequent actions.

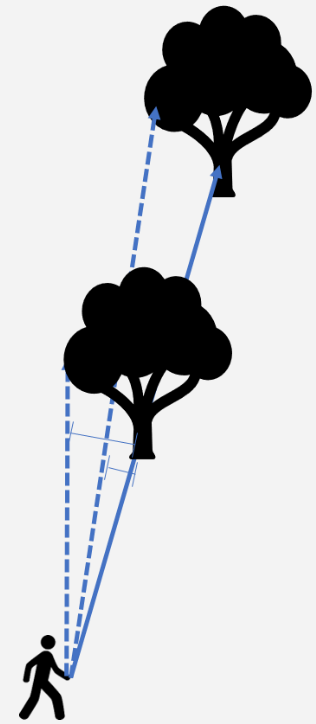


Figure 8 - Relative intensity of error when sighting variable distances

	Azimuth	Distance (X)
A	145	100’
B	23	2 chains
C	45	22 yards
D	234	1.5 meters
E	3	1/4 furlong

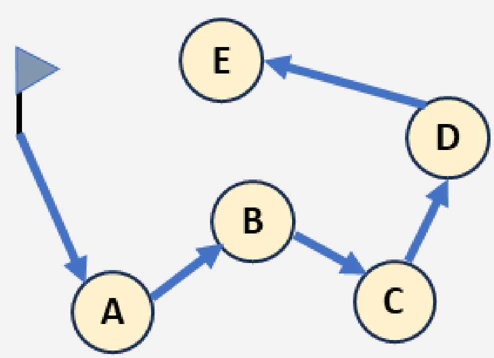
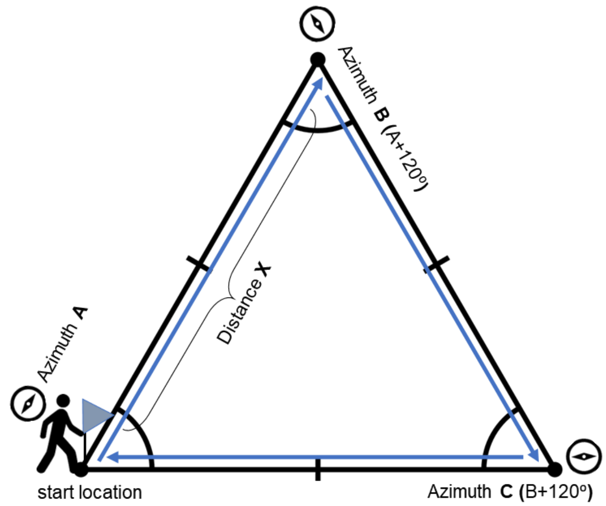


Figure 9 - Example traverse course direction table (direction of arrows for illustrative purposes only)

Closed Traverse Worksheet

Instructions

1) Mark a random start location with your pin flag.
2) Select and record a desired azimuth (Aº) and distance (X) to travel from the starting location.
3) Sight azimuth Aº, pace the chosen distance (X), then stop.
4) Add 120º to the original azimuth (Aº) to get a new azimuth (Bº). Sight and navigate in this direction distance (X) again, then stop.
5) Once more, add 120º to the previous azimuth (Bº) to get a final azimuth (Cº). Sight and navigate in this direction distance (X) one final time, then stop.
6) Note this end location and its proximity to the start location.



Azimuth	Distance (X)
A	
B	
C	

Discussion:
Compare results with your partner and consider the following.

1. How did you add degrees beyond 360° when determining azimuths?

2. Describe how close your start and end points were and what potentially contributed to your accuracy and precision?

3. Did you encounter any obstacles while traversing your triangle? If so, describe or draw the method you employed to circumnavigate the obstacle(s).

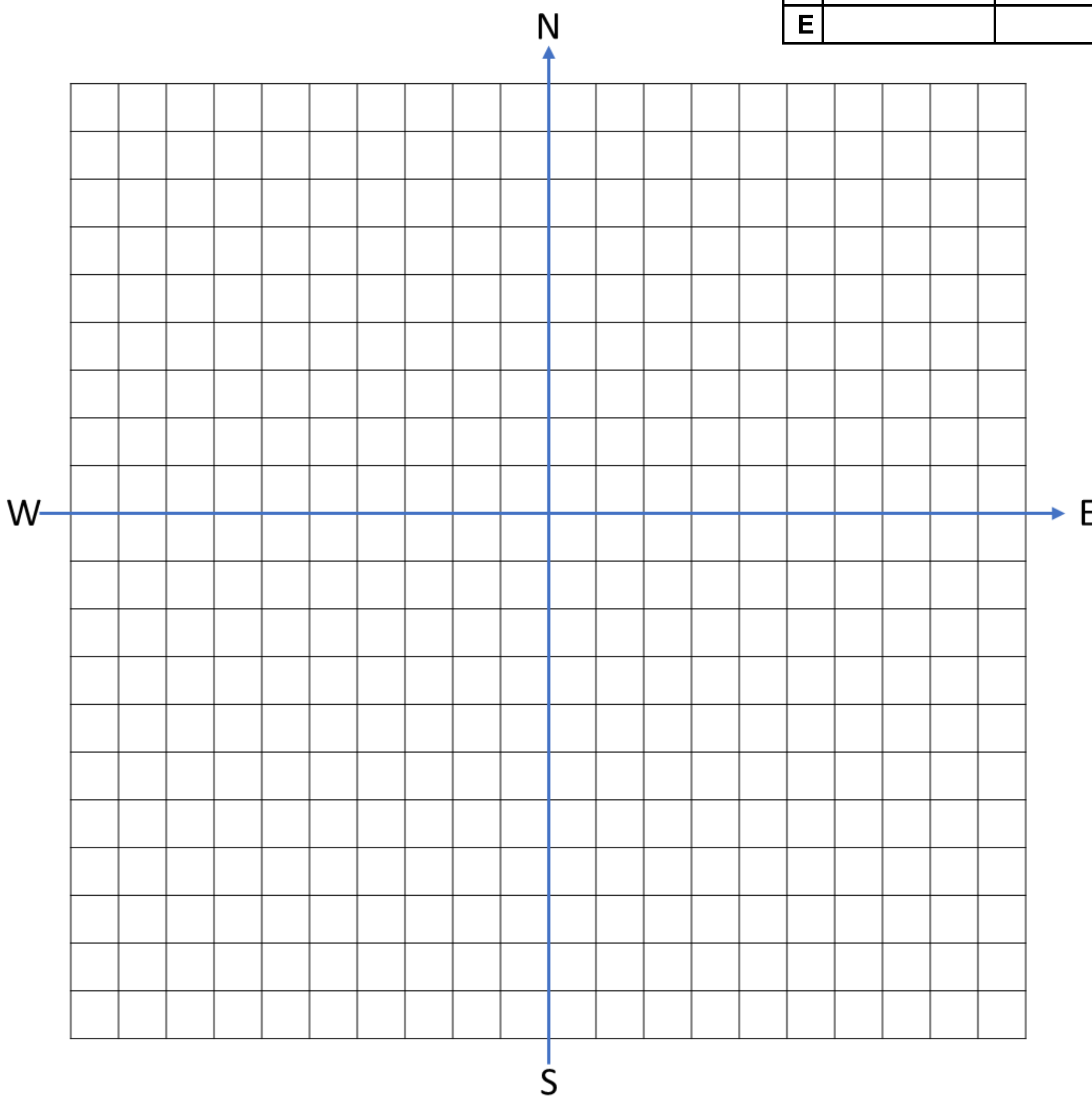
4. In what settings might this approach to field navigation be more advantageous than using GPS or other navigation technologies.

Open Traverse Course Assessment

Instructions:

1) Choose a start point in an open space.
2) Randomly select 4-5 azimuths and 4-5 distances.
3) Pace your azimuths and distances, charting it on the graph below as you go.

	Azimuth	Distance (X)
A		
B		
C		
D		
E		



Discussion:

1. How far did you travel?

2. How could you have made that traverse more efficient?